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Tellervo Härkki

Handling Knowledge

Three perspectives on embodied creation of knowledge in collaborative design

Academic dissertation

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Abstract
My research takes three embodied perspectives on collaborative design. In this research, collaborative design represents a specific type of knowledge creation oriented toward artefact creation, and a context for pedagogical practices in higher education. The three perspectives grew out of a continuum of research on the features and challenges of learning collaborative design in higher education, a multidisciplinary research project on forms of embodiment in design, and four identified gaps in the research literature. The first of the three perspectives is *sketching*, an acknowledged discipline-specific practice in design. The second perspective is gesturing. *Gesturing* is frequently characterised as spontaneous communicative behaviour, as opposed to practice. The third perspective entails a practice not always included in design discourses: *material explorations* that bridge designing and making.

Despite their obvious differences, not to mention different treatments that these perspectives have received from design researchers, a common grounding feature emerges when they are examined through the lens of embodiment: they are all body-based channels through which individuals' personal knowledge and experiences diffuse in two directions. To emphasise that they utilise capabilities shaped and developed by individuals' developmental and experiential histories, that they have an embodied base, I coin them embodied resources. When these embodied resources provide significant input and advance designing, they have an epistemically meaningful role in the process. This is what I call *embodied creation of knowledge*.

The theoretical part of my research consolidates prior key results on sketching, gestures and material explorations as well as ideation in design, and complements these with an extensive display of gesture research approaches and results. Together, they highlight the identified mechanisms behind idea generation and how the use of embodied resources could facilitate designing. In turn, this facilitation could yield embodied creation of knowledge, where the knowledge is relevant at least at the local level, for that particular design task.

Juxtapositioning the three perspectives deepen our understanding of their current uses and their possibilities for embodied creation of knowledge in the context of collaborative design in higher education. Accordingly, my three main research questions focus on the epistemic role of sketching and gesturing in

collaborative designing and the characteristics of collaborative creation of material knowledge through exploration. Identifying the epistemic roles, i.e. the characteristic uses that bring significant input and advance designing, required analysis of the collaborative processes.

For the empirical part of my research, process data from two collaborative design and make projects in higher education were collected. The primary data from designing was in video format. The data from making included textual diary entries with attached photographs. To tackle the well-known challenges introduced by transcribing, i.e. producing linguistic translations to describe the use of embodied resources, I developed *a video-based qualitative content analysis method*. This method permitted me to identify and examine design-relevant meanings fed by embodied resources. It was a rigorous micro-level analysis method that rendered not only the meaning but also the frequency of parallel channels of communication and thinking. According to my research results, sketching was especially strong for studying complicated structures that required precision and memory. Even if the uses for sketching were not completely related to structures, gestures had more versatile uses. Gestures were preferred for dynamic, spatio-motoric aspects, haptic meanings and embodied experiences, but were also used for less complicated structures. Research on material explorations showed that explorations were frequently used but the created material knowledge was treated as a vehicle to address challenges in making rather than a source of inspiration.

My research has several implications for design and gesture research. The active and rich use of embodied resources can turn collaborative designing into the drafting of a series of two-, three- and/or our-dimensional depictions. It is central for designing that in these depictions, *potentially essential features of the solution and the problem emerge as the indigenous characters of each resource guide and restrict the production of the depictions*. Equally important is that the drafting/production of the depictions implicitly tests those emergent features visually, spatio-motorically and/or kinaesthetically. Moreover, the use of the embodied resources along with the linguistic resources is related to patterns of collaboration and immediacy of sharing, and thus the unfolding of the working processes and collaborative creativity. When combined with active perception, *they can turn interaction into inspiraction, i.e. interaction that sparks inspiration in oneself and in others*. To conclude, the epistemic role of the studied resources is not necessarily limited to communication and thinking, but could entail the ability to elicit more ideas. This yields to a new approach for gesture research; gestures in the context of creative processes.

Keywords: design education, design sketching, gestures, material explorations, embodiment, collaborative knowledge creation

Helsingin yliopisto, Kasvatustieteellinen tiedekunta
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Tellervo Härkki

Kolme näkökulmaa keholliseen tiedonluomiseen, joka tapahtuu yhteisöllisen suunnittelun kontekstissa

Tiivistelmä

Tarkastelen kolmen kehollisen resurssin käyttöä ja rooleja yhteisöllisessä suunnittelussa. Yhteisöllinen suunnittelu edustaa tässä kohteellista, artefaktin luomiseen tähtäävää tiedonluomisen prosessia, jota voi luonnehtia keholliseksi, kun kehollisilla resursseilla on siinä merkittävä, episteeminen rooli. Luotava tieto on uutta vähintään paikallisella tasolla ja oleellista kyseisen suunnittelutehtävän kannalta. Tutkimuksen kohteeksi valikoituneet resurssit ovat luonnostelu, elehtiminen ja materiaalikokeilut. Kansainvälisessä tutkimuksessa nämä kolme ovat saaneet hyvin erilaisen kohtelun. Luonnostelu on arvostettu ja paljon tutkittu suunnittelukäytäntö, kun taas eleet nähdään sanattomana kommunikointina ja tiedostamattomana tapana käyttää käsiä. Materiaalikokeilut eivät kaikkien mielestä kuulu lainkaan suunnitteluun. Ne voidaan nähdä linkittämässä suunnittelua ja valmistusta.

Valitsemallani lähestymistavalla on teoreettista ja käytännöllistä arvoa. Tutkimukseni jatkaa aiempaa tutkimusta yhteisöllisen suunnittelun opetuksen haasteista yliopistotasolla ja täydentää kansainvälisen tutkimuksen aukkoja. Käsittelen yhteisöllistä suunnittelua sekä kehollisuuden kontekstina että pedagogisena lähestymistapana. Tutkimukseni sijoittuu suunnittelun tutkimukseen ja edelleen suunnittelun opetuksen tutkimukseen.

Valitsemani näkökulmat vaikuttavat erilaisilta. Yhteinen nimittäjä paljastuu, kun resursseja tarkastellaan kehollisuuden ilmentyminä. Kaikki kolme voidaan nähdä kehollisina kanavina, joiden kautta yksilöiden tieto ja kokemus diffundoituvat. Tämä diffundoituminen on kaksisuuntaista, sillä kanavat ovat mukana sekä tiedon ja kokemuksen näkyväksi tekemisessä että sen karttumisessa. Nimittämällä kanavia kehollisiksi resursseiksi korostan niiden yhteyttä yksilön kehitykseen ja kokemukseen – kehollisuuteen.

Tutkimukseni teoriaosuus kokoaa aiempia suunnittelututkimuksen tuloksia luonnostelusta, eleistä, materiaalikokeiluista ja ideoinnista sekä täydentää havaintoja laajalla eletutkimuksen koosteella. Esitän joukon ideoinnin taustalla vaikuttavia mekanismeja ja sen, miten kehollisten resurssien käyttäminen voi hyödyttää suunnittelua eli johtaa keholliseen tiedonluomiseen.

Kolmen kehollisen resurssin rinnastaminen lisää ymmärrystä niiden nykyisistä käyttötavoista ja mahdollisista hyödyistä yhteisöllisen suunnittelun opettamisen kannalta. Tutkimuskysymykset kohdistuvat luonnostelun ja elehtimisen

episteemiseen rooliin yhteisöllisessä suunnittelussa sekä yhteisöllisten materiaalikokeiluiden luonteeseen. Kontekstina on yhteisöllisen suunnittelun opetus yliopistotasolla.

Tutkimuksen empiiristä osaa varten videoitiin kaksi yhteisöllisen suunnittelun ja valmistuksen projektia. Lisäksi kerättiin teksti- ja valokuvamuotoista päiväkirja-aineistoa materiaalikokeiluista. Välttyäkseni sanalliseen vuorovaikutukseen keskittymiseltä ja videoaineiston litteroinnin aiheuttamilta ongelmilta kehollisten resurssien käytön kuvaamisessa kehitin videopohjaisen laadullisen sisällönanalyysin menetelmän. Se mahdollisti suunnittelun kannalta oleellisten, kehollisten resurssien välittämien merkitysten tunnistamisen ja analysoinnin. Tämä systemaattinen mikrotason menetelmä nosti esille kehollisesti välittyneet merkitykset ja sen, miten tiuhaan kehollista kommunikaatiota ja ajattelua käytettiin. Tulosten mukaan luonnostelu sopii erityisesti monimutkaisten rakenteellisten ratkaisujen tutkimiseen eli tarkkuutta ja muistia vaativiin tehtäviin. Luonnostelun käyttö ei kuitenkaan rajoittunut pelkkiin rakenteisiin. Silti eleiden käyttötarkoitukset olivat selvästi monipuolisempia. Eleitä käytettiin ilmaisemaan kohteiden ja toimintojen neliulotteisuutta ja dynaamisuutta, tuntoaistimuksia ja kehollisia kokemuksia, mutta myös yksinkertaisempia rakenteita. Myös materiaalikokeiluja tehtiin runsaasti, mutta niitä käytettiin pääasiassa käytännöllisten haasteiden ratkaisuun eikä niinkään inpiraation lähteinä.

Tutkimukseen pohjautuvat johtopäätökset liittyvät osaksi suunnittelun, osaksi eleiden tutkimukseen. Aktiivisen ja rikkaan kehollisten resurssien käytön ansiosta yhteisöllinen suunnittelu voi muodostua kaksi-, kolmi- ja/tai neliulotteisten hahmottelujen sarjaksi. Suunnittelun kannalta keskeistä on, että näissä hahmotelmissa ratkaisun ja suunnitteluongelman piirteet ilmenevät erilaisina variaatioina, koska kunkin kehollisen resurssin luontaiset ominaisuudet ohjaavat ja rajoittavat hahmotelmien muodostamista. Hahmotelmien luominen testaa (implisiittisesti) edellä mainittuja piirteitä visuaalisesti, spatio-motorisesti ja/tai kinesteettisesti. Toisaalta, koska kehollisten resurssien mikrotasolla tunnistetut käyttämisen tavat ovat yhteydessä yhteisöllisiin käytäntöihin sekä tiedon ja ideoiden jakamisen välittömyyteen, resurssien käyttötavat vaikuttavat työskentelyn ja yhteisöllisen luovuuden prosessien kulkuun. Kun kehollisten resurssien käyttöön yhdistyy aktiivinen havainnointi, vuorovaikutuksesta voi muodostua inspirationaalista.

Yhteenvetona totean, että tutkittujen kehollisten resurssien episteeminen rooli ei välttämättä rajoitu kommunikaatioon ja ajatteluun, vaan voi sisältää myös uusien ideoiden aikaansaamisen. Tämä johtaa uuteen lähestymistapaan eleiden tutkimuksessa: eleet luovan prosessin kontekstissa.

Avainsanat: suunnittelun opettaminen, luonnostelu, eleet, materiaalikokeilut, kehollisuus, yhteisöllinen tiedonluominen

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This is the hardest part to write. The simplest solution would be to list the people who have influcenced my thinking and supported this accomplishment, in one way or the other, since I started this research in July 2013: the academic community and the people in my private life. That list includes my magnificent supervisors Pirita and Kai, others involved in the project Handling Mind, several of the doctoral students of my time, a couple of vitising scholars, my dear friends and of course, my family. If it takes a village to raise a child, it takes an extended community to shape a scholar. I feel deep gratitude.

Yet when I look at the pages that I have created, the above listing feels lacking. Several people along the longer road have had a substantial impact on my thinking. They have guided me on how to think, what to believe and how to dig deeper to find elementary pieces. Those people, most likely, will never read my academic texts, not even these short first paragraphs. That's why I will not name them here but thank them in person, if I get a chance. For some, the chance will arrive. For some, it most likely won't. However, I feel indebted forever and try to pass on the deed.

Matinkylä, Espoo, 15.6.2018
Tellervo Härkki

List of original articles

This thesis is based on the following original publications, which are referred to in the text by their Roman numerals (*Publications I-III):*

I Härkki, T., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2016). Line by line, part by part: collaborative sketching for designing. *International Journal of Technology and Design Education,* 28(2), 471–494.

II Härkki, T., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2017). Hands on Design: Comparing the use of sketching and gesturing in collaborative designing, *Journal of Design Research,* 16(1), 24–46.

III Härkki, T., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2016). Material knowledge in collaborative designing and making: A case of wearable sea creatures. *FORMakademisk,* 9(1), Art.5, 1-21.

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Table of Contents

1 Introduction

I understand embodied resources—in this research, sketching, gesturing and material explorations—as two-way, body-based channels through which personal experience and bodily knowledge diffuse. At times, these embodied resources have a meaningful, epistemic role in knowledge creation: they provide significant input and advance the process of knowledge creation. That kind of process I call embodied creation of knowledge. The theoretical part of my research focuses on the mechanisms behind the diffusion. The empirical part of my research is about the roles that students in higher education gave to these embodied resources as they were jointly creating new knowledge while solving creative open-ended problems—while they were designing collaboratively.

Collaborative designing is a perfect context to study embodied creation of knowledge. Design is demanding: it entails a creative problem-solving process requiring wide experience, as the central challenges concern functionality, form-giving and user experience. One of the embodied resources I'm focusing on—sketching—has already an acknowledged epistemic role in designing. During designing, students' have to adjust their prior knowledge to fit with requirements imposed by a design task, to create and negotiate new knowledge through focused multimodal conversations and practical actions—they use embodied resources for knowledge creation. In this case, the knowledge is created as student teams design textile artefacts collaboratively (Figure 1).

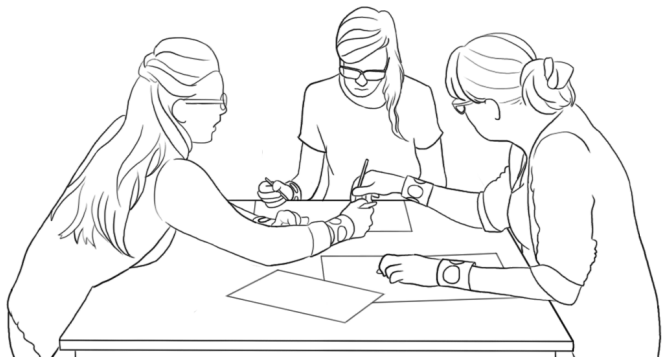


Figure 1. Embodied creation of knowledge, i.e. collaborative face-to-face designing, in progress. A stylized video frame.

In this first chapter, I describe the motives behind my research: the context of craft teacher education and its challenges as identified by previous researchers, as well as theoretical gaps in previous related research. That is followed by the overall aim of this research. Then, I introduce my central concepts: collaboration

and embodiment. I end this chapter with a reading guide for the remainder of this thesis.

1.1 Square one: Background and motivation

In Finland, design is an essential aspect of the school subject Craft (FNBE 2014). Craft is compulsory at grades 1–7 at comprehensive schools. As a voluntary subject Craft is offered to students at grades 8–9, and later, in some senior high schools. To qualify as a craft teacher, a Master's level degree with Craft and Education as majors is required. Finnish high-level standards for teacher education apply to craft teacher education as well; research-based development of educational practices is continuous in all four programmes where craft teachers graduate, namely at the universities of Helsinki, Turku, Eastern Finland and in Åbo Akademi.

Teacher education needs to provide its students with a toolkit that suits not only their personal needs and preferences but also the needs of their future students. Undergraduate craft teacher students (previously, textile teacher students) are often novices in conceptual designing, but usually substantially experienced in craft making. The distinction between designing and making appears fundamental for many in design and design research (Lawson, 1997, p.24). Conversely, Craft involves both. The Finnish notion 'holistic craft' ('kokonainen käsityö') refers to ideation, planning, making and evaluation as one single process, conducted from the very beginning to the end by the same agent (Kojonkoski-Rännäli, 1995, p.92; Kröger, 2003, p.116; Pöllänen, 2009). Further, Craft includes both individual and collaborative processes of designing and making, as the latest national curriculum defines Craft as one of the subjects promoting collaborative practices (FNBE 2014, pp.146, 270, 430). Therefore, *craft teacher students need knowledge about pedagogical structures and practices that support collaborative creativity and ways of organising collaboration.*

Teaching and researching collaborative design in higher education started at the University of Helsinki after the turn of the century. The previous dissertation studies (Lahti, 2008; Laamanen, 2016) revealed that students experienced several challenges while learning design. Students' views whether design is an innate talent or a capability that can be taught and learned varied (Laamanen & Seitamaa-Hakkarainen, 2014). Laamanen discovered that visualisation by sketching as well as experimenting with materials to generate new ideas were met with discomfort, and material experiments were understood as goal-oriented, part of making (Laamanen, 2012; Laamanen & Seitamaa-Hakkarainen, 2014). *The underlying reasons for promoting certain design practices do not appear to be clear to everybody, which implies that the conditions under which those practices best contribute to designing also remain unclear.*

My research continues in the footsteps of Lahti, Laamanen and partners. It belongs to a multidisciplinary research project Handling Mind that, in turn, is one of the 12 sub-projects of the Human Mind research project initiated and funded by the Academy of Finland. Handling Mind (2013−2016) entails four independent research tracks aimed to provide a bridge to areas of neuroscience, educational psychology, and design research concerned with embodied activities, social creativity, and the extended nature of the human mind. My research covers the major part of Study track B—a track interested in the role of embodied thinking during collaborative designing, the nature of collaboration and the mediating role that design artefacts play in students' collaborative design thinking.

The part of Study track B research that is not included here focused on the wider pedagogical settings (Seitamaa-Hakkarainen, Härkki, Lahti & Hakkarainen, 2017) and provided a macro-level view (Lahti et al. 2016), while *my research concentrated on developing a micro-level video analysis approach that would provide a deeper understanding of the features and possibilities of selected design practices*. The selection of practices was influenced by Study track B's overall focus on embodied thinking, the pedagogical model Learning by Collaborative Design (LCD) (Seitamaa-Hakkarainen, Raunio, Muukkonen & Hakkarainen, 2001; Seitamaa-Hakkarainen, Viilo & Hakkarainen, 2010) and previous research findings on practices, especially sketching and experimenting with materials (as presented above). As usual, a role was also played by the data, collected during the autumns of 2013 and 2014 at the University of Helsinki, at the department of Teacher Education, Craft Studies. In that data, gestures emerged as a frequently employed resource. Thus, *the three collaborative practices, or rather, embodied resources that I selected for the study were sketching, gesturing and material explorations.* It appeared that there were gaps both in our practical knowledge of how students used and benefited from using these resources, as well as in the related theoretical knowledge.

Combining the perspectives of sketching, gestures and material explorations under one title is not the most commonplace approach towards collaborative design. Completing this research endeavour as situated in the discipline of design research has required crossing over to territories of educational research, gesture studies, linguistics and cognitive science, just to name the most frequently visited fields of research. As I understand collaborative design as a special kind of knowledge creation and creative problem solving, my research could also have been situated in the field of educational research. However, the operational context of this research is collaborative design in higher design education, and the central part of the theoretical background comes from design research. Thus, in the following, I discuss theoretical gaps from the perspective of design research.

The roots of the design research discipline can be located in the 1950s and 1960s, to systems theory and cognitive science (Bayazit, 2004; Visser, 2006, p.xv). Ever since, cognitive science has been influential in design research, which is visible for instance in the emphasis given to external representations (Cross, 1999; Visser, 2006, p.xvii). Especially in the beginning, these external representations often took the form of sketches, which have been intensively studied (for an early review, see Purcell and Gero, 1998). Even though sketching now appears to have been thoroughly analysed, at least *one corner in the landscape has not been sufficiently covered*: *the intersection of sketching and the levels of collaboration.* While collaborative design appears to have been much studied in design research, a closer look reveals that the word 'collaboration' has been used to describe various kinds of interactive settings, for instance, interchangeably with co-operation. On the other hand, co-operation can be understood as a special type of collaboration with divided responsibilities (e.g. Simoff & Maher, 2000). Lahti and partners separated collaboration, that is, having a shared object of design, from co-ordination (no shared object) and co-operation, where the object was partially shared (Lahti, Seitamaa-Hakkarainen & Hakkarainen, 2004). Dissecting collaboration into different levels or degrees has not, however, gained popularity as an analytical tool. The reasons behind this might have a practical nature. Firstly, professional design teams often consist of practitioners with diverse expertise. They bring their professional opinions and solutions to the table when needed, and when new questions arise, they withdraw to individual work in their chambers to find a solution to bring back—they co-operate. In professional design that way of working makes perfect sense—often division of tasks and co-operation is the most effective way to accomplish the design task (Kvan, 2000). Secondly, it is normal that in a design project, the level of collaboration changes from time to time (Kvan, 2000: Simoff & Maher, 2000). Dissecting the levels requires laborious micro-level analysis, apparently not often considered worth the effort and with few practical gains. In design education, however, the situation should be quite different, especially when students learning to design are to teach design after their graduation—there is more need for analysing patterns of collaboration, for instance, in reference to sketching.

Whereas sketching is a celebrated design practice, gesturing barely has a role in design research. Studies of gestures in design exist, as well as studies on design sketching in conjunction with gestural communication. However, *systematic comparison between sketching and spontaneous gestures in advancing designing is rare*. The role of gestures for designing is clearly understudied (e.g. Visser & Maher, 2011; Cash & Maier, 2016). *Even fewer researchers have discussed gestures from the viewpoint of design education*: to my knowledge, only one study (Cash & Maier, 2016) has explicitly aimed to utilise the knowledge on gestures for training designers.

More gaps in research can be found when we move from ‘pure’ design to fields that acknowledge the centrality of material knowledge: product design and industrial design (Ashby & Johnson, 2010; Pedgley, Rognoli & Karana, 2016). Pedgley and partners claim that ”Deciding upon the role that a material will play within a product is one of the major challenges faced by designers” (Pedgley et al. 2016, p.614). While technical and quantitative knowledge of materials can be learned from books, tables and colleagues, knowledge on how materials are experienced is based on sensorial information—on designers’ embodied experiences. Translating that kind of knowledge into text or speech can be onerous, if not altogether impossible, whilst gestures easily lend themselves to expressing tactual and visuo-spatial experience. Therefore it is somewhat surprising that *spontaneous gestures have not been studied as vehicles for expressing material knowledge.*

Recent research, along with the rise of embodied cognition and practice-led research, has packaged designer’s embodied material experiences and embodied knowledge to forms such as ’material thinking’ (e.g. the journal Studies of Material Thinking) and ’experiential knowledge’ (for an overview on experiential knowledge in practice-led research, see Groth, 2017, pp.31–32). The usual viewpoint taken is of an individual designer’s, as the notion ’embodied experience’ clearly has a subjective and tacit, even private flavour. Learning tasks aiming to increase individual designer student’s knowledge on experiential qualities of materials are described by Pedgley, Rognoli and Karana (2016). Hasling and Bang (2015) describe a learning task that includes an individual but also a collaborative part: negotiation on the meanings that individual students associated with materials. That kind of task is a bit closer to my research, where students’ shared efforts of creating material knowledge take the form of negotiation and testing of materials. Students’ personal knowledge and working hypotheses act as input and results in joint material decisions and new knowledge as output. Their decisions are tested and knowledge validated during making; the finalised artefact manifests the material knowledge created. *Research on that kind of explorative manipulation—collaborative creation of material knowledge for immediate functional purposes and for fulfilling jointly prioritised design constraints—is rare.* However, an understanding of student teams’ objective setting and decision making enables teachers to adjust learning tasks and environments to better support students’ explorative and creative material processes. This understanding can also be used when creating design and make assignments that use materials as sources of inspiration—as potentials rather than solutions.

The above-mentioned approach in which teachers acknowledge students’ ways of knowing and working with knowledge, and then deliberately target to develop these practices is central to epistemic education (Barzilai & Chinn, 2017). Epistemic education targets promoting learners’ performance to achieve

valuable epistemic aims through competence, rather than by chance or luck (Barzilai & Chinn, 2017). In the case of craft teacher education, the valuable epistemic aim for students is to understand design and make processes and practices as well as learn to adapt their performance according to situational needs.

To sum up, my research takes several steps in grounding design education, a part of Craft Studies at the University of Helsinki, in systematic research results:

> *The overall aim of my research is to deepen our understanding of how embodied resources of gesturing, sketching and material explorations are used for embodied creation of knowledge in the context of collaborative design in higher education.*

1.2 Central concepts: Embodiment in collaboration

The operational context for my research is collaborative design in higher education. In a recent review by Patel, Pettitt & Wilson (2012), *successful collaboration appears to be dependent on a complex interplay of several factors and situational features*, such as the characteristics of the individuals, teams and their interaction processes, the support provided, the characteristics of the task and the context, as well as changes over time, just to name a few. Even if both face-to-face and distributed collaboration has been much researched in different fields—in education, workplace and organisational studies, for instance—the complexity of the phenomenon restrains researchers' attempts to generalise research results.

Collaboration entails a challenge: the need to actively communicate and co-ordinate team members' accomplishments. It also offers an incentive: end results can be much more than the totality of individual contributions. Unfortunately, that cliché does not hold true every time a team is set to work, and not with every team. In this research, ideal teamwork is associated with *collaboration*, where *participants have joint goals and work actively together to produce a single outcome* (Hennessy & Murphy, 1999), *engage in mutual appropriation, are receptive to adoption and adaption and make knowledge and practices visible* (John-Steiner, 2000). What follows is that a necessary condition for successful collaborative activity is that thinking is made publicly accessible as talk, gesture, use of artefacts or some other mediational instruments (Engeström, 1994, p.45). Further, *variations in microinteractional processes between collaborators lead to more or less productive collaboration* (Barron, 2003). Hogan, Nastasi and Pressley (1999) identified three kinds of interactive sequences: consensual, responsive and elaborative. In consensual interaction, one speaker carried the conversation and others participated minimally. In responsive interaction, at least two speakers contributed substantive statements

but with differing roles, whereas in elaborative interaction, speakers' multiple contributions built on or clarified others' prior statements. Hogan and partners (1999) concluded that the latter type of interaction was associated with more sophisticated reasoning. A similar pattern of well-performing teams was identified in higher education (Näykki, Järvenoja, Järvelä & Kirschner, 2017).

The above-mentioned results on the quality of interaction were obtained in educational contexts. However, rather than mere interaction, collaborative design represents a process of materially mediated *focused interaction that targets the creation of new artefacts* (Lahti, Kangas, Koponen & Seitamaa-Hakkarainen, 2016; Kangas, 2014, pp.25–33). These knowledge objects (Entwistle & Marton, 1994), that is, designs and design process phase products are crystallisations of designers' collaborative efforts, crystallisations of the designers' knowledge, skills and experience as applied to solving the design problem. For the purposes of this research, *I study embodiment—the use of embodied resources of sketching, gestures and material explorations for focused, artefact-driven interaction—as a social phenomenon with incontestable connections to individuals' histories, experience and knowledge.* I utilise Mondada's (2011) concept 'embodied resource', which refers to modalities such as gesture, gaze, facial expression and body position and separates them from linguistic resources. I stretch that concept to cover two visual expressive modalities central to designing and making: sketching and material explorations. Moreover, being inspired by Streeck (2009, 2015), I cross the bridge between the two paradigms on embodiment, named by Stevens (2012) as conceptualist and interactionist paradigm. He associates the conceptualist work with cognitive linguistics, with the view that "individual human beings have recurrent shared physical experiences and common biologically given bodies and thereby develop common internal concepts and conceptual systems based on these experiences" (Stevens, 2012, p.338). This view is well represented in the seminal works by Lakoff and Johnson (1980) and by Lakoff and Núñez (1997). The interactionist tradition analyses cognition and learning in the context of naturally occurring interaction, and sees the body as a public resource for thinking, learning and joint activity (Stevens, 2012). Seminal works by Goodwin (2000) and Heath (1986) represent this latter paradigm well, and a short history of interactionism is available in Streeck (2009, p.13).

My conceptualisation of embodiment as 'the use of embodied resources for focused, artefact-driven interaction' resonates with Lindblom's definition of embodied actions as not mere random movements, but goal-directed movements which have meaning for the actual person and having impact on the person's cognitive processes (Lindblom, 2007, p.195). However, *by preferring the notion 'use of resource' to 'action', I aim to emphasise that the actions studied here utilise capabilities developed and shaped by individuals' personal developmental histories and experiences.* I separate the use of embodied

resources, that is, *embodied processes* partaking in collaborative creation of knowledge from *embodied content*, that is, individuals' knowledge and experience. As the former is the main subject of this research, the latter is discussed only to a limited extent. Systematic scanning of the latter, individuals' knowledge and experience, is excluded from the empirical part of this research as my interest regarding individuals' knowledge and experience is not the actual content but the creation, use and function of that knowing. My approach towards knowledge follows the principles of design mode (Bereiter & Scardamalia, 2003, p.55–56), where the interest lies not on the truth value of a statement but on how well the statement serves its purpose and the potential it has for further development; that is, the use and function of the statement.

Streeck (2015) discusses the possible future convergence of the two embodiment paradigms mentioned above. For him, "the real difficulty at present appears to be finding a postdualist language" (Streeck, 2015, p.433). While working with these investigations, the challenge of finding expressions and ways of working that celebrate rather than distort researched phenomena has been very real, and not only because I am a non-native English speaker. Firstly, building on previous researchers' work, while honouring their respective commitments, combined with an approach that crosses the borders of paradigms, is always a challenge. Secondly, no matter what the paradigm(s), unavoidable text-based publication practices set demands to research on four-dimensional, ephemeral phenomenon of gestures—demands that appeared violent and often sacrificed the indegeneous characters of embodied resources. Thirdly, most sophisticated analysis methods take language as the starting point, as the legacy of interaction analysis (Jordan & Henderson, 1995) and conversation analysis (Sacks, Schegloff & Jefferson, 1974) is highly present in the current research of multimodal interaction. Twenty years ago, ten Have (1999, p.167) complained that "the analysis of talk tends to come first, and consideration of visually available details comes afterwards" and that principle is apt to set the tone—the primacy of talk—even today. Some exceptions exist, for instance Stevanovic and Monzoni (2016), and Mondada (2015). Unfortunately, I cannot rephrase the ethical statement often seen at the end of wildlife films and claim that 'no gestures were harmed' during this research. Yet I can assure the reader that the method developed during this research, and described later in the Methods chapter, was designed with the aim of preserving and cherishing the defining characters of gestures.

1.3 Foreshadowing: A reading guide

This thesis is comprised of two main parts: first, the introduction that summarises the central theory and my empirical research, and second, the details described in three original journal articles published in international peer-

reviewed journals. The introductory summary is divided into eight chapters, in the first of which I provide a tour round the research landscape and briefly introduce the main concepts, the motivation, the overall aim of this research and this guide for navigating the text.

The plan for the remainder of this summary part is as follows: in Chapter 2, I lay out the operational contexts of my research, that is, collaborative design and design education. I start by introducing central topics for design, such as creativity, situated and distributed design and design as knowledge creation, then I dig deeper into design practices that could boost the creativity of novice designers and briefly introduce central pedagogical approaches for design education. In Chapter 3, I present the three embodied perspectives I have taken on creation of knowledge. In more detail, I describe the characteristics of sketching, gesturing and material explorations that facilitate the sub-processes behind ideation, collaboration and knowledge creation. For sketching, an ample and convincing argumentation is already present in design literature, but for gestures, these arguments have not been collected under one title before, at least not to this extent, and the research on materials and material explorations feeding designing and (especially collaborative) knowledge creation is in its infancy. In Chapter 4, I compile my understanding of embodied creation of knowledge in collaborative design in the form of theory synthesis. Chapter 5 introduces my research questions. Chapter 6 begins the empirical part of my thesis by introducing my choices for research setting, my principles for collecting the data, and the methodological challenges encountered and overcome by the analysis methods I employed. In Chapter 7 I summarise the main findings that are explicated in more detail in my three publications, and in Chapter 8, I discuss the implications of my research on design and gesture theory and practice in design education, on research methods, and identify future research needs.

2 Design

> *[Design] involves a sophisticated mental process capable of manipulating many kinds of information, blending them all into a coherent set of ideas and, finally, generating some realization of those ideas.*
> Bryan Lawson, 1997, How Designers Think, p.10
>
> *A mental process? Let's see…*

Design is an activity that escapes final and simple definitions. Alexander (1964, p.1) defined design as giving form, organisation and order to physical things. Simon (1969) removed the material aspect from the equation and defined design as a rational set of procedures in response to a defined problem. Later, Schön (1983, 1991) brought back the material aspect with his definition of design as reflective conversation with the materials of the situation. Dorst and Dijkhuist (1995) compared the two influential paradigms, Simon's and Schön's, and concluded that *the rational problem-solving approach is apt with fairly clear-cut problems* and when the designer has strategies to follow, *while the reflective conversation approach works well when the designer has no clear strategies and a more explorative approach is needed.* Another synthesis was provided by Visser (2009): design as construction of representations. In turn, Le Masson, Dorst and Subrahmanian (2013) emphasised that even if design entails decision-making, optimising, modelling, knowledge production, ideation, prototyping and evaluation, it cannot be reduced to any or all of these activities.

How then should this multi-faceted activity of design in education be approached? In the following, I highlight the theoretical background of my operational context, collaborative design in higher education. I touch upon the question of creativity, then proceed to a construct that many design researchers prefer to creativity, namely design thinking, and outline mechanisms that are considered beneficial for creative ideation. I then outline the developments that led to understanding design as collaborative, situated, distributed, a kind of knowledge creation, and finally, as trialogical knowledge creation. After laying these cornerstones, I address two pedagogical practices relevant for my research: design studio and the Learning by Collaborative Design model.

2.1 Design is creative: But how Creative is creative?

Design has a logical element and a creative element (Alexander, 1964, p.84–94). A similar distinction was made by Gero (2000), who distinguished routine from

nonroutine designing. In routine design, no creation of knowledge occurs and created products entail (only) minor variations to existing designs, while *in nonroutine design, created products are noticeably different and new knowledge is created.* What comprises noticeable difference is oftentimes debatable. Csikszentmihalyi and Nakamura (2006, p.243) separated Big C from small c creativity, which they see as orthogonal. For them, creativity is a combination of originality, valuation by the community and completion of an idea or a product. Whereas Big C brings about cultural evolution, small c refers to personal ideas or experiences that make a difference to individual's quality of life. Later, Beghetto and Kaufman argued that little c creativity was too wide a category to be useful for research on creativity. They introduced mini-c creativity, the construction of personal knowledge and understanding, "the novel and personally meaningful interpretation of experiences, actions and events" (Beghetto & Kaufman, 2007, p.73). Further, mini-c creativity is close to Little k knowledge, which refers to "the knowledge that individuals possess for themselves" and "reflects their experience of work and understanding" (Garvey and Williamson, 2002, p.56 cited by Cain, 2010). Here, *concepts of creativity, knowledge and learning appear to be approaching each other.* Amongst the many definitions of creativity, I subscribe to Gero's (2000) definition. He introduced the notion of *situated creativity* (S-Creativity), which means that the designed artefacts contain "*ideas that are not necessarily novel in any absolute sense or novel to the designer, but that are novel in that particular design situation*" (Gero, 2000, p.190, emphasis added).

Likewise numerous definitions of creativity as a quality of the produced object, also numerous process models exist (Lubart, 2001). One of the few addressing distributed creativity, that is, the creative process at the group-level, is Sawyer's collaborative emergence (Sawyer, 2003a; Sawyer & DeZutter, 2009). However, even if creativity is central to designing and idea creation, many design researchers appear to prefer a different construct: design thinking.

2.2 Design thinking: Neither right nor wrong but apposite solutions

Nowadays design practices are also widely applied outside the traditional design discipilines: to organisational structures as well as to personal identities (Kimbell, 2009). According to Cross (2007), *design is distinguished from other human intelligent endeavors by two aspects: the kind of tasks that designers work with, and the way in which designers think.* Design tasks, commonly called problems, are often described in the form of constraints and objectives. These constraints and objectives are far from exhaustive but are ambiguous, inscrutable, even conflicting; accordingly, design problems are described as ill-defined, ill-structured or wicked (Rowe, 1987; Buchanan, 1992; Cross, 2007).

Rittel and Weber's definition of wicked problems describes aptly the nature of a typical design task: no definitive formulation for the problem exists, nor is the solution either right or wrong (Rittel & Weber, 1973). Taking another angle, Schön claims that instead of problems to be solved, designers work with ”problematic situations characterized by uncertainty, disorder, and indeterminacy” (Schön, 1983, p.15–16). Either way, *instead of being right or wrong, designers' proposals are apposite*, that is, potential solutions that, once expressed, can be recognised as satisfying certain central demands and accommodating other demands in a satisfactory way (Cross, 1997, see also Simon's notion of 'satisficing', as summarised by Visser, 2006, p.51–53).

The concepts of *design thinking* and *designerly ways of knowing* suggest that a component of a designer's professional capabilities is generic—a component that needs to be complemented with domain-specific knowledge (e.g. Lawson, 1997, p.30; Rowe, 1987, p.3). While the approaches to uncover design thinking are many (see, for instance, Rodgers, 2012; Kimbell, 2009), the following list is based on the seminal works of Cross (1982), Lawson (1997) and Rowe (1987). The central features of design thinking include:

(1) the finding and structuring of the 'real' design problem: understanding the central and critical features;
(2) focusing on the solution rather than the problem: while it is necessary to understand the problem sufficiently, the understanding is only a means to an end, to finding a solution;
(3) seeing things in a new way: finding a new perspective or a new interpretation to problems, constraints and possible solutions;
(4) integrating several partial solutions or features into one;
(5) exposing personal values, insights and visions: the outcome of a design process is always the designer's suggestion of how things should be;
(6) leaning on personal knowledge and experience, heuristics and guiding principles.

Over the decades, design research has identified various phase models and strategies for designing that reflect features of design thinking, such as naming, framing, moving and reflecting (Valkenburg & Dorst, 1998); seeing as, seeing that (Goldschmid, 1991); problem driven, solution driven, information driven and knowledge driven (Kruger & Cross, 2006), moving back and forth between a problem space and a solution space (Dorst & Cross, 2001; Goel, 1995); and moving between composition space and construction space, where composition

includes visual elements and construction includes technical design elements (Seitamaa-Hakkarainen & Hakkarainen, 2001).[1]

As suggested by list item six above, the general component of design thinking needs to be complemented with domain-specific knowledge. When designing material objects, *design domain-specific knowledge* includes knowledge on existing design solutions, typical ways and situations in which clients use the objects, as well as materials and ways to mould and process them (Christiaans & Venselaar, 2005; Seitamaa-Hakkarainen, 2000). *Many of the dimensions of material knowledge are primarily based on embodied experiences on working with diverse materials, manipulations and explorations, as well as the use of different techniques*. Multi-sensory material knowledge, physical interaction with materials is one of the cornerstones of design (Evans, Wallace, Cheshire & Sener, 2005) and a designer's past knowledge and skills suggest how materials can be used (Groth, 2017, p.64; Ramduny-Ellis et al., 2010).

Design thinking describes the ways of designers to address the challenges of design projects. But then how should we follow the list item number 3 above? How to teach students to 'see things in a new way'? The following focuses on general mechanisms behind creative ideation.

2.3 Some mechanisms behind creative ideation

Gero (2000) lists *five creative design (sub-)processes*: *combination, transformation, analogy, emergence and first principles*. By emergency he refers to the recognition of the extensional properties of a structure, and by first principles to the use of existing knowledge in an abductive way. According to Gero, other creative design processes exist, but they often comprise combinations of the five. Goel (1995) separates two types of tranformations: lateral and vertical. In *lateral transformation*, one idea yields to another, slightly different idea, while in *vertical transformation,* one idea is further developed into a more detailed version (Goel, 1995, p.119, cf. de Bono's vertical and lateral thinking, 1977, p. 37–43).

Casakin has identified approaches that are especially beneficial to novice designers: the use of analogies, especially visual ones (Casakin, 2010, 2012; Casakin & Goldschmid, 1999; Casakin & van Timmerer, 2014), metaphors (Casakin, 2011, 2013) and scenarios (Casakin, van Timmerer & Badke-Schaub, 2016). While analogies and metaphors rely on identifying similarities, scenarios

[1] Burnette (2018) notes that research on design thinking could do better in keeping up with recent developments in linguistics, psychology, neuroscience and computational sciences. He suggests an update by introducing notions such as conceptual metaphors, conceptual blending and embodied thought.

create alternative realities. According to Casakin, all the mentioned practices are based on abstractions of reality that enable one to focus on selected aspects and envision them from unorthodox viewpoints (2011, 2012; Casakin, van Timmerer & Badke-Schaub, 2016). Whereas analogies and scenarios are found to support idea generation, metaphors are more beneficial for problem framing (Casakin, 2012, 2016; Hey, Linsey, Agogino & Wood, 2008). Further, Choi and Kim (2017) claim that for more creative ideas, design students should be encouraged to abandon convergent thinking and linear process and engage in divergent thinking through analogies and metaphors.

Chrysikou (2015, p.236) suggests that *successful designing requires dismissing well-established ways of thinking in favour of creating new ones that address the needs of the situation*: the design objectives and constraints. A possibility to that dismissal is provided by the mechanism behind analogies and metaphors. First, a correspondence between two items—a design feature and its analogous/metaphorical counterpart—is recognised, and then the design feature is interpreted through the meanings related to or the qualities of the counterpart. To state the same in terms of abstractions, a higher level previously unknown abstraction is derived from a known abstraction of the counterpart and from an unknown abstraction of the design feature (Dejong, 1989, pp.361–363). From the idea generation viewpoint, the new interpretation of the design feature reached by the use of analogy or metaphor then acts as a source of inspiration and has the potential to spark new design ideas.

To be successful, that kind of mental acrobacy—*the use of analogies or metaphors—requires accessing and transferring structural information, previously acquired knowledge* of objects, attributes and relations, on previous design solutions, on how the design is about to be used, in what kinds of situations, by which users and their preferences, and so forth. However, teaching by providing examples for sources of analogies carries the risk of fixation. Students reproduce examples instead of using them as sources of inspiration (a recent review on this topic is provided by Chrysikou, 2015). A way to mitigate the fixation risk is to make direct copying impossible by selecting sources that represent a different modality than the targeted design object, for instance texts for designing chairs and clocks (Goldschmidt & Sever, 2010).

2.4 Collaborative, situated and distributed character of design

For a long period of time, design was considered an individual endeavour. During the 1980s, a general interest in teamwork and collaboration arose and so did research on designers working in teams. Typical for collaborative design is that ideas emerge from interactions. The father of the idea is not always evident. The mother of the idea, the one who is the first to state the idea aloud in full can

sometimes be located but sometimes the idea grows from tiny pieces, fractions of features that are compiled and transformed in various phases until they finally come together. Often this final compilation is not something that was obvious in the previous stage of the idea development. Even if design literature has introduced various models that provide us with insights into design ideation, *explaining how influential design ideas come about remains difficult, if not impossible*. The creative collaborative core eludes current analysis methods[2].

The turn to collaboration was not the only change that took place in the 1980s that complicated researchers' work. Suchman (1987, p.27–28) challenged the view of practical action as a systematic sequence of pre-planned steps leading to a goal and replaced it with the view that emphasised the situated nature of actions. For her, situated actions depend essentially on material and social circumstances that trigger further needs for action: improvisation relying on available locally relevant knowledge (Suchman, 1987, p.50). Approaching situatedness at the level of perception and memory, Clancey (1997, p.1–4) claimed that *every thought and action* is situated—adapted to the environment—and at least partially improvisatory due to the interconnectedness of what people perceive, how they conceive of their activity and what they physically do. Our understanding of things, our theories and conceptions "develop in our behaviour as we interact with and reperceive what we and others have previously said and done" (Clancey, 1997, p.3). In turn, Hutchins (1995) introduced distribution of cognitive processes. That distribution has three dimensions: distribution across team members, between internal and external (material or environmental) structures, as well as through time, which means that earlier products can transform the nature of later events (Hollan, Hutchins & Kirsh, 2000).

To summarise, the introduction of situational, social and material aspects of collaborative work and design advocated the recognition of the emergent and multimodal character of collaboration, as well as the role of external artefacts for thinking and cognition.

2.5 Design as knowledge creation

The themes of situationality and distributed cognition were clearly also visible in the works of Schön, who introduced design as situational knowledge creation (Schön, 1983, p.78–104). For him, moving, that is, making new proposals and changes, played a fundamental two-fold role: testing outcomes and conformity with earlier moves as well as probing and shaping the problem (Schön, 1983, p.94–95). Building on Schön, Gedenryd (1998, p.85) saw every action as

[2] The discussion on the difficulties of locating the creative core continues in 6.3.1.

moving, as having two purposes: to apply knowledge and to test whether that knowledge is suitable. According to Dorst and Dijkhuis (1995), these tests use three criteria: coherence with earlier moves, accordance with the requirements and advancement of the solution. Taking these together with the before-mentioned views on situatedness, *I take every turn-at-talk, gesture and practical action of collaborative design as a test of knowledge, an act of knowledge creation*. Each action of this kind simultaneously fulfils five functions: (1) to explore if the piece of knowledge fulfils the demands of the task, (2) to explore if it fits with the solution developed so far, (3) to explore if it aligns with self-induced objectives and vision, (4) to introduce the piece of knowledge to other participants and (5) to engage the participants in acts of evaluating and further developing the object of design.

Trialogical knowledge creation (Paavola & Hakkarainen, 2005, 2014) offers a model through which many of the above-mentioned themes can be applied to design education: the focus on authentic, challenging problems such as design assignments; the approach towards knowledge; the collaborative, situational and distributed nature of the work; as well as the central role of artefacts (representations, materialisations). The model places special emphasis on the progressive development of concrete knowledge-laden artefacts and related practices. Thus, it makes collaborative design, with its natural emphasis on the shared object of work, a prototypical example of trialogical knowledge creation.

In trialogical knowledge creation, the shared object of work becomes materialised as epistemic artefacts: design representations from different phases as well as the final design artefact. *The word 'trialogical' refers to the three-fold nature of these epistemic artefacts as tools for thinking, objects to be developed as well as concrete objects* (Paavola, Engeström & Hakkarainen, 2012); *the epistemic artefacts are dynamic visions pursued after and materialisations of the epistemic aims.* From the vantage point of (design) education, trialogical knowledge creation goes beyond mere knowledge acquisition or social participation; the students are encouraged to take the agency of their working processes and objects they are developing, as they engage into sustained focused activities, i.e. trialogical efforts of advancing shared epistemic objects (Paavola & Hakkarainen, 2005, 2014).

Trialogical knowledge creation can also be understood as a vehicle for epistemic education. According to Barzilai and Chinn (2017), the five key aspects for epistemic education include (1) engaging in discipline-specific practices that lead to achieving the set goals, (2) adapting performance according to situational needs, (3) meta-level performance regulation, (4) achieving the goals together with others, and (5) committing to and enjoying the achievements. Successful projects of trialogical knowledge creation fulfil all these five aspects.

A pedagogical practice that ties together collaborative design and trialogical knowledge creation exists. Before presenting it, I will describe the underlying signature pedagogy of design education: the design studio.

2.6 Pedagogy in design education

As curriculums differ, so do pedagogical structures. In design education, *design studio* is the ”signature” pedagogical approach (Suhlman, 2005), a cultural model of teaching and learning design (Sawyer, 2017). In a studio, students engage in designing while learning what design is and how to do it in practice (Schön, 1987, p.83). Traditionally, the studio is as much a place for designing as it is an instructional method: it provides an environment which imitates professional designer’s work place with plentiful materials and representations. Studio approaches are diverse (Kamalipour, Kermani & Houshmandipanah, 2014)—they range from emphasising individual tutoring sessions with teachers as the opportunity to students to acquire design skills and knowledge (Goldschmidt, Hochman & Dafni, 2010) to considering teachers as coaches or squires (Boling, Siegel, Smith & Parrish, 2011) and to understanding how one uses peer discussions with teachers as a choreographer (Mewburn, 2010). The latter two come close to two other typical approaches in design education: problem-based learning (Eilouti, 2006) and project-based learning (Lee, 2009). Since the 1990s, as the overall demand for collaboration between professionals rapidly increased, individual student work has often been accompanied with co-operative and collaborative design work. All these approaches emphasise working with open-ended design projects similar to those encountered in professional practice, but a profound difference between these approaches is the role assigned to students as participants in knowledge creation activities—their level of agency.

A pedagogical framework assigning collaborating design students to an active role in challenging design studio project is the *Learning by Collaborative Design (LCD)* model (Seitamaa-Hakkarainen et al. 2010). The LCD model engages the students in modelling, prototyping and creating material artefacts in addition to conceptual design. The model was first developed for virtual environments but lately it has been applied to face-to-face collaborative designing (Kangas, 2014; Seitamaa-Hakkarainen et al., 2017). Collaboration and distributed expertise are the heart of the LCD model, and the surrounding design process is depicted as spiral (Figure 2). This structure emphasises the prevailing character of collaboration during the entire design process. Further, successive process cycles are necessary in order to achieve a design that satisfies design constraints.

According to the LCD model, the collaborative design process begins with creating the design context and defining design tasks and constraints. That is

followed by creating conceptual and visual design ideas, evaluating design ideas and constraints, connecting with expert communities and collecting data, experimenting and testing design ideas by sketching and modelling, evaluating the functions of models, and elaborating design ideas and redesigning. Despite its cyclical character, the model itself does not prescribe design stages rigidly following each other in a particular order, rather, it describes intertwined increments of the iterative design process.

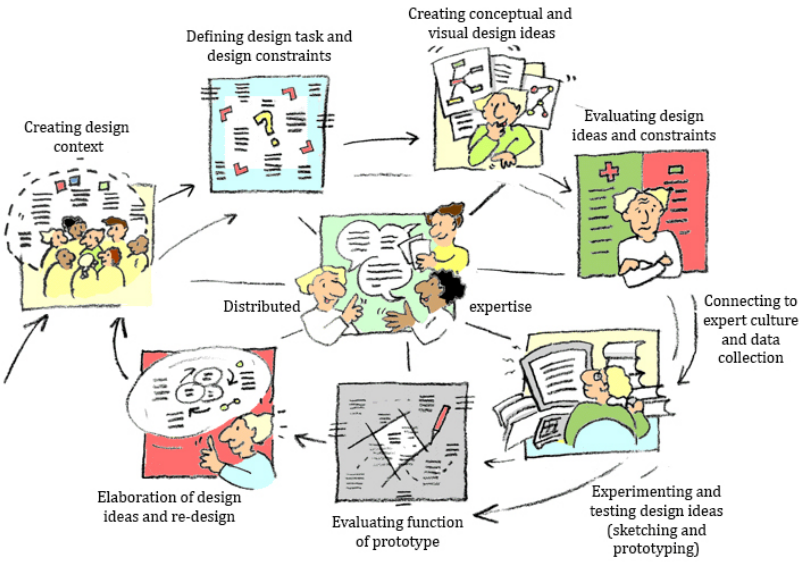


Figure 2. The Learning by Collaborative Design (LCD) model (adapted from Seitamaa-Hakkarainen et al., 2010).

The LCD model is a prototypical example of trialogical knowledge creation, in which students are encouraged to take agency of their own work, processes and objects (Paavola & Hakkarainen, 2005; 2014), as discussed previously. Henceforth, collaborative design is used as a synonym for trialogical knowledge creation. Recent research on the LCD model and trialogical knowledge creation at the level of elementary education reported that engaging with embodied thinking—in this case, the handling of materials and tools as well as using the dimensions of body and space—facilitated student advancement into thinking processes otherwise beyond their capabilities (Kangas, Seitamaa-Hakkarainen & Hakkarainen, 2013).

In the following chapter, Chapter 3, I provide a more detailed treatment of the topics of sketching, gestures and material explorations and their underlying mechanisms. The central themes of designing and the three embodied perspectives are then drawn together in Chapter 4.

3 The perspectives

> *All theory may be regarded as a kind of map extended over space and time.*
> Michael Polanyi, 1958, Personal Knowledge, p.4.

Human hands move—they perceive and depict, they explore and manipulate. For the purposes of my research, human hands provide three perspectives on the creation of knowledge: the use of embodied resources of sketching, gesturing and exploring materials. All these resources are linked with embodied, experiential knowledge; the resources provide a two-way channel through which personal experience and bodily knowledge diffuse. These linkages share some similarities but are also characteristically different.

When observing collaborating designers engaged in lively conversation and sketching it is sometimes difficult to recognise when a hand movement that started as sketching turns into gesturing, or vice versa. Descriptive gestures can be seen as forerunners of line drawing (Arnheim, 1969, p.117). Indeed, sketching and gesturing have several features in common. They produce *simplified abstractions that focus attention* on features that the person sketching or gesturing sees as being central to the task at hand (Streeck, 2009; Tversky, 2002). Clark (2016) parallels sketching and gesturing as depictions, as *physical analogues* of the scenes they depict, as scenes that people stage for others. He sees sketches as exhibited depictions and gestures as performed depictions (Clark, 2016). Design research has recognised that both sketching (Lawson, 1997; Schön, 1983) and gestures (Bekker, Olson & Olson, 1995; Tang, 1991; Visser & Maher, 2011) provide *essential information that is not provided by speech*. Moreover, when speech, sketches, and gestures are used in combination, each modality explains and disambiguates the others (Bly, 1988; Minneman, 1991; Tang, 1991). A central commonality for the purposes of this investigation is that in the collaborative setting, sketching (Cross, 1982; Lawson, 1997; Schön, 1983) and gesturing (Visser & Maher, 2011; Eris, Martelaro & Badke-Schaub, 2014) *facilitate design thinking and communication*.

On the other hand, sketching and gesturing are different. Sketching is a practical, physical action that produces permanent marks-on-paper, while gestures are temporary. Sketches are two-dimensional and static, while gestures are four-dimensional and dynamic. Their statuses in design research are profoundly different. Professional designing has frequently been associated with sketching (Purcell & Gero, 1998; Cross, 1999), but in design education, the benefits and role of sketching are subjects that invite research and opinions. The

role of gestures in idea generation, exploration and evaluation is not that well established, and studies of gestures in design education are rare.

While the first two perspectives, sketching and gesturing, create a pair that with ease can be compared and contrasted, the third, exploring materials, shares the perceiving, depicting, exploring and manipulating qualities with the other two, yet in different proportions. This difference complicates straightforward comparisons. In addition to comparisons, the introduction of this third perspective is an attempt to shift materials and material explorations from 'routine design' closer to 'creative design'. In Bauhaus, students were guided simultaneously by handicraft masters and masters of design, because both "intimate knowledge of materials and working processes" and "sufficient imagination" were considered necessary (Gropius, 1962, p.25). The introduction of this third perspective is also an attempt to close the circle from experiencing to demonstrating and building on that experience, from exploring and manipulation to sketching and gesturing.

At times, these embodied resources have a meaningful, epistemic role in collaborative designing and making; they provide significant input and advance the process of knowledge creation. This chapter elaborates on the characteristics of the three embodied resources and the underlying mechanisms. I emphasise features that facilitate collaboration and creative idea generation, exploration and evaluation.

3.1 Sketching

> *The investment with a sketch is in the concept, not the execution.*
> William Buxton, 2007, Sketching User Experiences: Getting the Design Right and the Right Design, p.111

At the most general level, sketching refers to the creation of a drawing that depicts something in an informal way and features (only) provisional decisions and (only) approximate details, yet across design domains, the types, properties and roles assigned to sketches vary (Eckert et al. 2012). Several classifications of design sketches and drawings exist (for instance, Ferguson, 1992; Pei, Campbell & Evans, 2010; Schenk, 2007), but for the purposes of this research, I paraphrase the definition by Eckert et al. (2012): *sketching is a hand-drawing technique, focusing on pivotal points on the image and elimination of unnecessary details.* The following sections discuss the mechanisms behind sketching and how they support ideation in designing, the ongoing discussion if sketching is beneficial to novice designers, and finally, sketching in collaborative design.

3.1.1 Sketches conceptualise, ambiguate and facilitate emergence

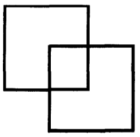
Goel (1995, p. xii) claims that he is not interested in how sketches depict or how accurately they resemble what they refer to, rather how sketches are imprecise, ambiguous, fluid, amorphous, indeterminate. This might sound like good news for all students struggling with feelings of inadequacy in design sketching: *the key to generative ideation process might lie elsewhere than in the precision and resemblence of sketches*. Indeed, (design) sketches are not intended to portray reality with photographic accuracy. Rather, they convey certain conceptions of reality by incorporating relevant and omitting irrelevant details, that is, by distorting (real-world) information (Tversky, 2002). In other words, first abstracting and then converting these abstract visualisations into concrete two-dimensional products (Orde, 1997). Sketches are abstractions, schematisations and conceptualisations (Tversky, 2011). Lawson (1997, p.242) suggests that sketches focus only on what is required at the time, at the level of precision that the designer is ready to commit to that moment. Furthermore, those features can make a design sketch difficult to understand outside its original context (Buxton, 2007, p.111). *Sketches can be extremely focused, situated and localised forms of thinking; design sketches differ from representational drawings that prioritise communicativity and expressivity.*

As abstract but permanent visual conceptualisations, sketches are material but ambiguous. According to Goel (1995, p.179), ambiguousness means that the basic elements of a sketch (elemental characters contained in the sketch) do not bear standard meanings but get interpreted differently in different combinations and in different sketches. A simple circle can be understood as a round object, a hole or the sun, depending on the context as well as on the person who is looking at it. *The same sketched, ambiguous element can convey meanings at different levels of abstraction, thus enlargening the number of possible interpretations.*

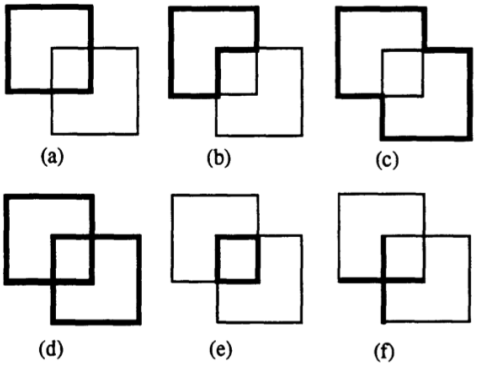
The ambiguousness of sketches also facilitates lateral transformations (Goel, 1995, p.218), that is, the generation of multiple slightly different ideas. A mechanism behind lateral transformations is the *emergence of shapes*. Emergence, much studied in design and psychology (for a review, see Soufi & Edmons, 1996), *enables the recognition of transformations and the generation of multiple interpretations* (Soufi & Edmonds, 1996) in a very concrete way. Enthusiastic readers can challenge themselves with the example on the following page (Figure 3): how many transformations can be generated from the rather simple original shape on the top without sketching (or seeing) the variations provided below the original shape? The first interpretative set is generated from the original shape by adding no new elements. The second transformative set is generated by adding some new elements in the form of boundary lines. Vertsjinen and partners have shown that emergence (restructuring in Verstjinen's terms) clearly benefits from sketching, as (even) expert designers struggled with emergence when using mental imagery alone but performed

much better when allowed to sketch (Verstjinen et al. 1998). *Recognition of emergent shapes and transformations is easy from sketches but practically impossible without sketches (or other types of representations). Thus, sketches can have a direct impact on the number of new ideas generated.*

The original shape:



Interpretations:



Transformations:

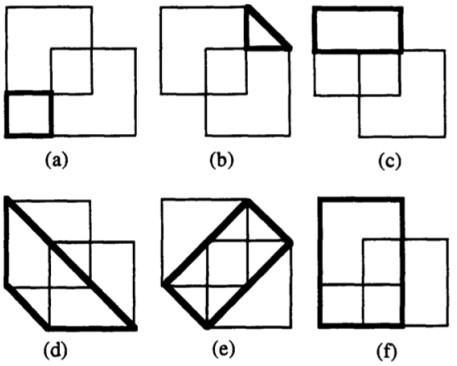


Figure 3. Recognising emergent shapes from the original shape (at the top): deriving various interpretations (in the middle), and deriving transformations (at the bottom). Soufi and Edmonds (1996). Reprinted with the kind permission of Elsevier.

The interpretations and transformations in the figure above might appear mechanistic. Where is the creativity? According to Stones and Cassidy (2010), the importance of a reinterpretation is that it functions as a source for new ideas. That can take place, for instance, through visual analogies discussed earlier.

Chamorro-Koc and partners (2008) noticed that representations receive different interpretations from different people, and these interpretations reflected their different experiences (Chamorro-Koc, Popovic & Emmison, 2008). Tholaner and partners suggest that sketches are important for designing not as individuals' expressions of their ideas but through the meanings collaboratively constructed around the sketches (Tholander, Karlgren, Ramber & Sökjer, 2008); sketches inspire teams to link new interpretations to the sketches, which could spark new ideas.

The local importance of sketches as thinking tools is emphasised by McKim's eight "thinking operations" that can be "amplified and supported" by sketching (McKim, 1980, in Kjellberg, 1999, p.350):

1. abstraction for generalisation and classification;
2. concretising for detailing, focusing and clarification;
3. modification through exaggeration;
4. transformation of picture identity through e.g. metaphors [analogues];
5. manipulation to rearrange or make separation;
6. time scanning of a sequence through successive sketching;
7. to express, study and develop, and
8. testing to find inconsistencies.

To conclude, McKim's "thinking operations", as well as the introduced features of sketches, resonate with many of the elements supporting creative idea generation processes, as identified earlier (section 2.3). Furthermore, the features of sketches important for generation and evaluation of ideas—designing—are different from features important for the communication of design ideas for wider audiences.

3.1.2 Do novice designers benefit from sketching?

Many books on design drawing celebrate eye candy as they address on good visual aesthetics (Baskinger, 2008, p.35). These books not only inspire but could also inflict feelings of inadequacy amongst novice designers. Booth, Taborda, Ramani and Reid (2016) listed a number of factors behind design students' reluctance to sketch, many of which related to *students' beliefs that they are not good enough.*

Another question is whether novices understand sketching as a means of generating, testing and developing ideas, as opposed to representating them– at least younger ones do not understand that and prefer three-dimensional modelling to sketching (Hope, 2005; Kelley & Sung, 2017; Rowell, 2002;

Welch, 1998). As Welch (1998) explains, a good reason for asking students to first sketch and only then move on to three-dimensional modelling is for the students to plan and explore ideas with a technique that allows for exploratory moves being (easily) reversed. Such an approach is less costly in time and resources and allows novices working with abstractions to avoid closing an idea too early in the process, to avoid acting before thinking it through. In other words, *the aim is to support students in reaching their creative potential*. But, as Welch points out, what if students cannot express their ideas clearly enough by sketching? Welch, Barlex and Lim (2000) emphasise that students should be taught to choose the method of modelling that is appropriate to the task at hand, as well as taught to use diverse modelling methods—amongst others, sketching for designing.

Research shows that experts benefit more than novices from sketching during idea generation (Goldschmidt 1991; Suwa and Tversky 1997). However, Eisentraut and Günther (1997) note that while drawing by hand is important to professional designers, the use of visualisations depends on the designer's style of problem solving; results reported by Jonson (2005) support this. Furthermore, while Bilda, Gero and Purcell (2006) suggest that professional designers may not need to sketch during conceptual designing, they also speculate that it may be that professionals' long experience of progressing their ideas through sketching enables them to design through mental imagery only, without sketching. Bilda and partners (Bilda et al. 2006) continue by emphasising the importance of sketching for learning how to design. To conclude, it appears that *currently not all novices benefit from sketching*. The challenge for design education remains to teach the underlying reasons for using different modelling techniques and how these techniques are best used to support creativity.

3.1.3 Sketching in collaborative design

Sketching has been considered an important thinking tool for designers for quite some time (for reviews, see Bar-Eli, 2013; Brun, Le Masson & Weil, 2016; Purcell & Gero, 1998). The flexible role of sketches (Bar-Eli, 2013) have inspired several categorisations of functions and properties, e.g. Tang (1991), Ullman et al. (1991), Ferguson (1992), Goel (1995), van der Lugt, (2005), Kirsch (2010). In collaborative design, shared sketches provide *a common platform, a repository of ideas, forms, structures and functions that mediate teams' generative and evaluative actions.* However, there is a difference in studying sketches—the impact of the form and shape of the marks—and in studying sketching—the impact that the process of making those marks has on thinking, as Stones and Cassidy (2010) point out. *Sketching changes the character of the design task.* Verstjinen and partners reason that sketching fulfils a basic need arising from the limitations of imagery—otherwise, designers

would not sketch (Verstjinen, Heylighen, Wagemans and Neuckermans, 2001). Moreover, sketching enhances a (mostly) language-based design brief by introducing visual modality into the process. *The complementary relationship between verbal and graphic representations has been viewed as central to the creation of new ideas: a constant "oscillation" between language and sketching* (Akın & Lin, 1995; Goldschmidt, 1991) or between sketched (externalised) and internal visualisation (Kavakli, Scrivener & Ball, 1998).

Pursuant to collaborating designers, an even more important change is the one related to the stage at which sketches are shared. Sharing sketches is necessary for distributing cognition between team members, between internal and external structures and time-wise (Hollan, Hutchins & Kirsch, 2000). Moreover, sharing is necessary for active, productive collaboration (Engeström, 1994, p.45), as well as for trialogical knowledge creation (Paavola et al. 2012). *Communicating ideas as early as they start to emerge and 'real-time' sharing of sketches feed and enrich collaborating designers' thinking and provide props for their creative processes, such as combining, transforming, analogy and emergence* (as introduced in section 2.3). In collaboration, one's thinking processes are stimulated by the actions of the others—their thinking processes are no more independent rather than interactive (Saunder & Yin, 2016). On the other hand, the amount of simultaneous stimuli in the form of sketches and speech increases the possibility of designers' thoughts not following the same trails, or focusing on the same feature; while one designer is evaluating one idea, another might propose a totally new one building on some previous sketch.

The models describing thinking central to idea generation, that is, explorative cycles of sketching, reinterpretation and evaluation available in think-aloud protocoals (e.g. in Goldschmidt, 1991; Valkenburg & Dorst, 1998) do not always straightforwardly present themselves as time-sequential acts of sketching and speech because more than one designer is simultaneously engaged in design conversation and collaborative sketching. *Not all features of design ideas—knowledge created collaboratively—are reducible to individual actions, nor can we define linkages between each individual action and proposed design ideas*. Sawyer's (2003a) model of collaborative emergence captures well this analytical challenge, even if it is not based on design research. It describes processes of collaborative creativity as the interaction of two simultaneous and intertwined processes: collaborative emergence and downward causation. The first-mentioned process creates a conversational frame. That frame is a dynamic structure: each conversational action changes it and creates a context for future conversational actions (cf. Clancey as presented in 2.4). That context, i.e. that frame guides and constrains the future actions of the participants, which constitutes the process of downward causation (Sawyer, 2003a). Sawyer claims that the frame is unintended, emergent and analytically irreducible (Sawyer, 2003a, p.80). A frame that has causal power is like an invisible participant in the

conversation. Thus, only some of the developments are visible and audible. Further, the picture becomes no less complicated when we take into account the topic of the next section: gestures.

3.2 Gestures

> *Middle class British-American children are actually taught not to gesticulate because it is regarded as impolite.*
> Albert Scheflen & Alice Scheflen, Body language and the social order, 1972, p.88 as cited by Graham & Argyle, 1975, p.58.

"The word 'gesture' needs no explanation", begins McNeill in his seminal book Language and Gesture; however, others have tried. The Oxford English Dictionary provides several, such as "A movement of the body or any part of it. Now only in restricted sense: a movement expressive of thought or feeling." According to Kendon (2004, p.7), a gesture is "a visible bodily action when it is used as an utterance or as a part of an utterance"; he further defines 'an utterance' as a communicative 'move', 'turn' or 'contribution'. Kendon (2004, p.108) also provides a definition built not on communicative features but on kinesic forms and functions of gestures: "units of visible bodily action identified by kinesic features which correspond to meaningful units of action such as a pointing, a depiction, a pantomime or the enactment of a conventionalised gesture" (Kendon, 2004, p. 108). My research is restricted to hand gestures.

Even with that restriction, the topic is complicated because hand gestures come in various shapes and functions. A well-known taxonomy of gestures introduced by McNeill (1992, p.76–80) describes iconic, metaphoric, deictic and beat gestures. Iconic gesture depicts aspects of physical, concrete objects or scenes, such as form, size, orientation or tactual quality, as well as type or trajectory of movement. Metaphoric gesture depicts abstract concepts; they are hand signs associated (within a specific community) with a direct verbal translation, such as the "OK" sign and "V for victory" in the West. For some people, the word 'gesture' is directly associated with metaphoric gestures. Deictic gestures, in turn, are pointing movements directing our attention, indicating a location, object or person in our immediate surroundings, and so forth. Beats are movements without discernible meaning but synchronised with our speech. Further, iconic, metaphoric and deictic gestures can be grouped together as *representational gestures* (Kita, Alibali & Chu, 2017). In this research, most attention is devoted to representational gestures.

As with the capacity to learn language, the capacity to learn to gesture is also innately given. Substantial differences exist among individuals (Chu, Meyer,

Foulkes & Kita, 2014), but even congenitally blind (that is, individuals blind from birth) have been found to gesture. Congenitally blind persons use iconic gestures in ways resembling those of sighted individuals (Iverson, 1999; Iverson & Goldin-Meadow, 1997; 2001), and differences among speakers of different languages (for a review, see Kita, 2009) are larger than differences between blind and sighted (Özçaliskan, Lucero & Goldin-Meadow, 2016). That suggests that for the development of gesture, the influences of language, or more precisely, structures and conceptualisations omitted from or supported by the language, are more significant than the influence of seeing others gesture—or visual experience in general (Özçaliskan et al. 2016). The following sections present how gestures become part of our behavioural repertoire during early childhood development, and how gestures' functions to listeners and speakers, as well as situational, social and experiential factors shape gestures.

3.2.1 Gestures develop during childhood

During the early years, the development of gestures is closely related to the development of language skills: each major milestone in language development between the ages of 6 to 30 months is preceded or accompanied by specific aspects of gesture (Bates & Dick, 2002; Capone & McGregor, 2004). For example, before a child can combine two words to express two different meanings, he or she can usually express two different meanings by combining a pointing gesture with a word (Capirci, Iverson, Pizzuto & Volterra, 1996). Early pointing is indicative in various ways, as it has been found to predict later size of vocabulary (Rowe, Özçaliskan & Goldin-Meadow, 2008; Rowe & Goldin-Meadow, 2009), complexity of first sentences (Iverson & Goldin-Meadow, 2005), and the development of later social-emotional concepts (Vallotoon & Ayoub, 2010). Like language, *gesture reflects the status of a child's cognitive development* (Capone & McGregor, 2004). For instance, a child's ability to name (categorise) an object emerges at around the same time in words and in 'recognitory gestures' which are stylised versions of using the object (for a review on the related research, see Iverson, 2010). Further, a child's ability to abstract a spoken 'word' from its physical referent is related to his or her ability to abstract a gestural form from its referent (Capone & McGregor, 2004). Goodwyn and Acredolo (1998) report that this decontextualisation (Werner & Kaplan, 1996, p.94, 166–168) can occur faster in gestures than in words, resulting temporarily in larger gestural than linguistic 'vocabulary'.

According to a review by Capone & McGrecor (2004), the development of gestures follows a predictable order and children's ability to relate gestures to speech changes with age. First come rhythmic hand movements that accompany babbling, then, before the first words, come pointing gestures seeking attention and maintaining communication with adults. Iconic and not yet stabilised 'pre-

iconic' gestures usually emerge before the child can say 25 words. These *early iconic gestures reflect a child's own experience—most often manipulations of objects rather than perceptual qualities*—but some may emerge from within interactive play routines such as songs and rhymes with actions (Capone & McGregor, 2004). Children's use of iconic gestures is linked to the development of multiword speech (Colletta, Pellenq & Guidetti, 2010), and these iconic gestures are used together with speech, not to replace speech (Nicoladis, 2002). Further, Nicoladis, Mayberry and Genesee (1999) found that the use of iconic gestures correlates with longer utterances, which they suggest show attempts to express more complex concepts.

Gestures scaffold spoken expression and comprehension and aid in the transition to concept acquisition up to school years (Capone & McGregor, 2004; Whitebread & Basilio, 2012). An extensive research by Goldin-Meadow and partners (Alibali & Goldin-Meadow, 1993; Church & Goldin-Meadow, 1986; Perry, Church & Goldin-Meadow, 1988) on gesture-speech 'mismatch' (that is, information conveyed by gesture but not in accompanying speech) has shown that *children's understanding of complex concepts can emerge first in gestures and only later in speech*. Thus, gestures reveal to a teacher if a child is likely to benefit from instructions and master the concept in question—to advance to a new level in understanding and thinking. Goldin-Meadow and partners also found that gestures facilitate knowledge transfer (Garber, Wagner Alibali & Goldin-Meadow, 1998) with a mechanism discussed in the next section. Henceforth, the word 'gestures' refers to representational gestures if not otherwise indicated.

3.2.2 Gestures schematise experience, action and perception

Though iconic gestures usually simulate actions and manipulation of objects, that simulation rarely includes all aspects of their original counterparts. Rather, researchers describe gestures as schematic actions grounded in everyday experience of actions and things (Streeck, 2009, p.201; 2015) or as schematic representations (Calbris, 2011; Chu & Kita, 2008; de Ruiter, 2000, p.291–295; Goldin-Meadow, 2015) that reflect the features of the actions the speaker has actually performed (Wagner Cook & Tanenhaus, 2009; Kita et al. 2017) or perceived (McNeill & Levy, 1982, p. 279–280).

For designing and knowledge creation, the aspect of not being a perfect copy of the corresponding action or perceived world could possibly be the most important feature of gesture; in a recent study, Novack and partners (2014) found that *generalisation of knowledge was facilitated only by gestures, not by simulation of action or by action with objects*. They claim that this effect is due to the features that differentiate gesture from action: as representational actions, gestures can omit irrelevant aspects and direct our attention to important ones

(Novack, Congdon, Hemali-Lopez & Goldin-Meadow, 2014). Goldin-Meadow (2015) came to similar conclusions: we are able to use gestures to focus only on certain dimensions of a situation, as action is accompanied by all the details and is tied to a particular real-world context.

Kita and partners' Gesture-for-Conceptualization hypothesis proposes that *gestures schematise information, that is, focus our attention only to a small part of the available spatio-motoric information*—information that is potentially relevant for the task at hand (Kita et al. 2017). In general, schematised information is more economic to handle. Schematisation also influences how the listener schematises the situation at hand (Mumford & Kita, 2014). For communication, learning and knowledge creation, this focusing of attention should be beneficial. However, Streeck (2009, p.3) challenged the significance of gestures by suggesting that their meaningfulness "is not even beyond reasonable doubt". Gestures do not appear to be equally important for all.

3.2.3 The active listener's viewpoint: Is it all about understanding?

Gestures convey meanings that are not available in the accompanying speech, and listeners pick up these meanings (Graham & Argyle, 1975; Holler, Shovelton & Beattie, 2009; Kelly, Barr, Church & Lynch, 1999). This can happen even when the information conveyed by gestures contradicts the accompanying speech (Cassell, McNeill & McCullough, 1998). According to Hostetter's (2011) meta-analysis, *the effect of gesture on the overall understanding of a message is moderated by several factors*, including:

(1) *type of meaning*: gestures demonstrating spatial qualities or motor actions were more communicative than gestures about abstract topics;
(2) *redundancy*: gestures complementing or supplementing the accompanying speech were more effective than redundant gestures (that is, gestures with no additional information with regard to the accompanying speech).

The first argument is based on gestures being characteristically suited to convey spatial information, as abstract meanings could be more difficult for listeners to glean. The second argument appears at first to be simple: non-redundant, that is, new, or additional information is obviously more valuable than replicating the same message already stated in speech. Redundancy, however, is not a straightforward topic. *Rather than being a dichotomous scale, redundancy is a continuum* (Bavelas & Chovil, 2000). Figure 4 provides an example of a (seemingly) redundant gesture: drawing a circle with your index finger while saying: "How about making round pieces?" The same gesture would appear perfectly non-redundant when accompanied by a sentence "How about making the pieces like this?"

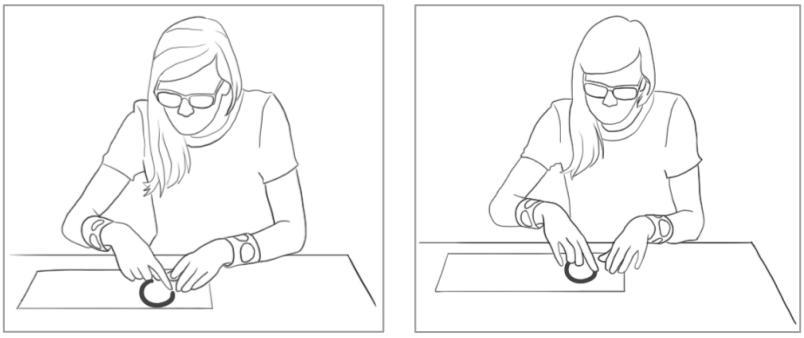


Figure 4. Redundancy as a continuum rather than a dichotomy. The more redundant gesture on the left: "How about making round pieces?" The non-redundant on the right: "How about making the pieces like this?" Two stylized video frames.

Disturbingly, in addition to the apparent meaning (a circle as the intended shape) the gestures unavoidably convey information about the size of the circle. Whether that information is meaningful depends on the situation. Whether the gesture in the first example is non-redundant depends on the listener's perception of the meaning of the size information. Further, while all gestures are not as easy to interpret as the above examples, different listeners might well interpret a gesture in different ways. Listeners are not just passive observers (Kendon, 1994, p.195) who catch and swallow the intended meaning of the gesture. Encoding a gesture is based on listeners' prior experiences and understanding of the situation in which the gesture appears (Calbris, 2011, pp.10–11; see also Ping, Goldin-Meadow & Beilock, 2013). Thus, a consensus about the redundancy of an ambiguous gesture might be difficult to reach among listeners with different experiential bases; *redundancy is in the eye of the beholder*.

Discussion regarding whether gestures are redundant or non-redundant to accompanying speech can be understood as arguments that gestures are unnecessary, a waste of time, or add no value. Alternatively, *gestures can be seen as co-expressive, reducing the ambiguity of a message and rendering it more graspable*, *irrespective of whether the gestures are redundant or not* (Kelly et al. 1999; Matoesian & Gilbert, 2016, but Wu & Coulson, 2014). Further complications for weighting the value and redundancy of gestures arise when considering not only the representational functions of gestures, but also the pragmatic functions that change the interpretation of a communicative action, as well as interactive functions orchestrating turns-at-talk (Kendon, 2004, p.158–159). Even an apparently meaningless hand beat might not only track speech rhythm but also hold the conversational floor for the speaker and direct attention to important (material or rhetorical) components (Congdon, Novack, Wakefield & Franconeri, 2016; Matoesian & Gilbert, 2016).

In communicative situations, gestures "manu-facture" understanding (Streeck, 2009, pp.1–3). Adversely, successful designing is not first and

foremost communication rather than the generation, evaluation and development of ideas. The challenge goes beyond understanding. A perfect harmony—shared understanding reached easily—might spark fewer ideas than misunderstandings and disagreements. Further, gestures employ a different conceptual dimension than speech, and invoking that spatio-temporal dimension might elicit different thoughts and ideas than the lexical one. To sum up, even if for communication the most invaluable feature of gestures might be their ability to focus attention on what matters the most, as discussed earlier, *for designing and creative problem solving, the most invaluable feature of gestures might be their ambiguity and spatio-temporal character that invokes new interpretations, thoughts and ideas, steers work in new directions—directions that were not originally intended* by the person that made the gestures.

3.2.4 The speaker's viewpoint: Speaking and thinking

Gestures are for communication, no doubt about that. Yet gestures have other functions as well—functions oriented to the speaker, namely self-oriented functions. Producing gestures—meaning-bearing hand movements co-ordinated with speech—can have a beneficial effect on performance, as they lighten the load on working memory (Wagner Cook, Yip & Goldin-Meadow, 2012). The benefits for speakers do not distribute evenly as variations in gesture frequency are apparent across population and tasks. For instance, in a study by Lavergne and Kimura (1987), spatial topics doubled the number of gestures in comparison to neutral topics, while another study by Rauscher, Krauss and Chen (1996) found that preventing gesturing affected the fluency of speech when speaking about spatial content but not about nonspatial content. In her review on the role of gesture in spatial cognition, Alibali (2005) concluded that some of the *variations are associated with the level of spatial task content and some with individual differences in spatial and verbal abilities*. However, current findings on the relationship between gesturing and visuo-spatial abilities (especially on working memory) are not conclusive nor, at this point, compelling. For designing tangible objects and interactions with such, the ability to manipulate spatial content is crucial; thus, broadening the understanding of the role of gestures is central.

A recent account of self-oriented functions is provided by the Gesture-for-Conceptualization hypothesis (Kita et al. 2017) mentioned earlier. The hypothesis identifies four main observable functions of gestures, all behavioural in nature: activation, manipulation, packaging and exploration of spatio-motoric information. Through these functions, *gesturing can lead to changes in the content and direction of speech and thought, to generation of new ideas and ideas that cover a wider range of conceptualisations, to revealing emerging knowledge not available in speech, as well as to enhanced abilities to perform*

spatial transformations. The following four paragraphs summarise the relationships between the four main functions and the above-mentioned outcomes. In the following, the references providing empirical proof for each claim are based on (but do not include all) the references of the original article by Kita, Alibali & Chu (2017).

First, *gesturing activates spatio-motoric information* in two ways. In cases where spatio-motoric representation is already active, producing a gesture helps to maintain and lengthen that activation (Wesp, Hesse, Keutmann & Wheaton, 2001). In the opposite case gesturing promotes the expression and use of new, i.e. not previously activated spatio-motoric representations (Alibali, Spencer, Knox & Kita, 2011)—not only for the purposes of gesture production but also for speaking and thinking. This activation can, in turn, invoke new ideas or directions for speech and though (Beaudoin-Ryan & Goldin-Meadow, 2014).

Second, *gestures facilitate manipulation of spatio-motoric information*—rearraging, translating, rotating, taking new perspectives, etc., especially when such manipulation is difficult. Producing a gesture offloads information in working memory to the hands (Chu & Kita, 2011), thus redistributing the load between brain and moving body parts. The benefit of using gestures for difficult spatial manipulation tasks is not necessarily only one-off and momentary: frequent use of gestures has been found to yield enhanced abilities to simulate the above-mentioned spatial transformations (Atit, Gagnier & Shipley, 2015; Chu & Kita, 2011). Thus, gesturing can enhance performance in tasks involving spatio-motoric manipulation, of which designing is one example.

Third, *gesturing helps package spatio-motoric information into units (more) suitable for the task at hand*, be that speech or problem solving. The piece of information selected for a gesture—the aspect conveyed by a gesture—can be utilised in chunking the information for other information-processing purposes. When experimenters manipulate speakers' spontaneous chunking or gesture content, it is noticeable that speakers use different gestures and the concurrent speech or problem-solving strategy changes accordingly (Goldin-Meadow, Wagner Cook & Mitchell, 2009; Mol & Kita, 2012). Thus, gesturing changes the content of speech and thought.

Fourth, *gestures help to explore a range of options* before a suitable one is found and expressed in speech (Alibali, Kita & Young, 2000; Kita, 2000). There are several options for this: using a variety of gestures before settling with one; starting a gesture and then aborting it, as if abandoning the idea before completing the gesture (Chu & Kita, 2008; Kita et al. 2017); trying a separate idea with gestures rather than in concurrent speech, as in cases of gesture-speech mismatch. The exploration can lead to generating more ideas than without gestures (Broaders, Wagner Cook, Mitchell & Goldin-Meadow, 2007; Kirk & Lewis, 2017). Yet, Kita and partners (Kita et al. 2017) caution that in light of the current evidence, it is premature to claim that gesture is the cause of the change

of thought or speech. However, exploration with gesture can reveal emerging knowledge that is not yet ready to be expressed in accompanying speech (Alibali & Goldin-Meadow, 1993; Church & Goldin-Meadow, 1986; Goldin-Meadow, Alibali & Church, 1993; Pine, Lufkin & Messer, 2004; Perry et al. 1988).

Resultingly, the Gesture-for-Conceptualization hypothesis suggests that a speaker who produces a gesture, engages spatio-motoric thinking, enriches the conceptual resources involved in the situation, and enhances the domain of possible solutions. All the identified functions are shaped by the ability of gestures to schematise information (Kita et al. 2017).

The above formulations of the findings, however important, depict speakers as more or less isolated islands, speaking and solving problems in social, situational and historical vacuums. In real-world contexts, speakers focus on securing the orientation of their partners and plan their practical and communicative actions in detail according to the needs of the listener (Goodwin, 2000, p.1499). More importantly, speakers aim not just to convey a meaning but to have an effect on the listener's understanding (Enfield, 2009, p.21)—to create a 'degree of resonance', to create collaborative knowledge. The following section addresses gestures in social interaction and in complex real-world settings.

3.2.5 Gestures are shaped by situational and social factors, not to mention personal experience

Many of the findings discussed above have been done in controlled research settings. Letting the variables loose and using material settings with endogenous courses of action shift the focus to gestures as practical, instrumental actions 'in the wild', as in studies by Goodwin (1996, 2000, 2007) and Heath and Luff (1992). Goodwin emphasises the role of material environment not merely as a context but as an integral constituent of the gestural action with his notion of environmentally coupled gestures (Goodwin, 2007). He also acknowledges a difficulty in determining the role of gestures within an activity—often the recipients of a particular gesture provide no clear response, not signalling in any obvious way that they have appreciated the gesture (Goodwin, 1986). Yet, that difficulty relates not only to gestures but also to the overall aim of establishing causal relationships between actions at this level of detail—people do not engage in activities with the aim of providing objectively recognisable clues to outside observers.

Instead of outside observers, individuals making gestures do pay attention to their partners in interaction. Gesturing is shaped by the same social mechanisms as other aspects of our behaviour. As discussed earlier, speakers tailor their gestures according to the (assumed) needs of the listeners (Goodwin, 2000, p.1499). This kind of behaviour is called recipient design (Koschmann &

LeBaron, 2002; Sacks, Scheglof, and Jefferson 1974). Speakers' involvement with the topic appears in mimicking each others' bodily and verbal conduct (Branigan, Pickering, Pearson & McLean, 2010), for instance, they use the same words (Brennan & Clark, 1996). This mimicking of each others' iconic gestures brings gestural cohesion (Koschmann & LeBaron, 2002) and plays a role in creating mutually shared understanding. *Gestural repetition has been identified to signal agreement on the conceptualisation of a particular entity, asserting total acceptance and incrementally building understanding* (Cash & Maier, 2016; Chui, 2014; Holler & Wilkin, 2011; Mol, Krahmer, Maes & Swerts, 2012; Yasui, 2013). However, the gestures are not always repeated as they first appeared for they lose details (Chu & Kita, 2008; Schwartz & Black, 1996). In comparison, speakers try to minimise their efforts (cf. the principle of least effort, Clark, 1996, p.224) and develop increasingly referential expressions during the conversation. Finally, they might settle on a level of referentiality that is not intelligible to outsiders (Schober & Clark, 1989). Similarly, repetition of a particular gesture might end up with a locally defined gestural form that is oversimplified for the purposes of successfull communication with outsiders (e.g. 'insider gesture' by Koschmann & LeBaron, 2002). *A group's joint conversational history can surface as a developing set of local gestural conceptualisations—a gestural vocabulary.*

In many gesture studies, the iconic character of gestures is treated as an objective property. However, Occhino-Kehoe, Anible, Wilkinson and Morford (2017) question that assumption. They argue that what appears as objective iconicity is in fact a product of culturally constructed norms or, in more detail, an individual's own sensory-motor, perceptual, cultural and linguistic experiences shaped by his or her native language. Thus, *people 'recognise' iconic gestures through the conceptualisations adopted from their native language system and their personal experience.* According to this view, iconic gestures are largely local interpretations, and 'the level of locality'—the level of objectivity in regard to iconicity—varies according to the size of the reference group.

A further challenge to the idea of similarity between an iconic gesture and the phenomena it refers to comes from Streeck, who views iconic gesture as an analyses of the object, a manual practice that "shows the world not as it is, but as we understand it by virtue of our practical engagements" (2008, 2009, p. 204). He separates two different functions behind iconic gestures: depicting and ceiving (Streeck, 2009, p.151). Depictive gestures represent and describe real or imaginary objects, whereas ceiving is the manual equivalent of conceiving, that is, developing a conceptualisation by gesture, a bodily concept (Streeck, 2013). Both depictive and ceiving gestures produce fabrications of virtual objects which are closely tied to experiential knowledge about the material world (LeBaron & Streeck, 2000; Streeck, 2008). Rather than visuality, haptic and kinaesthetic

perception and experience is the essence: *gesturing entails more than making visual reproductions of the significant visual features of the referents as the movements of the gesturing hands follow the ways in which the same hands make and experience the material world* (Streeck, 2013). Gestures organise the world fundamentally differently than words allow—it is a vehicle for together understanding the world (Streeck, 2009, p.205).

The strong emphasis on experiential knowledge as a background to iconic gestures has inspired Streeck to question research practices that separate a particular gesture from the particular individual body that makes it (Streeck, 2003, p.434). Indeed, rigorous, observational interaction analysis appears orthogonal with a holistic view of the human body. As an answer to his own question, Streeck proposes research that shows ”how the tacit and personal abilities with which our bodies are invested are themselves brought into being in social interaction” (Streeck, 2013, p.89).

3.3 Sketching and gestures in design: The power of multimodality

As discussed earlier, designing is in many respects a more complex endeavour than mere social interaction. Conversation is mostly sequential: a series of turns-at-talk that follow each other. Analytical treatments and transcribing practices enforce this impression of sequentiality. Collaborative designing, on the other hand, is frequently ‘interrupted’ with designers engaging in simultaneous activities such as making notes, sketching and modelling. In that kind of multimodal undertaking, gestures have an important organising role: pointing gestures attract and direct visual attention (Goodwin, 2007; Stevanovic & Monzoni, 2016; Wardak, 2016). Pointing can also remedy interactional troubles such as misunderstandings and disagreements (Donovan, Heineman, Matthews & Buur, 2011). A review on gesture studies in design is available in Visser and Maher (2011). However, the following focuses on the use of iconic gestures and sketching in designing with an emphasis on findings specific for design (in contrast to collaborative work in general).

Much of the design research addressing both sketching and gesturing has been motivated by the development of groupware (Bekker et al. 1995; Bly, 1988; Detienne & Visser, 2006; Donovan et al. 2011; Tang, 1991; Visser, 2009; 2010). The first design-specific function identified was demonstrating users’ actions while handling and using the design objects (e.g. Bly, 1988; Tang, 1991, Bekker et al. 1995). Next, Visser (2009) separated designating and specifying: designating gestures introduce the design entity and specifying gestures further specify the entity (Visser, 2009; 2010). The notions of introducing and further developing also appeared in Murphy (2012)—not as functions of gesture types but in transmodal modulation, a phenomenon between and across modalities

(speech, sketching, gesturing). In transmodal modulation, or transmodality, *the design ideas gained weight as they were further rendered first in one and then in another modality, as the specifics of the modalities transformed—enriched and trimmed—the ideas*. Likewise, generative moments have been identified to correlate with regular shifts between thinking and sketching (Akin & Lin, 1995; Goldschmid, 1991), as well as gesture sequences (Cash & Maier, 2016). Thus, it appears that changing from one modality to another is fruitful for designing.

Some researchers have studied the roles of sketching and gesturing. Eris et al. (2014) suggested that the roles changed according to the design phase; gesturing was favoured for exploring the problems and generating concepts, whereas sketching was favoured for detailing a concept once it had been identified. Instead of phases or functions, Adler et al. (2004) recognised individual styles. Some designers preferred gesturing while others preferred sketching, and some sketched even to substitute pointing gestures. The tendency to use sketching and gesturing for the same purposes was also recognised by Detienne and Visser (2006). In Murphy (2005), some architects used gestures to 'add' new buildings to drawings, and then treated these gestured buildings similarly to the sketched ones. Interestingly, that behaviour was not restricted to the creators of the buildings but also applied to other participants of design meetings. Gestures became permanent marks. *It appears that the roles of sketching and gesturing vary, and at least for some purposes, are interchangeable*.

3.4 Material explorations

> *Thus, the properties of materials […] cannot be identified as fixed, essential attributes of things, but are rather processual and relational. They are neither objectively determined nor subjectively imagined but practically experienced. In that sense, every property is a condensed story. To describe the properties of materials is to tell the stories of what happens to them as they flow, mix and mutate.*
> Tim Ingold, 2007, Materials against materiality, p.10

As discussed earlier, though in premature ways, materials have different roles in different design sub-disciplines. According to Mäkelä and Löytönen (2015), in Art and Design education material explorations are an integral part of the learning process. Extensively discussed is material mediation—the use of various artefacts and physical models for designing (Bucciarelli, 2002; Ewenstein & Whyte, 2007; Hare, Gill, Loudon & Lewis, 2014; Jacucci & Wagner, 2007; Perry & Sanderson, 1998; Seitamaa-Hakkarainen & Hakkarainen, 2010) and design education (Charlesworth, 2007; Kangas, 2014;

Laamanen, 2016; Welch, 1998; Youmans, 2011). Materials are usually represented by material artefacts, not treated as such. In product and industrial design curricula, materials are usually approached from technical and performance viewpoints only (Lucibello & Ferrara, 2012; Pedgley et al. 2016).

While craft teacher students are often familiar with textile craft techniques and materials (and many show remarkable dexterity), in general they have quite a traditional approach towards materials—experimenting appears to be a way to explore technical details during making rather than to develop ideas during designing (Laamanen & Seitamaa-Hakkarainen, 2014). According to Laamanen (2012), students were not motivated to experiment without a clear goal, merely to ideate, to 'produce trash'—their orientation was utterly pragmatic. To shake up that way of thinking, a teaching experiment to explore the impact of materials on student team ideation was organised as a pilot study for the Handling Mind project (Lahti, Kangas, Koponen & Seitamaa-Hakkarainen, 2016). The results showed that concrete physical materials (masking tape and thin cardboard; wire and non-woven interfacing fabric) supported the teams' efforts in transforming their design from 2D to 3D, whereas mere pen and paper did not. The difference for idea development and evaluation was clear—materials that afforded 3D moulding were important for developing the shapes. Similarly, Ramduny-Ellis and partners (Ramduny-Ellis et al. 2010) as well as Groth and Mäkelä (2016) found that the nature of the materials drove the design. *It is not irrelevant what materials and at which point of the design process they are introduced. Yet materials do not appear to be the same for everyone*: even if each material has its own 'characteristic set of uses', the ways of using the material are also affected by the designers' past knowledge and skills in working with that particular material (Ramduny-Ellis et al. 2010).

The current ways to include materials in design education has been questioned by Pedgley and partners (2016), as well as by Lucibello and Ferrara (2012). In the following, I approach that question first from the design education curriculum viewpoint, and then from the collaborative knowledge creation viewpoint.

3.4.1 From technical parameters to experiential qualities

For several decades, design education treated materials as sets of technical parameters—sets of performance values documented in materials libraries and optimised to fit a given design task. The view of materials as providers of technical functionality was broadened by Ashby and Johnson with a view of materials as creators of the personality of an artefact (Ashby & Johnson, 2010, p. 5). That personality is constituted by emotional connections—perceived attributes and associations (Ashby & Johnson, 2010, p.81). Other experience-centred approaches have followed, such as Dent and Sherr (2014), as well as

Lefteri (2014). Although Ashby and Johnson's seminal book was first published as early as 2002, much of the design education is still focusing on technical aspects (Lucibello & Ferrara, 2012; Pedgley et al. 2016). *This technical approach to materials has been found insufficient*: design students were identified as having difficulties in selecting materials during the designing, students delayed material decisions as much as possible, and they avoided using new materials or learning about new processing techniques (Karana, 2010).

A transition from imparting (technical) knowledge to generating personal experience is driven by an international design education initiative 'Materials experience' (Pedgley et al. 2016, p.613). This initiative is driven by three design educators, Pedgley, Rognoli and Karana, who have specialised in materials in design, with a basic tenet that *understanding materials experience is fundamental to meaningful designing* (Karana, Pedgley & Rognoli, 2015). By 'materials experience' they refer to both individuals' experiences with the materials and the skills and knowledge necessary for designers. The experience has three components: aesthetic (sensory) experiences, meanings attributed to materials, and emotional experience elicitated by materials (Karana, Pedgley, Rognoli, 2015). They address each of these components through active learning exercises with an emphasis on experiential evidence and rationale. Most of the exercises are collective, designed to reveal the complexity and multiplicity of relations between materials, products, sensorial experience, meaning attribution and emotional responses. The overall learning goals entail an understanding of the role and dynamics of materials experience, and the rationale for the choice of material based on the relationships between the user, the material and the product (Pedgley et al. 2016).

An approach with a similar emphasis is, for instance, the integration of aesthetic sensitising labs with a design course (Akner-Koler & Ranjbar, 2016). A design education programme with more ambitious objectives is described by Lucibello and Ferrara (2012). The approach entails three perspectives: perception, cultural (that is, artistic and conceptual) meanings, and creativity, by which they mean innovating and opening up different scenarios (Lucibello & Ferrara, 2012). Within that approach, not only do students understand and select but produce new visions of materials. In those exercises, students create new material innovations by simulating and reproducing materials using alternative substances, for instance food materials (Lucibello & Ferrara, 2012); *students are encouraged to go beyond their current knowledge on materials.*

3.4.2 Creation of material knowledge: Personal and collaborative processes

In design or educational research, rather than playing the leading role, material knowledge appears as a side issue of skill learning (Johansson & Illum, 2009;

O'Connor, 2009; Wood, 2006) or artistic processes (Mäkelä, 2016; Nimkulrat, 2010). Centring on the creation of experiential, or embodied, material knowledge is rare. Yet, some exceptions exist. Groth discusses controlling and respecting the material and tactility, "seeing through hands" (Groth, Mäkelä & Seitamaa-Hakkarainen, 2015, p.63). Kosonen and Mäkelä (2012) describe a design course that introduces an approach characteristic to artists—an approach where the creative process is kept open and reframed several times due to surprises and insights taking place during the process. Groth and Mäkelä (2016) studied the same course and reported that students' previous material experiences guided them even before they entered into the actual physical manipulation stage. *The material experiments were intertwined with the creative process and the final design object emerged from the process of experimenting with materiality* (Mäkelä & Löytönen, 2015).

The above-mentioned accounts emphasise the highly personal character of material knowledge. An obvious challenge for researchers to discuss experiential knowledge in other than individual settings is (at least partly) the tacit character of materials experience. By 'tacit' I refer to Polanyi's account of knowledge that is largely acquired by personal experience, knowledge that is easier to demonstrate than describe verbally (Polanyi, 1958, p.87–92). Along the lines set by Polanyi, Onians (2010) writes that the only way to share experiential knowledge with others is to have similar experiences; the co-located, collaborative design process that provides the operational context for my research offers shared experiences, a platform for creating and sharing experiential knowledge. *For the purposes of my research, the creation of material knowledge can take place, in addition to more or less silently sharing collaborative hands-on material explorations, through a negotiative process where individuals share their prior personal (embodied) knowledge with the support of gestural and linguistic resources, without involving the material(s) in question.* In practice, this means that not all the materials concerned need to be at hand, as long as they can be sufficiently described—in other words, participants share relevant embodied experiences up to a sufficient degree.

A similar approach was also taken by Kangas and partners, who studied collaborative knowledge creation processes where at least part of the created knowledge was about materials (Kangas & al. 2013). For my research, the most interesting aspect of the collaborative creation of material knowledge is not the level which involves actual materials but the process of how student teams proceeded with material explorations. In the paradigm of knowledge creation, the emphasis is not on the situatedness of cognition or on social practices alone, but rather on the progressive, collaborative development of these practices and artefacts through mediated activities (Paavola, Lipponen & Hakkarainen, 2004). Instead of swallowing each others' proposals as such, students should collaboratively engage with the iterative improvement and advancement of

ideas, which involves questioning, turning, refining and building on previous ideas. Knowledge creation takes place through interaction between various forms of knowledge and between practices and conceptualisations (Paavola & Hakkarainen, 2014). *New ideas and innovations emerge between individuals, conceptualisations, artefacts, explorations and other materialisations* (Hakkarainen, Paavola, Kangas & Seitamaa-Hakkarainen, 2013).

In designing and making, or in holistic craft, the end result is an artefact, a design object that has been materialised. Within the process, material explorations and material knowledge may end up having no value as such. Rather, they become necessary building blocks in constructing the final artefact. Wastiels, Wouters and Lindekens (2007) report that professional architects do not think of materials, elements and spaces. Instead, architects think about the experience they want to create and the attributes they need for that particular experience. For this line of thinking, materials are resources—not important as such. Similarly, materials explorations can be seen as tools for design students. On the other hand, the richer the knowledge of materials, the more solutions a designer can see and express (Alesina & Lupton, 2010, p. 4). Laamanen (2016, p.64) sees a potential for material explorations in design education. According to Jacucci and Wagner (2007), translating the ideas from one material format into another can yield important design decisions. Material explorations can be seen as technical designing but also as possible resources for creative process, enriching and providing new perspectives before 'closing' the design. *In the light of the theory discussed above, translations, that is, the mechanism of ideas passing through interpretative layers, be that between expressive modalities or between individuals, appear to play a significant role in the creation of new design ideas, and thus, in the creation of knowledge.*

4 Embodied creation of knowledge in collaborative design

> *It is a common practice in the disciplines that study human communication that categorical distinctions are drawn between the various media, symbol systems, and modalities of communication. […] But these clear-cut distinctions are abstractions.*
> Jürgen Streeck, 2011, The Changing Meaning of Things, p.67

In the previous chapters I laid out the operational context of my research investigations—collaborative design in higher education—and described the three perspectives—sketching, gesturing and exploring materials. The emphasis has been on the characteristics which are potentially beneficial for collaborative knowledge creation, idea generation and design learning. In this chapter, I briefly summarise the core theoretical ideas of the embodied creation of knowledge in collaborative design. But before entering into my summary (4.1), I will present one more concept that is important for the embodied creation of knowledge. That concept is conceptualisation. Since the 1990s, that topic has raised heated conversations between embodied and 'traditional' accounts of cognitive science. According to the traditional view, conceptual knowledge is represented abstractly in amodal symbols, or, in other words, in representations that are not indigenous to any particular sensorimotor modality and are context-dependent (Anderson, 2003; Pezzulo et al. 2011, Wilson & Foglia, 2017). Embodied accounts (Barsalou, 1999; Gallese & Lakoff, 2005; Glenberg, 2015; Lakoff & Johnson, 1980; Shapiro, 2010, just to name a few) advocate that sensory and motor experiences play a causal, functional, constitutive, or grounding role for conceptual representations, while the radical embodied account (Chemero, 2009) denies the existence of any representations. Lately, hybrid models (e.g. Dove, 2011; Zwaan, 2014) have started to emerge. As my research is situated outside the field of cognitive science, I will not discuss the details of the above-mentioned accounts. Rather, I support a definition by Givry and Roth (2006): *conceptualisations are dialectical relations of simultaneously available speech, gestures, and contextual structures*. They also emphasise that conceptualisations cannot be reduced to verbal rendering because of the different dimensions available for each of the participating modalities. *This definition allows for multiple simultaneous structures, with varied and changing levels of abstraction, and features indegenous to relevant modalities.*

4.1 Theory synthesis

In collaborative design, students engage in focused knowledge work. They have joint goals, they engage in mutual appropriation and they are receptive to adoption and adaption as they work actively together to produce a single outcome—a design object, a material artefact. That material artefact fulfills customer demands, the constraints set by an open-ended design problem. In the design process, knowledge emerges in between the collaborating participants, conceptualisations, artefacts, explorations and other materialisations. I take every turn-at-talk, gesture and practical action of (intense) collaborative design as an act of knowledge creation. Each of these actions fulfils five functions: 1) testing whether the piece of knowledge fulfils the demands of the task, 2) fulfils self-induced objectives and vision, and 3) fits with the solution developed so far, 4) introducing the piece of knowledge to other participants and 5) engaging the participants in acts of evaluating and further developing the object of design. The knowledge is new and relevant (at least) in the context of that particular design task. The knowledge is active and is used for advancing designing. Furthermore, parts of that knowledge become recorded in knowledge artefacts such as mind maps, 2D rough sketches, 3D models, and in the final design object.

To design and make material artefacts, students need not only creative and apposite design ideas but also knowledge about materials, techniques and tools to process the materials. They need to succeed in collaboration, which is dependent on several intertwined factors, such as the participants and their interaction processes as well as the characteristics of the task and the context. They need to succeed in design ideation that entails reinterpretation, the use of combinations, lateral and vertical transformations, analogies, metaphors and scenarios, as well as abandoning well-established ways of thinking in favour of creating new ones that address the needs of the situation. The above-mentioned list represents (epistemic) design practices that support the achievement of relevant epistemic aims: apposite design ideas and new active knowledge that is somehow incorporated in the final design object.

Amongst design practices, sketching has an acknowledged role in facilitating idea generation and communication. Characteristic for design sketching is the focus on pivotal points and elimination of details that, at that particular moment, represent unnecessary features; sketching produces focused, situated and localised depictions. Resemblance and precision are not important, in fact, these qualities could even be harmful for the purposes of facilitating ideation. Contrastingly, sketching is considered valuable because it abstracts, schematises and ambiguates. These qualities allow for multiple interpretations and more importantly, multiple reinterpretations at different levels of abstractions. This multiplicity increases the potential for the emergence of lateral transformations

and analogues. In sum, ambiguousness increases the potential for inducing new ideas.

These valuable characteristics of sketching have also been identified as typical to gesturing. A critical difference exists, though. While sketches are permanent, gestures are not. Even if participants sometimes remember influential gestures much later, and even if gestures can become a part of a team's local lexicon, it remains debatable (or, to my knowledge, still unresearched) how powerful gestures are in triggering multiple interpretations and reinterpretations. However, not all the power to induce multiple interpretations is based on providing a memory aid. The interpretations that people give to gestures (and to sketches) are dependent on their personal experiences and the conceptualisations they recognise in the gestures they see. Thus, in collaborative encounters, the more versatile backgrounds the participants have, the more potential that encounter has for inducing multiple interpretations: new design ideas, new knowledge.

Sketching changes the nature of a design task. In comparison to purely language-based treatment, involving sketching adds another channel with which to think and ideate. Constant changing from language to sketching and vice versa facilitates idea generation; likewise changes between language, sketching and gesturing. While the embodied resources of sketching and gesturing complement and interact with language-based resources, they also complement and interact with each other and with other embodied resources, such as body movements and the manipulation of objects and materials. Together, these resources can reduce the ambiguity of a message and render it clearer. Conversely, these transitions between modalities can involve changes from one conceptualisation to another and from one (re)interpretation to another. Thus, I assume that multiplying the frequency of these transitions can intensify ideation.

Central for both sketching and gesturing is perceiving. They both reflect personal embodied experiences, which, in turn represent a kind of analysis based on perceiving: abstractions and conceptualisations of the referred object or situation. At times, they convey information essential for designing, information not included in accompanying speech. While gesturing is often seen as a spontaneous, naturally occurring communicative habit, sketching is frequently regarded as a skill requiring practice or talent. I propose that they are to be treated as ways of thinking, developing and inducing new thoughts and enriching the pool of inspirational material for designing.

That treatment should extend to the exploration of materials. Explorations are primarily vehicles for creating and testing knowledge on materials, but also on the tools and ways to process those materials. While exploring, students perceive and collect embodied experiences on materials. These experiences are food for generating design ideas and for refining existing ones; they provide a source of

inspiration that is elemental for designing and making, for holistic craft and craft teachers.

The embodied creation of knowledge utilises resources such as sketching, gesturing and exploring of materials that are intertwined with each other and with linguistic resources. This intertwining appears central for the creation of new design ideas: when the ideas pass through interpretative layers of modalities and individuals, these ideas are evaluated and enriched by the indigenous characteristics of each modality, and by the personal experiences and knowledge of each individual. The ideas are translated from one mode and way of conceptualisation to another. On the one hand, these translations test the ideas, on the other hand they build up the ideas. The embodied creation of knowledge occurs when the embodied resources provide significant input and advance the processes of collaborative designing, that is, when the knowledge-creators cast these resources to epistemically meaningful roles.

In a truly collaborative pedagogical setting (such as Learning by Collaborative Design), students are invited to share: rather than making their design ideas public, they are encouraged to make their thinking process public. Such a challenge requires a level of trust. The expression of ideas in public requires courage but also practice as well as previous positive experiences in similar situations. That is a challenge for design education: to create appropriate learning environments. Further, research on design education should provide both knowledge to create such learning environments but also knowledge of ways in which students can and do feed their collaborative creativity by using their embodied resources. The latter is what these investigations are all about.

5 Research questions

> *It would be much more interesting to know how very good designers actually do work than to know what a design methodologist thinks they should do.*
> Bryan Lawson, 1997, How Designers Think, p. 39
>
> As I see it*:*
> *It would be much more interesting to know how students actually design than to know what a design educator thinks they should do.*

I follow the ideal of epistemic education that targets promoting students' performance to achieve valuable epistemic aims through competence (Barzilai & Chinn, 2017). The two cornerstones for this are acknowledging students' ways of knowing and knowledge practices, and deliberately targeting the development of these practices. Having said that, developing the practices requires a deep understading of the underlying mechanisms.

The overall aim of this research is to deepen our understanding of how the embodied resources of gesturing, sketching and material explorations are used for the embodied creation of knowledge in the context of collaborative design in higher education.

To follow that aim, I started with a theoretical part focusing on the underlying mechanisms of the embodied resources. After that came the empirical part, addressing students' ways of working with knowledge (i.e. designing and making) and seeing if and when the embodied resources provide significant input and advance knowledge creation (i.e. designing and making), thus, estimating what is the role of the embodied resources. I set three main research questions (MRQs):

What is the epistemic role of sketching in collaborative designing?

What is the epistemic role of gesturing in collaborative designing?

What are the characteristics of collaborative creation of material knowledge by explorations?

To answer these three MRQs, I conducted four studies, reported in three original publications. For each study, more detailed sub-questions were specified. The relationships between the MRQs, the sub-questions, the studies and the original publications are specified in Table 1.

Table 1. The main research questions and the specified sub-questions per study and publication.

Main research question (MRQ)	Specified sub-questions	Study	Publication
(1) What is the epistemic role of sketching in collaborative designing?	What ways of collaborative working are reflected in sketching?	I	I
	In what ways does collaborative sketching contribute to designing?	I	I
	In what ways does collaborative sketching advance designing?	I	I
	To what extent does sketching complement accompanying speech?	II	II
	What aspects of designing does sketching complement?	II	II
	For what design tasks is sketching used?	II	II
(2) What is the epistemic role of gestures in collaborative designing?	To what extent does gesturing complement accompanying speech?	II	II
	What aspects of designing does gesturing complement?	II	II
	For what design tasks is gesturing used?	II	II
	How is gesturing used to express material knowledge during design conversation?	III	III
(3) What are the characteristics of collaborative creation of material knowledge by explorations?	How is material knowledge built via decisions and explorations during the making?	IV	III

The sub-questions specified in Table 1, as well as many of the methodological decisions are largely reflections of the data collected for the Handling Mind research project, that is, the student teams' emergent working practices. In the Handling Mind, we began with macro-level analysis of the design assignment '3D Textile puzzle' (Lahti et al. 2016). We formed an overall understanding of the teams' design processes and their ways of working. I became increasingly familiar with the data through many readings and with many lenses. I kept parlous notes, memos to myself, and built an advanced system of at once laying out my assumptions and then critiquing them. The critiques led to new and better assumptions and the new and better assumptions led to new and better critiques. I became convinced that these macro and intermediate level analysis practices did not paint the full picture of the phenomena available in the data. Something else was needed. The methodological challenges and the path that I discovered to overcome these challenges are described in the next chapter.

6 Methods

> *The great linguist Leonard Bloomfield used to tell students that in published work one should not bring the reader into the kitchen. But it is in keeping with the canons of science to let the kitchen sometimes be seen. Always to conceal the turmoil behind the scenes is ultimately to be misleading.*
> Dell Hymes, 1981, "In vain I tried to tell you", p.12.
>
> *Now, let's take a peek into the kitchen.*

In this research, embodied creation of knowledge is examined as a meaningful use of embodied resources—sketching, gestures and material explorations—for the purposes of collaborative design and make, that is, with a clear orientation to produce a design artefact. As the role of sketching as an important tool for design thinking and communication has been acknowledged for several decades, the logical starting point was to analyse the use of sketching in this particular context, then continue with the use of the other embodied resources. Initially, my aim was to compare the role of sketching with the role and prospects of materials in collaborative design from the perspective of idea generation. But the collected data proved unfavourable. Materiality did not play the leading role for which it had been cast. On the other hand, the interplay between sketching and gesturing, as well as between gesturing and speech was loud and clear. Each study revealed new avenues, which where then scrutinised. Thus, gestures boldly took the part of materiality, and the room for materiality was considerably diminished. My overall aim changed to understanding the roles played by the three embodied resources—sketching, gestures and material explorations—with an emphasis on ideation.

In this chapter, I describe the research setting and the two collaborative design and make projects, as well as the data collection methods. Next, I briefly discuss the two major methodological challenges I encountered—challenges which are also well known in the literature. I end with the methodological path taken, which summarises the reasoning behind data selection, the analytical steps and the use of qualitative content analysis for video data in Studies I-III and for textual eDiary data in Study IV. All details regarding the developed and utilized classification schemes are available in the original publications. The central parts of the schemes are introduced in the Results chapter.

6.1 Setting: Two collaborative design and make projects

Students of craft teacher education at the University of Helsinki start their introduction to design at the first semester by participating in a collaborative design and make project and by attending lectures about the nature of design problems, the theories of the design process and the role of visualisation and craft education. The design and make projects conducted during a 10-week period at the autumn semesters of 2013 and 2014 provided the research setting for this research. Three compulsory courses were involved: 'Basics of Craft and Design Studies' (design), 'Sewing Technology' (make; 2013 and 2014) and 'Knitting and Crocheting' (make; 2014). The design part of the setting was piloted in 2012 (not included in this research but reported in Lahti, Kangas, Koponen & Seitamaa-Hakkarainen, 2016).

In 2013, the design and make project had the theme '3D Textile puzzle for visually impaired children' aged 3–6, and in 2014, the theme was 'Wearable sea creature for children visiting a public sea aquarium, SEA LIFE Helsinki'. Each design and make project entailed a design brief and detailed tasks that followed the same overall division into three phases: defining design constraints, 2D visualisation, and modelling. The brief described client's needs and constraints. The detailed tasks varied slightly from year to year. For instance, in the '3D Textile puzzle', the modelling was done with pre-assigned materials while for 'Wearable sea creature', the teams could choose the materials they wanted to work with. A significant variation from the perspective of this research was that the collaborative sketching task for '3D Textile puzzle' was preceded by an individual creative problem-solving task involved with combinations, analogies and transformations of geometric forms. That task influenced the teams' design processes and designs probably more than we had anticipated. For each design task, a maximum of 90 minutes was reserved, and making was conducted during four 3-hour workshops. To demonstrate the nature of the design and make projects, examples of the teams' phase products for the '3D Textile puzzle' and for the 'Sea creature accessory' are provided in Figure 5 and Figure 6.

The pedagogical structure assured that the teams focused their attention on pertinent aspects of designing and making, and provided both sources of inspiration and limiting design constraints. The pedagogical structure was progressive in nature, as not all the information was given to teams at the outset; this gradual introduction of new instructions, tools and materials was intended to inspire the teams to further develop their designs. An analysis of the pedagogical setting utilising the Pedagogical Infrastructures Framework (Lakkala, Muukkonen, Paavola & Hakkarainen, 2008; Lakkala, Ilomäki and Kosonen, 2010) is provided in Seitamaa-Hakkarainen et al. 2017 (not included in this research), and further details of these projects and tasks are available in the original publications.

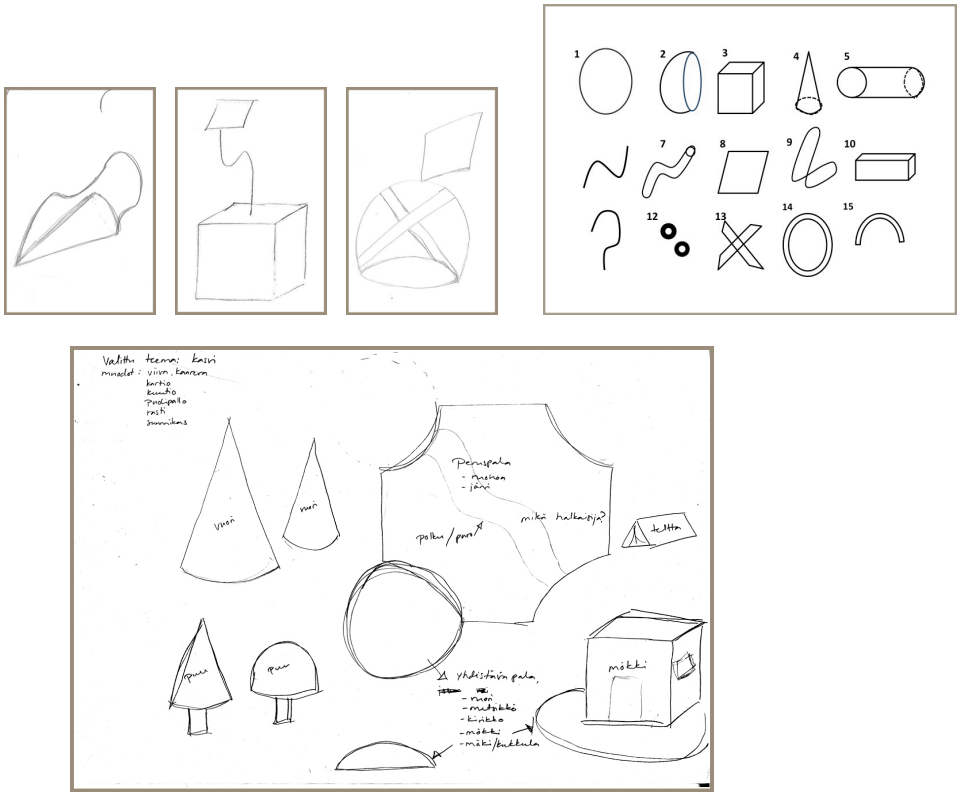


Figure 5. Team Landscape and the '3D Textile puzzle'. At the top left, team members' individual solutions for the creative problem solving task that asked students to create a potentially useful, given theme-related product by combining three forms picked from a large selection of forms (at the top right). The task was adapted from Sawyer (2013, p.33). In the middle, collaboratively designed and sketched puzzle pieces. At the bottom left, a mock-up of the puzzle made from modelling clay, and the finalised puzzle at the bottom right.

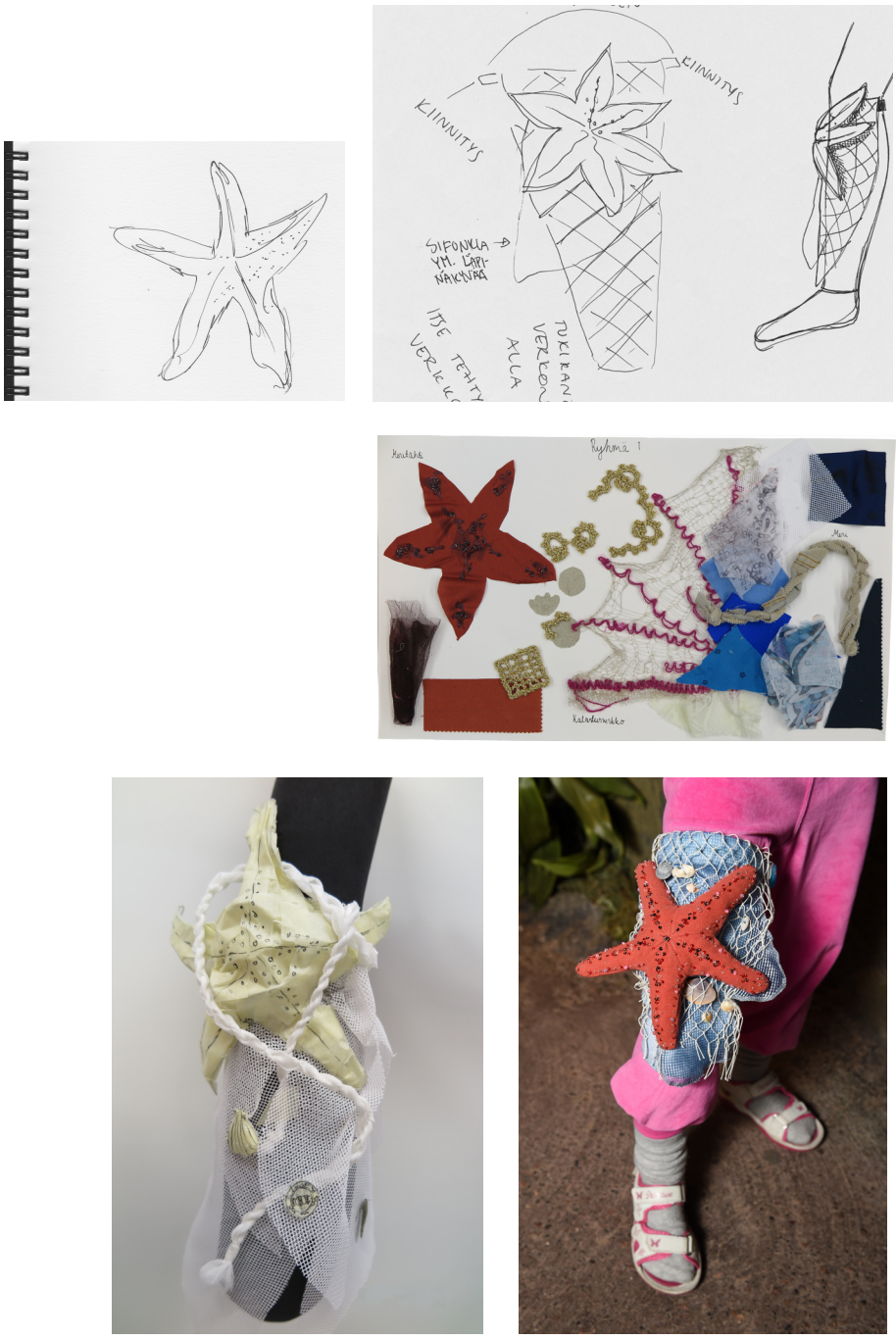


Figure 6. Team 1 and the 'Wearable sea creature accesory'. At the top left, a starfish sketched in SEA LIFE HELSINKI, and a detail of the collaboratively designed and sketched sea creature accessory, a starfish on a net at the top right. In the middle: a material collage to demonstrate the visual and haptic palette. At the bottom left, a mock-up of the starfish accessory made from masking tape, fabric net and cardboard, and the finalised accessory in use.

The research participants were all first-year undergraduate students from the University of Helsinki who were studying to become craft teachers, and attending both the 'Basics of Craft and Design Studies' and 'Sewing Technology' courses. The selection of research participants was based on students' willingness to volunteer. For the 3D Textile puzzle, we selected 12 students (between 21 and 45 years of age) from 38 course attendees. For the Wearable sea creature, we selected 12 students (between 20 and 48 years of age) from 36 attendees. None of the participants had a university-level degree in design or textile craft. For the collaborative team tasks, the participants were divided into teams of three based on their curriculum and their sketching habits. Before any data collection activities started, informed consent covering the use of all collected data, including video still frames in publications, was obtained from the participants.

6.2 Collecting data by video recordings and an event sampling method

This research was planned as video research. From the design and make projects, three collaborative design sessions were video recorded: Defining Design Constraints, 2D Visualisation and 3D Modelling. Two stationary cameras were used, one providing a top-view and one a side-view of the teams (Figure 7).

Figure 7. The two camera views: from the top and from the side.

That arrangement yielded a total of 24 hours of video data from the design phase, as detailed in Table 2. As one hour of data is calculated to include both the top-view and the side-view video footage, the presented figures also show the time spent by the teams in designing.

Table 2. Overview of the data collected for the Handling Mind research project.

Design Projects & Collected Data	3D Textile puzzle for visually impaired children (2013)		Wearable sea creature for children visiting SEA LIFE (2014)	
Sessions	**Video Data**	**Documents**	**Video Data**	**Documents**
Design Brief	-	-	-	73 sketches
Design Constraints	3.25 hours	4 lists of questions 4 mind maps	2.25 hours	4 mind maps
2D Visualisation	4 hours	26 sketches	3.75 hours	6 sketches
3D Modelling	5.5 hours	4 mock-ups	4.5 hours	4 mock-ups
Making	-	4 puzzles	-	42 eDiary entries 4 accessories
Feedback	-	-	2.5 hours	-
Stimulated Recall Team Interviews	4.5 hours	-	2.25 hours	-

In the 'Wearable sea creature' project, process data also from the make phase was gathered with a web-based event sampling method named eDiary. Compared to video recording, it provided descriptions and photos focused on meaningful parts of the process rather than producing large quantities of video footage, which due to the necessary logistic arrangements during the making would have been of poor quality. In practice, every time the teams experimented with materials or made a material decision, they filled in a web-based query. In total, they recorded 42 eDiary entries.

Together, the video data from the design sessions and the event sampling data from the making constituted the primary data sets. Secondary data included documents and artefacts produced by the teams during design sessions. Also included were video recordings of stimulated recall team interviews. When necessary, this secondary data served to support the interpretation of the primary data. The stimulated recall interviews (Lyle, 2003) were conducted with each of the teams after the feedback session. In these interviews, the teams were prompted by selected episodes from the 2D Visualisation session (for '3D Textile puzzle') and eDiary entries (for 'Wearable sea creature').

6.3 Challenges to overcome

I encountered two major methodological challenges. First, design research has not yet provided a method that reveals the complete trail of influential design ideas that are in the process of being developed: *a unified theory of design ideation and the related mechanisms, a complete model linking ideation with the underlying sources of knowledge creation has not yet surfaced*, as discussed

recently by Cash and Štorga (2015). A link is missing; a mechanism remains unknown. In creative idea generation, explicit and inexplicit components of design thinking are intertwined, as emphasised by a constructive computer simulation by Taura and partners (2012). Notably, only the explicit component can be observed and accounted for. Section 1.3.1. describes my iterations that aim to pave way to further methodological development in this respect.

Second, *grounding analyses of other than language-based modalities on verbal transcripts is a practice that is subject to profound ontological problems*. Traditionally, video data has been approached through time-stamped transcripts, appended with screenshots and references to collected secondary data whenever necessary. Yet, the elements of linguistic meaning making are different (Givry & Roth, 2006) and subject to insensitivity to finer detail during a selective, interpretative and representational process of transcribing. Further, linguistic input entails only a small part of the situation at hand and what has happened before—it provides an insufficient interpretative frame for the use of embodied resources in design learning, as noted also by Kangas (2014, p.32). Furthermore, when examining multiple modalities and several participants, this method has proved laborious (Candy et al. 2004). I decided to find another approach, which is summarised in sections 1.3.2. and 1.3.3.

6.3.1 Rigorous tracking of development of a design idea—or not

What exactly happens when a creative design idea is constructed? In 1994, multiple researchers at the Delft Design Protocol Workshop tried to explain how a certain design concept "seemed to come out of nowhere after a lengthy period of explanation and problem analysis" (Cross, 1997, p.311). According to Cross (1997), the method that came closest in identifying the path to influential design ideas was Linkography by Goldschmidt. Linkography is based on rigorous analysis of all verbal design moves (statements, turns-at-talk). The key idea is that influential design ideas are produced by 'critical design moves', that is, influential steps that have multiple links to preceding and following moves (Goldschmidt, 1995). Thus, *it is not one moment, one move, but a web of moves that produces the central design idea*. This applies for a designer working solo, and for a team of designers working together (Goldschmidt, 1995).

Systematic tracking of all moves and linkages between them appears good science. 'Design move' is an accepted concept in design research (Chai & Xiao, 2012; Perry & Krippendorf, 2013). However, as Perry and Krippendorf (2013) point out, even if the definition of a move seems clear, the reality of designers' collaborative interactions with interrupted turns-at-talk, repetition, etc. makes it very difficult to define the boundaries of design moves. Several researchers criticise Linkography due to the subjective character of the links between the moves (Kan & Gero, 2008; Perry & Krippendorf, 2013; van der Lugt, 2001). In

collaboration, each designer's thinking processes are stimulated by actions of the other participating designers—their thinking processes are no longer independent but are instead interactive (Saunder & Yin, 2016). *Some of the developments are visible and audible, but a complete trail for each creative idea is often not available for observing researchers.* Design researchers have accepted that they have no perfect tool for tracking the origins of creative ideas. In spite of the critique, Linkography is widely used (e.g. by El-Khouly & Penn, 2012; Kan & Gero, 2008; Shaw, 2007; van der Lugt, 2005; a sketch-based version: Cai, Yi-Luen Do & Zimring, 2010).

I did not use Linkography in my studies. Yet I struggled with the problems listed by its critiquers. Sawyer (2003a) claims that the creative achievements of a collaborating group cannot be reduced to the contributions of the participants, but there is an invisible participant: collaborative emergence, the constantly changing frame constructed by earlier contributions. I bring up Linkography and collaborative emergency to highlight the challenges of systematic processing of design conversation at the micro-level and the fact that currently even popular methods only 'come close' to revealing the creative core while leaving considerable room for criticism. Whether a method provides results much depends on the data, and in the case of a fragmented conversation highlighted above by Perry and Krippendorff (2013), identifying linkages between moves is close to impossible. It looks like that in the search for the creative core, *the possibilities of systematic tracking of all moves and linkages between them appear to be dependent on the data and what is considered a design move.* With my data, the clarity of the boundaries between moves varied considerably between different teams. That also explains the turn after Study I in my methodological path.

That path began with my first readings of the research data following the inductive approach (Derry et al., 2010). The inductive approach begins by considering the entire corpus, and then progressively zooms into parts. The first analyses of the 3D Textile puzzle project provided a macro-level understanding of the teams' design processes (Lahti et al., 2016). Through the many readings of the data, I became convinced that supporting the macro-level view with a full-scale micro-level analysis of selected design sessions would provide new insights into the novice teams' emerging sketching practices. In Study I, I incorporated all micro-level events of sketching and note-writing (together coined inscribing) my analysis, and created linkages between them and neighbouring turns-at-talk. I encountered the challenges of a fragmented design conversation—a type of talk that signals emerging knowledge, knowledge being created or in transition: talk that includes false starts and self repairs, deletions and long pauses (Perry & Lewis, 1999). *Even if this kind of talk signals that knowledge creation—the very target of my investigation—is going on, it eludes systematic linkages at the level of turn-at-talk.* The students in the data disclosed

their premature thoughts and knowledge creation processes—unfortunate for the creation of linkages but possibly very fortunate for the collaborative designing, as the other team members were able to 'follow' and get inspired by these unconstrained processes. After some iterations I managed to develop a linkage-based approach that fulfilled my research aim and provided a more detailed picture of sketching practices central for exploration and advancing designing. For the next study, a similar linkage-based approach proved impossible, however. As the importance of gestures became evident for some developments and for some teams, I decided to include gestures in my analysis; moreover, I decided to make them a central focus area. For that, design moves and their interconnectedness was not a fruitful approach. Instead, for Studies II and III, I further developed my video analysis practice (described in the following section 6.3.2) into an approach I coined as video-based qualitative content analysis (further described in section 6.3.3).

6.3.2 Saving the indigenous characters of the embodied resources

Another type of analytical challenge was to recognise those characteristics of embodied resources (sketching and gesturing) that are fundamentally different from the characteristics of language, and to preserve them throughout the analysis. Working primarily with running video footage offered a solution to reducing the unwanted side effects of language. Yet it was acknowledged that brief verbal translations of the events, as well as a possibility to add synchronised notes (i.e. annotations) would be needed; reaching any analytical conclusions worth committing to is not possible without keeping a record on several, often simultaneously unfolding layers of interaction (cf. holistic analysis by Silver & Pataschnick, 2011). To reach those targets, I audited several video data analysis software packages and finally selected INTERACT.

INTERACT offered an interface for simultaneous observation of all the components relevant for analysis: video, transcripts and annotations, as well as coding results over a graphical time-line view—and it supported data-driven coding (see also Candy et al. 2004; Erickson, 2006, p.187). The graphical time-line graph rendered visible many patterns in the data that, once seen, could be systematically tracked. The ability to watch a video frame-by-fame was a necessity, as the gesturing events could be as short as 0.2 seconds, and the average duration for sketching events was 9 seconds. The possibility of watching the running video, transcripts and annotations simultaneously through one main window (of which an example is provided in Figure 8) enabled a more holistic analysis (Silver & Patashnick 2011). Equally important, it saved the nuances of gesturing and sketching from unnecessary forced labelling with words; the different ontologies of sketching and gesturing did not have to be sacrificed to the ontology of language.

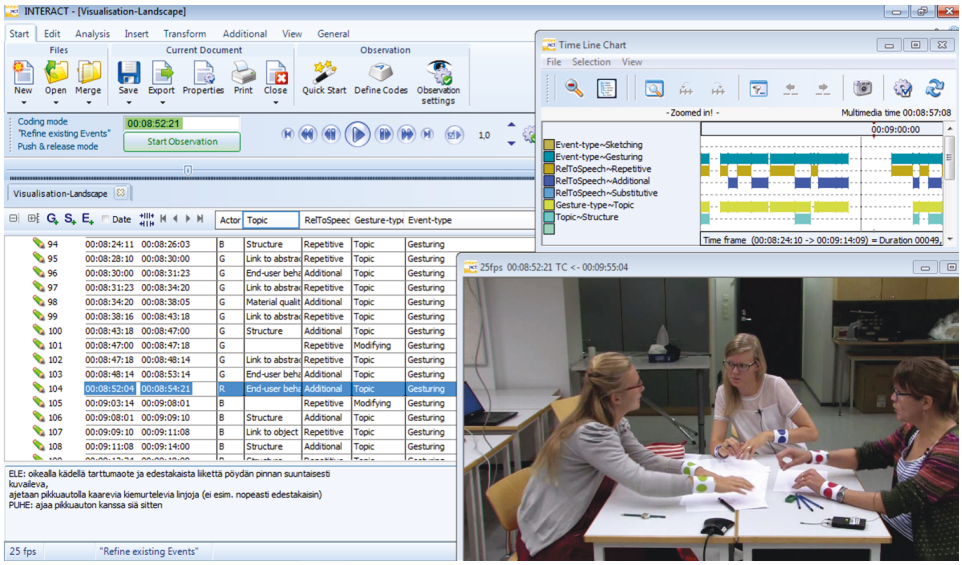


Figure 8. Working with INTERACT video analysis software. Simultaneously available video window (bottom right), list of events and classifications (left), and annotations (bottom left) related to selected event (the row in blue) provided all the necessary information sources for coding and a critical evaluation of previous analytical decisions. When necessary, coding results presented by the graphical time-line chart (top right) could be visited.

However, even if the written annotations were only used alongside running video footage, they appeared to have a tendency to take over: like transcripts (Tilley, 2003; Knapton, 2013), they began to guide the analysis and to stop the analyst seeing other interpretations and features. The annotations tended to become the truth, the whole truth and nothing but the truth—they seemed to take the place of the data. Had that been allowed to happen, the end result would have been the same as if working from written transcripts. Thus, the number and the role of the annotations had to be kept to a minimum, and the role of linguistic elements had to be consciously kept at bay (Calbris, 2011, p.65; Poulsen & Thorgensen, 2011), even if that at first felt counterintuitive. *Having running video always present simultaneously with annotations meant that no element was removed or disregarded, only some elements were highlighted, as we aimed to capture not only the immediate but the more nuanced meanings* conveyed by gesturing and sketching until trustworthy enough interpretations were reached and documented. Further, for the fine-grained micro-level analysis, an interface like INTERACT was a necessity—this kind of an analysis could not have been conducted with the traditional 'transcripts-in-excel' approach.

Several iterative rounds of watching video and reading theory were required to recognise the characteristics of sketching and gesturing that fundamentally differed from the characteristics of language; in other words, the mechanisms by which sketching and gesturing conveyed meaning. The importance of context sounds self-evident. In this case, where the teams had no previous history of

working together, the development of team's interactive practices over time (as discussed in section 3.2.5) emphasised the centrality of the teams' communicative history as a context. Gestures were especially vulnerable in this respect. Without the knowledge of the previous unfoldings, a single gesture could be given an interpretation very different from the interpretation given when the same gesture was seen and understood as belonging to a series of unfoldings of a particular concept. Further details of the procedures to attach context-sensitive interpretations to sketching and gesturing events are available in Publication II and III.

6.3.3 Summarising: conducting video-based qualitative content analysis

The video analysis conducted shares many of the commitments of interaction analysis (Jordan & Henderson, 1995). Additionally, throughout the analysis I maintained a special emphasis on sketching and gesturing: in the temporal organisation of moment-to-moment, real-time interaction, acts of gesturing and sketching were all considered analytically equivalent to turns-at-talk and segmented as events. Thus, I did not analytically separate visuo-spatial, kinesic and kinaesthetic thinking and communication from language-based thinking.

The fine-grained analytical procedures of this research are best described as *video-based qualitative content analysis*. The procedures much followed the guidelines and steps described in Chi (1997). Instead of text-based data that is traditionally used for content analysis, the data for video-based content analysis comprises multimodal interactions in video format. Furthermore, while quantitative content analysis produces numbers (such as frequencies and word counts) to be evaluated statistically, qualitative content analysis produces descriptions or typologies that are grounded in the data—the data that have been selected specifically to inform the research interests, and vice versa, rather than by random sampling (Zhang & Wildermuth, 2009). This approach is typical for inductive sciences.

Hsieh and Shannon (2005) identified three distinct approaches to qualitative content analysis: conventional, directed and summative. The first two aim to describe a phenomenon, but they have different approaches towards the coding scheme. Deriving coding categories from data is referred to as *conventional (i.e. data-driven) approach*, while starting with theory or previous research findings and developing this initial coding scheme to reflect the data is referred to as *directed (i.e. theory-driven) approach*. Their third approach, *summative*, has a fundamentally different aim: to understand contextual differences by comparisons. In this research, all three approaches were utilised. In the following, the methodological rationale is described for Studies I–IV reported in

Publications I–III. The relationship between Studies and Publications appears in Figure 9 below.

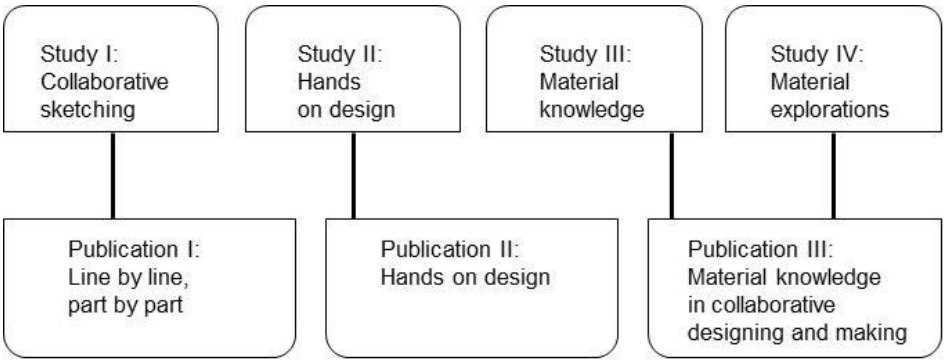


Figure 9. The relationships between Studies I–IV and Publications I–III.

6.4 Study I: Collaborative sketching

Sketching is one of the most researched aspects of designing. Yet before any comparisons between sketching and the other embodied resources could be made, an understanding of the role of sketching in the research context had to be established: how do craft teacher students use sketching for collaborative design? In other words, the first main research question (MRQ I) on the epistemic role of collaborative sketching was set. Study I: Collaborative sketching (reported in Publication I) focused solely on that and approached the role of sketching from two viewpoints: from the collaboration and from the advancing designing perspective. A representative data sample of various ways to collaborate by sketching was available: the 2D Visualisation session of the 3D Textile puzzle project. Of the four video-recorded teams, one picked their structural idea from a pattern book instead of developing it by themselves. Therefore, that team was excluded from this study. The role of sketching was approached through three measures: (1) the amount of sketching, (2) the value of sketching for designing, in particular, the valuable contributions that advanced designing, and (3) the characters of those valuable contributions. The amount of sketching would tell how much the student teams used sketching for designing, indicating how meaningful a tool it was for them.[3]

[3] At this point, a note on the terminology appears in order: in Publication I, 'inscribing' refers to both sketching and note-writing. The first steps of the analysis proved that note-writing had a merely documentative role. Consequently, it was dropped from the later analysis focusing on contributions with a specific value for designing. Henceforth, note-writing is excluded from these discussions and the focus is solely on sketching.

To begin with, sketching-events were identified and pictured by a graphic time-line chart. A question arose when evaluating the amount of sketching done. How can one compare periods of time when only one member of the group sketches with those periods of time when two team members sketch and with those periods when they all sketch? Simple quantitative measures such as 'cumulative time used to sketch' appeared to hide and distort what was visible in the data. To compare apples with apples, an analysis on 'the ways of sketching' (i.e. how the teams organised their sketching-activities) was conducted with the help of conventional content analysis. The aim was to get a more illustrative measure of both *the amount and quality of the sketching activity* and to highlight how *agency changed from individual to collective*. Thus, at this first analysis-level, four qualitatively different ways of sketching were identified. Of those four, three that were considered collaborative were further analysed at the second level. This analysis-level targeted identifying whether collaborative sketching was valuable for designing or mere scribbling, copying previous contributions or documenting (i.e. repeating) what was said. For that, the sketched contributions needed to be identified and valued. To define explicit criteria for collaborative sketching that contributed to designing, I sought inspiration from the literature on the quality of talk in knowledge construction. Especially appealing were Mercer's notations of exploratory, cumulative and disputational talk (Mercer, 1996; Mercer & Wegeriff, 1999). As a result, collaborative sequences (i.e. successive events of collaborative sketching and linked neighbouring speech) were required to fulfil two conditions: active collaboration and contributing to designing. With conventional content analysis, these sequences were then categorised into separate advancing contributions. Of the three identified types, only the two that were considered advancing designing were further analysed at the third analysis level. The third level targeted understanding in more detail the features of the valuable advances, and the strengths of sketching for collaborative design. For that, conventional content analysis was used to classify collaborative sequences that advanced designing first for three functions and further for six capacities. Full details of this relatively complicated method are available in Publication I.

6.5 Study II: Hands on design

The 3D Textile puzzle data involved a team particularly 'skilled' in gesturing, which offered a possibility to focus on the potential of gestures for designing. That team used diverse gestures frequently as well as developed their design by sketching, thus enabling a comparison between sketching and gesturing. I formulated the second main research question (MRQ II): what is the epistemic role of gestures for collaborative designing? To analyse the possible difference between tasks with different characters, two design sessions, Defining Design

Constraints and 2D Visualisation, were selected for comparison. Thus, the data partially overlapped with Study I. An initial idea to include the session 3D Modelling into the analysis had to be rejected due to difficulties in recognising gesture forms from the practical actions of building the model. Therefore, in Study II: Hands on Design (reported in Publication II) sketching was compared with gesturing through three measures: (1) the relationship between speech and sketching/gesturing, that is, whether it was complementary or not providing any additional information, (2) the aspects of design complemented by sketching/gesturing, that is, the strengths of sketching/gesturing, and (3) the types of operations particularly suitable for sketching/gesturing, that is, 'natural' functions for sketching/gesturing.

To begin with, events of gestures and sketching were identified and the meanings conveyed by those events were interpreted with a context-sensitive method based on Enfield (2009). The meanings were then compared with the accompanying speech to identify events with complementary meanings. These complementary events were further examined using conventional content analysis for the aspects of designing they represented. After that, the use of sketching and gesturing was compared at the level of the two differently oriented design sessions: conceptually oriented Defining Design Constraints and spatially oriented 2D Visualisation by Sketching. This comparison represents summative approach to qualitative content analysis. Finally, with the help of the graphical time-line view, the data were examined for emergent design tasks that favoured sketching. The assumption was that if sketching dominated a particular type of design task, then sketching was particularly suitable for that task-type (cf. Mondada, 2016, p.341). A similar analysis was also conducted for gesturing. Further details of this analysis are available in Publication II.

6.6 Study III: Material knowledge

The Wearable sea creature project inspired the teams to centre on materials in a way that was not visible in the 3D Textile puzzle. Subsequently, two studies on embodied resources in relation to material knowledge were conducted and reported in Publication III to provide complementary viewpoints to the teams' processes. Study III: Material knowledge, utilised data from the design phase and the methods used is described in this section. Study IV: Material explorations, centred on the make phase and is reported in the next section 1.7.

In the Wearable sea creature project, expressions of material knowledge were especially rich in the design session 2D Visualisation by Sketching. Yet materiality was not expressed through sketching. Instead, the teams used linguistic and gestural resources—especially the latter in particularly active and versatile ways. The idea that gestures are powerful in describing spatial and motoric aspects is well documented in the research literature. However, this data

provided a chance to take a step away from refining previous results and to analyse gestures in a new territory—as carriers of material knowledge. Consequently, in this research the findings of Study III contribute to the role of gestures (MRQ II). The developed measures were (1) the number of expressions of material knowledge, both in words and in gestures, and (2) the dimensions of material knowledge conveyed by words and gestures. The dimensions were intended to indicate the strengths of each modality.

The method for identifying gestures and the related meanings was the same as in Study II. The difference between Study II and III was that while in Study II, all gestures were analysed, Study III concentrated on gestures that contributed to the content of the conversation (i.e. substantial gestures by Kendon, 1994). In other words, gestures organising the interaction (meta-communicative gestures) were excluded, as they contained no indications of material knowledge. In addition to gestures, linguistic expressions of material knowledge were included in the analysis. To examine the dimensions of the material knowledge in gestures and in words, a classification scheme by Wastiels and partners (2013) that described qualities and meanings related to materials was finetuned to reflect our more versatile data; the approach towards qualitative content analysis was directed. As reported in Publication III, the expressions in words were further scrutinised to identify patterns, but that analysis is excluded from this thesis.

6.7 Study IV: Material explorations

In Study IV: Material explorations, the four teams finally worked with 'real' materials: experimented with materials and techniques and produced finalised sea creature accessories. My first aim had been to gather process data from making in video format, but that proved unfeasible. As the next-best option, I asked the teams to photograph and document in writing all their material explorations and material decisions using eDiary-tool, which provided the structure for their entries via open-ended questions of the process. Naturally, the different character of the data had implications on the research questions. The third major research question (MRQ 3) also reflects the fact that material explorations and the making are not as mature a research topic as the other two embodied resources included in this research. Thus, MRQ 3 takes a wider view on explorations as the collaborative creation of material knowledge. In spite of the differences between the datasets, the measures selected for Study IV followed much the same overall logic as measures for Studies I–III: (1) the number and (2) the dimensions of material explorations, as well as (3) the characters of the explorations.

The teams' knowledge processes were first identified from eDiary entries and stimulated recall interviews. Conventional qualitative content analysis was used

to examine the dimensions (i.e. reported objectives), and the process characters: the decision criteria as well as success rates and the consequences of their decisions and explorations. Additionally, a formulation by Bohnenberger (2013, p.191) was further developed into a classification scheme that reflected the hands-on nature of the teams' approaches. In other words, this analysis used directed content analysis. Further details of the method are given in Publication III.

Before moving on to the next chapter presenting and discussing the results, I have summarised the data used and the analytical focus of each study in Table 3.

Table 3. Summary of the data analysis: data, units of analysis and analytical focus for Studies I–IV.

Studies / Data analysis	Study I: Collaborative sketching	Study II: Hands on design	Study III: Material knowledge	Study IV: Material explorations
Design project	3D Textile puzzle	3D Textile puzzle	Wearable sea creature	Wearable sea creature
Participants	3 teams of 3 students each	1 team of 3 students	4 teams of 3 students each	4 teams of 3 students each
Data	3 hours of video	1.5 hours of video	3.75 hours of video	42 eDiary entries
Unit of analysis	Event; Sequence; Sequence that advances designing	Event	Event	Material decision or exploration
Focus of qualitative analysis	Collaborative sketching; Sequences that contribute to designing; Capacities to advance designing	Sketching and gesturing that complements speech; Complemented design aspects	Dimensions of material knowledge	Objectives; Approaches; Decision criteria; Consequences of material decisions and explorations
Quantitative description	Frequency distribution Temporal distribution	Frequency distribution	Frequency distribution	Frequency distribution
Supporting data	14 sketches 3.5 hours of video (SR team interviews)	9 sketches 1.5 hours of video (SR team interviews)		2.25 hours of video (SR team interviews)

7 Main findings

> *Things are not labelled "evidence" in nature, but are evidence only to the extent to which they are accepted as such by as observers.*
> Michael Polanyi, 1958, Personal Knowledge, p.30

This chapter summarises the key findings on how the studied embodied resources—sketching, gesturing and material explorations—were utilised for the services of collaborative creation of knowledge, in the context of collaborative designing and making. The main findings are first reported per study and then abridged per main research question. At the end of this chapter, a table summarising the relationship between the key findings, studies and publications is provided. A discussion on the implications of the results, starting with a summary of the results is provided in the final chapter, General discussion.

7.1 Study I: Collaborative sketching

Study I examined how sketching contributed to collaborative design. Two viewpoints were covered: collaboration and the provision of design-relevant content. Four qualitatively different ways of sketching were identified: disclosed, collective, co-ordinated and silenced. In *disclosed sketching*, one's act of sketching was either a 'public' part of the conversation, or one sketched while someone else was talking and immediately shared the sketch when the conversational space became available. *Disclosing the sketch was one design move in the flux of collaborative designing*. This way of sketching can also be compared to a turn-at-talk in regard to spontaneity, immediacy and agency: the individual that was sketching made the decision to disclose in order to initiate a design move. Disclosed sketching much resembled gesturing as it was immediately shared, as I later (during Study II) understood. *Collective sketching*, on the other hand, was regulated by the team: first the feature was introduced to the other team members and when it was accepted, it was added to the teams' collective solution. *Collective inscribing was more documentative than generative.* The third way, *co-ordinated sketching* was also regulated: the team agreed on a division of labour, the individual tasks were executed (by sketching) and then the end results were discussed. *In co-ordinated sketching, individuals develop their ideas and disclosing was delayed until the ideas were complete.* In the fourth way, *silenced sketching*, the ideas were not disclosed at all, or it took a considerably long time before they were disclosed. Silenced sketching was apparently for private thinking. It amounted to only 13% of all sketching-events,

which suggests that *sketching collaboratively appeared to be a natural choice* to the studied teams. This identified division into four ways of sketching can also be interpreted as structures that regulate collaborative work.

The strong role of collaboration in the teams' sketching practices also became evident through the sequences of interlinked sketching-events and turns-at-talk: 87% of all those sequences were collaborative, that is, at least two team members (of a total of three) participated. The value created by sketching to designing was revealed when the sequences were classified as explorative or documentative. Additionally, some sequences with a regulative character were also identified. The teams could have chosen to explore their design ideas by speech and have used sketching only to document their decisions, yet from the total number of collaborative sequences, 70% were explorative. This implied that *sketching collaboratively was a central resource for the teams and was valuable for advancing designing.*

Further classification of the explorative and regulative sequences revealed the kinds of advances that were attained through collaborative sketching. First, three major types of advances were identified: (1) sketching a full proposal, (2) sketching to further enhance a proposal, and (3) sketching to regulate collaborative processes. These functions were further classified into six capacities: (1) sketching a full proposal, (2) exploring with spatial and structural qualities, (3) incremental refinement of a feature, (4) adding a minor feature, (5) depicting constraints or ways of working, and (6) regulating the working atmosphere. Structural ideas constituted the field for collaborative sketching, as exploring with spatial and structural qualities was the most frequently used capacity to enhance a proposal. Yet the number of proposals was only slightly lower than the number of enhancing a proposal, suggesting that sketching was not limited to conveying structural ideas (although suggesting a structure is one of the indigenous characters of a sketch). Regulation unfolded as depicting constraints or ways of working, as well as regulating the working atmosphere. The latter highlights the versatile possibilities of collaborative sketching that entrench even to securing collaborative relationships. While Study I confirmed many previously reported findings, *the detailed micro-level analysis also revealed the versatile ways and functions in which sketching can be carried out collaboratively.* In collaborative sketching, agency shifts from individual to individual, from individual to team, and vice versa. Simple actions of sketching (often without speech) can be used to regulate conversation and bid for a conversational turn, to valuate a proposal and express an opinion, as well as to instantiate and substantiate design ideas. *Collaborative sketching is not limited to studies of spatial configurations, even if these configurations appear to be the main function.*

7.2 Study II: Hands on design

Study II examined how gestures and sketching contributed to collaborative designing through comparative settings. Firstly, the two embodied resources were compared with speech; secondly, the use of sketching was compared with the use of gestures; and thirdly, their use in the more conceptually oriented Defining Design Constraints and in the 2D visualising session were scrutinised.

Findings showed that the indigenous characters of the embodied resources entailed an abundance of meanings not carried by speech; these findings were elemental for the rest of the study and for drawing substantial conclusions on our data. Nearly all sketching provided additional (complementary) content in comparison to accompanying speech (100% in the first, 85% in the second design session). The corresponding levels for gestures were clearly higher than half of all gestures (respectively 58% and 64%). *The combination of speech, sketching and gestures provided clearly more meanings than speech alone*.

Classification of these additional meanings produced five dimensions which are valuable especially for designing: (1) structural features, such as shape, size, construction, (2) material qualities, such as texture, flexibility, weight, (3) enacting sources of inspiration, for instance, personal experience, (4) enacting making, for instance, simulating embroidery, and (5) enacting end user behaviour and use of the artefact. Additionally, three more general dimensions were identified: (1) linking to object upon sight (i.e. pointing), (2) linking to abstract objects, such as an imagined object, a situation, time or previous conversational topic, and (3) metacommunicative, which entailed regulating either the communication or the design process by, for instance, reserving conversational turn or simulating sketching. Based on research literature and the results of Study I that had revealed the centrality of structural considerations in this data, it was expected that *structure dominated for both sketching and gesturing. Additionally, meta-communication was frequent for both embodied resources. However, sketching had almost no other uses than those two, while gestures had more versatile uses.*

The difference between sketching and gesturing became clearer with the analysis of tasks particularly suited for sketching and gesturing. *When precision and memory was required, sketching was preferred*, as in the case of the central but complicated creation of a puzzle base structure that allowed for multiple locations for each puzzle piece while simultaneously including as many given forms as possible. On the other hand, suggesting and developing ideas about puzzle elements based on the given forms pictured on a task sheet (i.e. identifying visual analogies) was a task for gestures, as well as tasks including enactment of motor actions. *When designing required inclusion of spatio-motoric and experiential content as well as understanding of action-sequences, gestures were preferred over speech or sketching*.

Designing structural and material aspects benefited from the indigenous characters of gestures, as demonstrated by the first data excerpt in Publication II. The excerpt 'Tucking fabric to create whorled branches of a spruce' describes two team members ideating and negotiating gesturally the details of making a puzzle piece detail, i.e. the branches of a spruce. The fine gestural details signal meanings for people familiar with tucking techniques and fabrics, but most likely remain unnoticed by others. The process was not described in words. *Gestures provided a channel to ideate fine details clearly and with precision by employing both visuospatial and kinaesthetic feedback. However, not all of these details are attainable for people who lack the underlying experience.*

To demonstrate the power of gestures to conceptualise differently than linguistic resources allow, Publication II provided another excerpt: 'imagining as 'pushing inwards'. The team members discuss children imaging things. The Finnish word originally used ("kuvitella") and the English translation provided in the transcript ("imagine") both refer to forming mental pictures. Yet the gesture used shows how the content is pushed inwards, into the head—more like 'pushing something in' rather than creation of new visualisations (Figure 10). Gestures conceptualised the idea of imagining very differently than words.

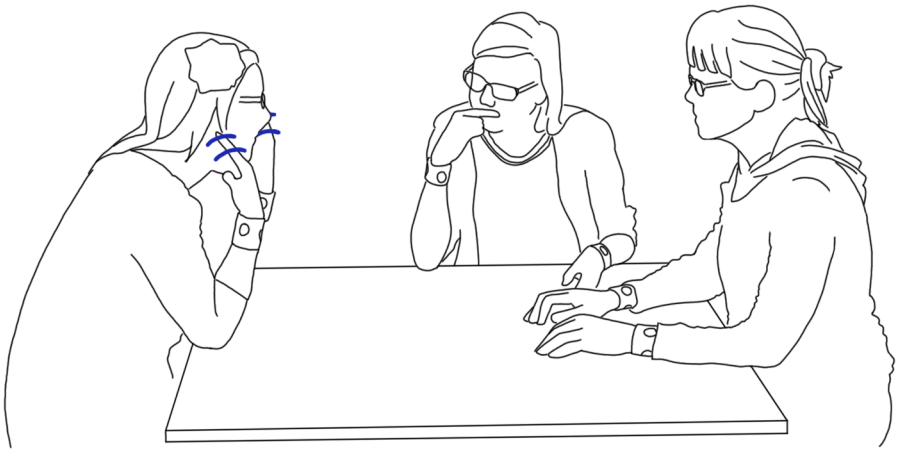


Figure 10. 'Imagining' as "pushing something in'. A stylised video frame.

Further, the concept of imagining as 'pushing in', into the head was repeated by the other team member, with no accompanying mention of 'imagining'. Later, the concept was repeated three more times with the same meaning. Each time that the concept reappeared, the gesture was slightly simplified, yet it was clearly recognisable as the same concept. The gestural concept had become part of the team's shared knowledge (see LeBaron and Streeck, 2000)—a gestural concept (Streeck, 2009) that was part of the team's shared 'conceptual lexicon'. Thus, *the role of gestures was not only about providing additional details that are easier to enact with gestures, but also that gestures revealed a*

conceptualisation that was different from words. This conceptualisation then has potential to activate listeners' embodied conceptualisations and spark new design ideas.

To conclude, gestures provided ample 'additional' meanings to the design conversation. Most of those meanings were of types not easily conducted by sketching or speech; gestures, sketching and speech supplemented each other. Gestures provided another modality to conceptualise, to build on personal experiences with the material world. This modality invited others to follow, adopt and enrich conceptualisations. *A strength of gestures as a resource for creative collaboration is that gestures invite designers to share and communicate rather than withdraw.* An understanding of the importance of collaboration, or more specifically of the importance of the immediacy of sharing, emerged alongside the rigorous micro-level analysis and the comparisons between characteristic uses of sketching and gesturing conducted for Studies I and II. *The practice of sharing ideas as they emerge (and when they emerge) might benefit novices as much as any single design tool*. The different types of peer-level collaboration, such as types of collaborative sketching identified in Study I, would appear to be underrepresented phenomena in research on design education.

7.3 Study III: Material knowledge

Study III examined how gestures contributed to the collaborative creation of material knowledge. As the teams did not have access to actual materials, they expressed their material knowledge (material ideas and challenges) with linguistic and embodied resources (in this case, gestures). These expressions represented personal, embodied knowledge—and followed the idea of the design mode (Bereiter & Scardamalia, 2003, p.55–56).

Reading the results at the surface level, the teams favoured words over gestures: only a quarter (23%) of all the expressions of material knowledge were gestural. However, a clear specialisation of modalities was revealed by a further classification. Material knowledge was classified into dimensions describing (1) the behaviours of materials, (2) sensory qualities, (3) expressive or (4) associative meanings, (5) valuations of materials and (6) identifying (naming) a material, a manipulation technique or an object that represented a particular material. According to this classification, identifying was the most frequent (43%), sensory the second (31%) and behaviour of the materials the third (19%), while the remaining dimensions were relatively rare. *All the teams favoured words for identifying, but gestures for practically everything else.*

The gestures that the teams used were descriptive: depictions of qualities associated with the materials in question. The data was especially rich in sensory expressions, which also included expressions based on spatial qualities. As

spatiality is a known strength of gestural expressions, a division into spatial, visual and tactual was needed. As expected, spatial meanings explained well more than half of all gestural-sensory expressions, visual meanings being the second and tactual the last. The low amount of tactual expression was contrary to expectations, because the design brief of the Wearable sea creature project was intended to emphasise materiality, including tactual aspects. The most plausible explanation was that very few people have any personal, tactual experiences with corals, sea horses, octopuses, sharks and so on, and this caused the teams to resort to visual experiences. Further, our assignment structure, which included a visit to the sea aquarium, provided the students with visual but not with tactual experiences. Thus, the assignment left less room for tactual experiences—an important dimension of materiality—than intended. Having said that, expressions of materiality were in total ample enough.

Though the classification scheme demonstrated the abundance of gestural expressions (180 expressions in 3.75 hours, that is, 3 gestural expressions every 4 minutes), it did not do justice to the richness and conceptual power of gestural expressions. Data excerpts were required. The first of the excerpts in Publication III exemplifies how the combined shape and movement of a piece of light fabric is easily described by a single gesture when words fail to convey the meanings; *gestures pack richer content more economically than words when the task is to express spatiality or movement.* The second excerpt complements the understanding created by Study II, as it pictures a gesture as a window to a conceptualisation that is not available in words. In the second excerpt, one team member uses a gestural conceptualisation of a fluffy ball (a plastic toy). The other team member recognises immediately the toy in question as she shares the embodied, tactile-kinaesthetic material experience. Yet for the third team member the toy remains unrecognisable even after multiple gestures and verbal descriptions. The plastic toy and two depictive gestures appear in Figure 11.

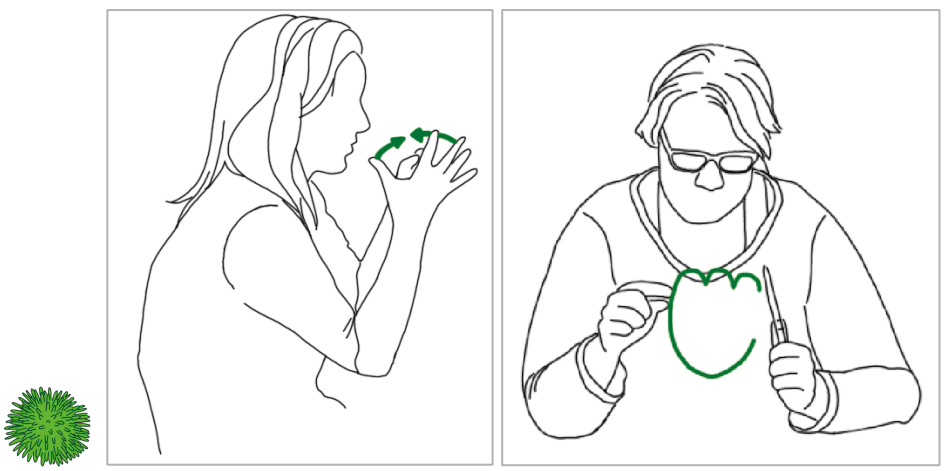


Figure 11. A fluffy ball, and its two gestural conceptualisations (stylised video frames).

Only the mention of the typical bright colours of the toy (visual impression) appears familiar to her; *as her conceptualisation of the toy was based on a different sensorial dimension, the gesture was not helpful*.

Furthermore, the second excerpt provided another example of the aspect already reported in Study II: as the gesture became part of the teams' shared conceptual base (or 'lexicon') and was repeated during the conversation, each instantiation of the gesture was a little simpler than the previous ones. This follows the tendency of linguistic expressions to become more and more referential as the conversation continues, as reported by Schober and Clark (1989). At least in this respect, *gestures appeared to follow the same conversational rule as the linguistic content*.

7.4 Study IV: Material explorations

Study IV explored the epistemic contributions of the material explorations to the collaborative creation of material knowledge from the viewpoint of the make phase. To start with, the data coverage was good, as in the final interviews the teams confirmed that they had reported nearly all their explorations and decisions by eDiary, and the few missing ones were covered during the interviews. The good coverage also implied that *the teams made decisions on materials collaboratively and knowingly*, using explorations whenever they deemed their previous knowledge insufficient. This meticulous approach yielded to around twenty explorations and decisions per team. Practically all material aspects of any importance were tested prior to actual implementation, which implies that *the teams considered materials and the testing of their materials important.*

The teams' objectives for the explorations could be summarised according to three dimensions: (1) making decisions about which materials to choose, (2) practising their techniques and use of tools, and (3) testing their material knowledge related to combining materials. Selecting materials and testing the combinations aimed directly at ensuring good material decisions, while practising techniques and the use of tools to manipulate materials aimed at enhancing practical skills. *For the teams, material knowledge was a resource to address the challenges of making, not an end itself.* The clear majority of the explorations (61%) focused on decisions, which is probably more due to the course schedules than the teams' ambitions. Moreover, many of the students were novices in some of the needed textile techniques, and not only with regard to designing; hence, practising was necessary.

The practical approach towards material knowledge was also reflected in the characteristics of the explorative process. During the process, the teams shared, assessed, adopted and adapted material knowledge. As the assignment emphasised that the accessories were to have as an authentic look and feel as

possible, the task of selecting suitable materials was not easy. Well over half (63%) of the decisions were based on material manipulations, rather than sensory perception at a superficial level or prior knowledge on the materials in question: the teams appreciated first-hand embodied experience, even though the schedule was pressing. The pressures showed more concerning their criteria for approving the results of the material tests. More than half of the tests passed on the first trial, and two-thirds of the tests passed because the result was considered fit for the purpose, that is, good enough for the time being. Another indication of the pressured schedule of the making was that virtually none of the innovative material ideas proposed in the design phase were even considered, let alone tested, in the make phase. This became evident when the material ideas expressed in the design phase were compared with the reported decisions from the make phase. It appears that *for the most part, materials were considered to be practical solutions rather than sources of inspiration and new ideas*.

7.5 The main findings per research question

The following collects the key findings concerning the main research questions, which is followed by a table indicating the relationship between the findings, the publications and the studies.

RQ1: What is the epistemic role of sketching in collaborative designing?

Within this data, the student teams frequently engaged in sketching. Collaborative sketching appeared to be a natural choice as a substantial part of all sketching was collaborative. Collaborative sketching led to invaluable advances for the three studied teams, albeit in different ways as the teams organised their working around sketching differently: the level of regulation varied. For some ways of collaborative sketching, regulation and agency took place on the team level (co-ordinated and collective), and for some at the level of the individual team member (disclosed sketching). From all collaborative sketching, a substantial part was explorative in character. The detailed analysis revealed the functions for sketching collaboratively: studying spatial configurations was frequent, yet almost as frequent was proposing (other) ideas through sketching, and some regulating of the physical or social working environment took place. Especially for complicated structural studies requiring precision and memory, sketching was the preferred choice. Further, when compared with accompanying speech, nearly all sketching produced complementary content. This content was mainly related to the structural aspects of the design, but the content also conveyed meta-communicative meanings.

RQ2: What is the epistemic role of gestures in collaborative designing?

The studied teams used gestures frequently to share and develop design ideas in all studied design dimensions. In comparison to sketching, gestures were favoured for dynamic, spatio-motoric aspects, haptic meanings and embodied experiences. Within the structural dimension, gestures were utilised for simple constructions and sketching for more complicated constructions. In comparison to accompanying speech, the majority of gestures provided complementary meanings; especially sensory-spatial meanings and descriptions of material behaviour were more often gestural than linguistic. On the other hand, materials were named (identified) with words more often than with gestures, even though gestures were also used for naming and valuation. Even if the majority of all expressions of materiality were linguistic, and only a quarter gestural, gestures conveyed clearly and precisely richer, more nuanced content than words. When team members shared the same experiential base—the same kind of embodied experience—gestures provided fast transmission of concepts based on those experiences. Moreover, gestures provided a resource to conceptualise the world differently. Some of these gestural conceptualisations became part of the team-level knowledge and lexicon, and they appeared to follow the same conversational rule as linguistic content, namely becoming more and more referential as the conversation continued.

RQ3: What are the characteristics of the collaborative creation of material knowledge by explorations?

Materials and testing of their material decisions appeared important for student teams, as they reported exporations and decisions related to nearly all of the implemented features. Half of the explorations were focused on selecting suitable materials for particular design features, while the other half was divided between practising techniques and tools as well as testing combinations of materials. Well over half of the decisions were based on material manipulation rather than mere sensory perception or prior knowledge, indicating that the teams valued embodied experience. Yet the pragmatic character of the teams' explorative processes was evident; most material tests passed on the first trial, and the majority passed because the result was considered good enough. Further, with few exceptions, the innovative material ideas from design were not considered worth exploring. All in all, the teams frequently used explorations to create material knowledge, which was treated as a vehicle in addressing challenges of making rather than as a source of inspiration.

Table 4. A table summarising the relationships between main research questions, main findings, studies and publications.

	Publication I/Study I: Collaborative sketching	Publication II/Study II: Hands on design	Publication III/Study III: Material knowledge	Publication III/Study IV: Material explorations
(1) What is the epistemic role of sketching in collaborative designing?	Collaborative sketching led to invaluable (mostly structural) advances. Level of regulation varied (co-ordinated, disclosed, collective, silenced). Three functions and six capacities. Substantial part collaborative and explorative.	Nearly all sketching was complementary (rather than redundant) to co-speech. Sketching contributed to structural aspects (especially requiring precision and memory) and meta-communication (regulating design process and communication).	–	–
(2) What is the epistemic role of gestures in collaborative designing?	–	The majority of gestures were complementary to co-speech. Gestures frequently employed, providing a precise way to share and develop spatio-motoric aspects, haptic meanings & embodied experience. Gestural conceptualisations differed from linguistic, some incorporated into the team knowledge and lexicon.	A quarter of expressions of materiality were gestural. Sensory (spatial) meanings & behaviour of materials more frequently in gestures than in words. Gestures used also for naming and valuation. Gestures provided richer content than words, fast transmission of ideas & sharing of embodied experience.	–
(3) What are the characteristics of the collaborative creation of material knowledge by explorations?	–	–	–	Explorations frequent, mainly to select a material, also to test combinations or to practice. Most decisions based on the manipulation of materials. Pragmatism: over half of the first propositions passed as fit for the purpose. Innovative ideas from design not considered or explored.

8 General Discussion

> *Speaking and writing is an ever renewed struggle to be both apposite and intelligible, and every word that is finally uttered is a confession of our incapacity to do better; but each time we have finished saying something and let it stand, we tacitly imply also to that this says what we mean and should mean it thereof also to the listener or reader. Though these ubiquitous tacit endorsements of our words may always turn out to be mistaken, we must accept this risk if we are ever to say anything.*
> Michael Polanyi, 1958, Personal Knowledge, p.207.

Design education is about change: changing 'what' and 'how', students' knowledge and skills. Epistemic education brings about change by acknowledging students' knowledge and knowledge practices and then deliberately addressing these epistemologies (Barzilai & Chinn, 2017). My research targeted design education and students' use of embodied resources of sketching, gesturing and material explorations for advancing collaborative designing in higher education. I addressed collaborative design as an archetypical form of trialogical knowledge creation, a process that emphasises the artefact-oriented character of the collaborative work and encourages students' agency (Paavola & Hakkarainen, 2005; 2014).

My theoretical investigations consolidated prior key findings on sketching and material explorations in design, and provided an extensive display of gesture research approaches and results that have relevance for design education and design, as well as education in general. My empirical findings showed the characteristics and strengths of the studied embodied resources via their typical uses. My results showed how students used the resources to advance designing and making, that is, the epistemic roles they assigned for those resources. These findings have relevance for design, for all educational fields that apply design-based approaches and for gesture research. Further, the developed rigorous research method brought to the fore the abundance of multimodal actions of collaborative designing and knowledge creation, that is, how the numerousness of 'additional' meanings were fed into the design conversation and the parallel channels of communication and thinking were activated.

In the following, I present the theoretical and practical implications of my research in three sections. First, I address the research gaps I indentified in the

introductory chapter, second, I propose a new approach to enrich the research on embodied resources and gestures in particular, and third, I highlight aspects of collaboration that could be beneficial for design education. I continue with methodological implications and the limitations of this research. I conclude this chapter and this research by laying out certain proposals for future research in the fields of design education and gesture studies.

8.1 Addressing the identified research gaps

In the beginning of this research I identified four gaps in the design research literature. First, the intersection of sketching (the design practice that is close to being over-researched) and collaboration (a way of organising the work). Second, systematic comparison between sketching and gesturing in advancing designing. Third, how gestures are used to express material knowledge. Fourth, how material explorations are used in advancing designing and the production of the designed artefact. My research both deepens and widens the theoretical field of design research by introducing themes more familiar in educational science, linguistics and gesture research. In the following, I address these four gaps and conclude by contrasting all the three embodied resources: sketching, gesturing and material explorations.

Sketching and collaboration. Sketching has been proved beneficial for designing: for generating and developing ideas and for communication (Purcell & Gero, 1998). Researchers have expressed concerns that novice designers avoid sketching and do not understand why they should sketch (Booth & al, 2016; Orthel & Day, 2016). Being a novice designer entails that the discipline-specific practices have not yet become routines, probably not even active skills. Novices' skills are products of the educational system and their free-time activities. Curricula at the elementary level seldom endorse sketching as a tool for developing ideas, and this was visible in the products created by ninth-grade students (Syrjäläinen & Seitamaa-Hakkarainen, 2014). From these premises, novices' sketching in collaborative design setting could take several forms.

Sketching skills represent only half of 'collaborative sketching'. Collaboration requires skills other than individual work, such as communication, organising and regulation of the work processes (Järvelä & Hadwin, 2013; Perry and Sanderson, 1998). Patterns of participation (Dillenbourg, 1999, p. 6–10) could have dramatic effects on the team performance (Barron, 2003). In design education research, however, these challenges related to collaboration have not been addressed at the same level as in general education research. Yet addressing a demand to collaborate while learning a whole new way of (designerly) thinking and related practices is not so straightforward. Starting with the understanding that collaborative design sketching is a new practice to be adopted by students, my empirical research rendered visible the differing

levels of regulation and sharing of sketching as they emerged in the Puzzle project. The identified four patterns varied from 'individuals produce representations' (co-ordinated sketching) to 'sketching as an immediately shared design move' (disclosed sketching). The identified pattern of disclosed sketching resembled gesturing in its immediacy but also in tending to (relatively) small fragments of ideas at a time. Rather than presenting large, complicated and fully incubated ideas, it focused on the aspect that appeared important at that moment, at the level of abstraction necessary in that particular unfolding situation.

These four patterns show that there is more than one way of dedicating time and effort to sketching. *Yet different sketching patterns yield to different unfoldings of the trialogical processes: the level of granularity of the design move directs the trialogical processes. The level of detail and abstraction guides the intertwined, situated creative processes of the individuals. Early and unreserved sharing harnesses the creative power of the team at the most elemental and engaging level, as it frequently invites others to evaluate, refine and become inspired.* However, the claim here is not that 'disclosed sketching' is preferred. All the identified patterns have their uses and can yield to fruitful, yet differing unfoldings. The identified patterns have value especially for design-based and collaborative educational approaches.

Sketching and gesturing. According to the literature reviewed in chapter 3, sketching and gesturing abstract, schematise and ambiguate. These qualities facilitate multiple, unintentional interpretations and reinterpretations—mechanisms central for designing. Moreover, both sketching and gesturing can reveal underlying conceptualisations, personal experiences and knowledge. What ostensively separates those two embodied resources is the medium onto which they are 'inscribed'. Gestures utilise four-dimensional conversational, public but transitory space whereas sketches are 'frozen' on two-dimensional paper. The differences in the dimensions but also the radically different properties of archivability heavily influenced the ways in which sketching and gesturing were used. Eris et al. (2014) have suggested that gestures are more important in the initial and conceptual phases of designing, whereas sketching is used to represent and detail a concept after it has been identified. Conversely, my empirical results show that even if sketching and gesturing had their own strengths, their roles were not restricted by the phases of the design process, and even during visualisation by sketching, gestures had versatile uses. According to my findings, sketching was better suited to tasks requiring precision in building on prior ideas, and detailing complicated structures. Gestures, on the other hand, allowed for materially effortless depiction of ideas and the enactment of motor actions. Both sketching and gesturing provided multiple 'additional' meanings to the design conversation—additional when compared to using only linguistic resources. My rigorous quantification of these 'additional' meanings confirmed the previous general level of understanding that gesturing provides design-

relevant meanings which are not available in the accompanying speech (Eris et al. 2014; Tang, 1991; Visser, 2009). Moreover, my research grounded the theory of embodied conceptualisations in the context of collaborative designing and showed that gesturing provided an 'additional', embodied channel for thinking. These results on gestural conceptualisations have value in closing the gap between conceptual and interactionist research paradigms on embodiment (see section 1.2.).

Eventually, contrasting sketching and gesturing facilitated a novel formulation of the essence of design sketching: *No one would expect a gesture to be an exact replica of its referent, complete or polished. A gesture is quickly drafted, focuses on the essentials and omits the unnecessary. That is also how design sketching should be approached: like gesturing.* Whereas the formulation could have more value for design education, these results deepen the understanding on sketching and gesturing in designing, thus creating value for design and gesture research, but possibly for educational research as well.

Gestures and material knowledge. This part of my empirical research continued to ground the previous gesture research results in the realm of materiality in collaborative designing. Gestures were identified as conveyors of sensorial and experiential knowledge and related conceptualisations. *Gestures conveyed materially effortless substantiations of materiality: material features of design ideas and interactions with material world. They enriched the interactive, creative space between the designers with the (absent) materials of the situation by bringing out structures and abstractions at differing levels that were frequently not available in speech.* These results also provided a rigorous quantification of the relationship between meanings conveyed by gestures and accompanying speech and revealed the abundance of gestural meanings that enriched the conversation. The results are novel both for design and gesture research and, likewise the results mentioned in the previous paragraph, have value in closing the gap between embodiment paradigms.

Material explorations. Targeting the material explorations in the early phases of making was a novel approach. These material explorations were closer to technical design than prototyping or actual production of the artefact, as they focused on testing and selecting structural and material details one by one. My empirical findings showed that the teams valued materials and material knowledge. However, almost all innovative ideas that surfaced in the design phase were dropped without testing or further discussion in the exploration phase; the apposite nature of the decisions was explicit. Considering the importance of the teams' explorations for succesful making, it was unfortunate that video data could not be collected. Yet this research provides an opening and invites other design researchers to follow.

Ultimately, my research on material explorations inspired to contrast all the three embodied resources: sketching, gesturing and material explorations. These

resources all facilitate seeing things in a new way, structuring and re-structuring, interpreting and reinterpreting, and it is precisely these activities that are central for many design thinking and process approaches. My contrasting of the three embodied resources yields the following formulation: *A material exploration substantiates the idea in material form, which enables evaluation and further development which is not otherwise possible to a similar degree. Sketching and gesturing serve designing in a similar way: they instantiate the idea in emergence in an embodied format. That embodied format (a 2D visual depiction or a 4D spatio-motoric depiction) enables visual, spatio-motoric or kinaesthetic testing, evaluation and further ideation in a way that is not achievable with mere linguistic 'depictions'*. It is not the depiction but the evaluation and further ideation, acting in accordance with the principles of the design mode (Bereiter & Scardamalia, 2003, p.55–56) that is valuable. The depiction is merely a tool, a stepping stone.

8.2 From communication and interaction to inspiraction

The importance of communication appears self-evident for collaborative design. The word communication implies that shared understanding is at least targeted if not always established: that the message is interpreted as intended. Embodied resources reduce the ambiguity of a message and make it easier to understand, as discussed in section 3.2.3. The meanings provided by the embodied resources complement, further define and contextualise the meanings provided by linguistic resources. They are intertwined. This intertwined character also facilitates design thinking: seeing things in a new light. Or at least, seeing new features in the old things. I build on Murphy (2012) to argue that the translation from one resource to another forces the designer to account for the indigenous characters of each resource. During the repeated translations of the idea, new features emerge; the designer is invited to make new analogies, new transformations, new reinterpretations. *Collaborative designing can be understood as drafting series of essential features (of the problems and the solutions) in different formats, which build on linguistic and embodied resources.*

However, serving understanding is not the only function of design communication. During designing, designers' actions function as sources of inspiration. For inspiration, complete understanding is not necessary. Contrarily, 'misunderstanding' might be more beneficial: it generates reinterpretations. My empirical results confirmed that the use of embodied resources along with the linguistic ones multiplied the volume of meanings. This kind of multiplication amplifies the potential to capture the attention of the various channels and spark inspiration. *At best, active and rich use of embodied resources alongside the linguistic ones can turn interaction into inspiraction, that is, interaction that*

inspires—elicits new ideas and (even) more productive interaction. Further, *the epistemic role of the studied embodied resources is not necessarily limited to enriching communication and thinking but could entail the ability to elicit more ideas by enhancing the intensity and richness of collaborative designing*.

However, a word of caution is in order. Simply having multiple ideas or reinterpretations does not guarantee 'good' design. Moreover, many professional designers have a tendency to select their solutions quite rapidly (Cross, 2004). What then is the motivation behind producing multiple ideas? Firstly, genuinely original ideas emerge only through series of sustained iterative efforts, not by change. Secondly, evaluation of the ideas entails probing design constraints, re-structuring and framing the design problem (Dorst & Cross, 2001; Seitamaa-Hakkarainen, 2000, p.187; Wiltschnig, Christensen & Ball, 2013). Through evaluation and rejection of (multiple) ideas, previously unnoticed features of the design context become visible. These new structures, frames and features, in turn, could facilitate generation of not so obvious ideas.

The value of these implications is not restricted to design research but extends to gesture research. Thus far, gestures have generally been approached from two directions: one treating gestures as a form of communication, while the other complements the communicative view with the suggestion that gestures are a form of thinking. Very little research has focused on gestures' features specific for creative work. This approach is visible both in design research (e.g. Eris et al., 2014; Visser & Maher, 2011), and in gesture research. *Turning from communicative to inspiractional capabilities, from preserving the interpretation or revealing inner thoughts to evoking new ideas in oneself and in others, is a shift of paradigm.* This proposed new approach requires a new kind of research on gestures, both in the field of design and in gesture studies. Some preliminary research items within the suggested approach are identified in section 8.6. But before that, we shall take a look at a couple of implications potentially beneficial for design education.

8.3 Implications for design education

My empirical research identified several collaborative design practices, ways of knowing and working with knowledge among the students researched. According to the principles of epistemic education, acknowledged practices should be deliberately developed (Barzilai & Chinn, 2017). Many of the theoretical implications above directly translate into messages that design educators can use. As many highly recommendable suggestions related to introducing sketching as a tool for designerly thinking and materials as sources of inspiration already exist (e.g. Laamanen, 2012, 2016, p.64; Lucibello & Ferrara, 2012, p.272–274; Orthel & Day, 2016), the following centres on the part played by collaboration in collaborative design.

As already stated, collaborating team members (should) use each other's actions as sources of inspiration. This requires that suitable actions exist and are paid attention to. Different micro-level patterns of sharing, such as revealed by my empirical research on sketching, yield different micro-level unfoldings of the design sub-processes. The more that is shared, the more potential there is for new ideas. From this viewpoint, the strength of gestures is that they guide us towards communicating rather than withdrawing, to sharing immediately. Using sketching or material explorations like turns-at-talk in conversation—like a design move among others—accounts to a similar effect. This *immediacy of sharing could be an important factor for collaborative creativity*.

However, harnessing the potential created by active use of the embodied resources requires that designers are sensitive to, responsive to, appreciative of and even curious about the actions of their team members. According to Sawyer (2003b, p.8), the meaning of one's act is defined by how others respond to it; this is a defining feature of group creativity. Acts not disclosed, as well as acts that remain unnoticed or get rejected do not contribute to the collaborative creative process. The participants' ability to recognise and build on acts taking place within the creative process is also dependent on their embodied experiences: it is difficult if not impossible to appreciate expressions of very specialised experiences if these experiences are unfamiliar. Therefore, active participation is not only about producing. Silent but active perceiving, such as listening, seeing and touching are also important for collaborative creativity. To conclude, *immediate and unreserved sharing together with appreciative and curious perception could mean that interaction grows into inspiraction.* This kind of collaboration could be as important as any design practice. In the end, any practice is only as useful as what we make of it.

8.4 Methodological implications

Capturing the characteristics of collaborative work is hardly a task for any single method used in isolation (Hmelo-Silver, 2003). I used a selection of analytical techniques: qualitative content analysis of the video data, quantification of the coding results (frequencies), graphic data representations on the time-line, data illustrations by word clouds and chronological representations of embodied events. The methods I developed operated mainly on the micro-level, with some meso-level analysis. The macro-level understanding of the processes and the pedagogical setting was provided by studies not included in this research (Lahti et al., 2016; Seitamaa-Hakkarainen et al. 2017).

The challenges of capturing the embodied and collaborative process was discussed in section 6.3. and my solutions in sections 6.4—6.7. Detailed documenting of my analysis practice (in Publications II and III) provides a sound basis for other researchers to critique, adopt or further develop my

interpretative methods. The practice has *three cornerstones that aim at maximising the preservation of the indigenous characters of the embodied resources by*

(1) replacing transcripts with running video footage in making analytical decisions;

(2) using a video analysis software that supports data-driven coding, graphic time-line views and an unlimited number of annotations;

(3) using complementing annotations to record analytical hunches, parallel and even conflicting interpretations as well as critiques.

The introduction of these three cornerstones freed researchers' resources from finding verbal expressions to describe the use of embodied resources. More importantly, it ensured that gestures or sketches were not reduced to those interpretations that were meaningful for the person making the transcripts, or the first impressions possibly sacrificing other but not as commonly shared interpretations. The practice increased the validity of the results, and made all the decisions transparent. This required practice. Yet the experiences from the parallel coding of gestures for Study II proved that written descriptions of the gesture categories were not sufficient: the only way to reach an understanding of the categories was to ground the definitions on sample gestures on the running video. This developed method benefits both video-observation-based design research and gesture research, and also multimodal video research in general.

Multimodal research emphasises the need to analyse interaction from a holistic perspective in order to take into account all modalities, actions, and context (Goodwin, 2010). In my experience, it is not possible to account for the subtle details of all modalities at the same time, even though the modalities are intertwined, supporting and building on each other. On the other hand, *it is not possible to study one modality without acknowledging the importance of the others.* When looking at the big picture—in my research, three students actively talking and acting, making design moves—subtleties are easy to miss. Fortunately, extensive prior research on design sketching and gesturing provided pointers and facilitated in both forming the big picture and the details, at least within the approaches of communication and thinking. Consequently, for future studies focusing on a specific contribution by any non-linguistic modality, such as materiality, I propose that a two-tier approach be taken. First, a holistic view of all the activities is accomplished through macro-level analysis. Next, the modality in question is taken under detailed scrutiny. The latter calls for other embodied and linguistic resources to be given second priority and the modality in question to be emphasised—taken to the fore—as I did in studies II and III. Finally, combining the findings from these two analytical tiers provides a fuller picture than either of the tiers alone.

From the viewpoint of design research, the developed rigorous micro-level methods proved suitable: it increased understanding of the special roles that the

embodied resources played in the collaborative designing. Yet I have only scratched the surface. More method development is needed. Typically, systematic observation-based design research considers design moves involving speech, sometimes sketching and in a few cases, other materialisations. In this research, I have considered every turn-at-talk, gesture and practical action of collaborative designing as an action of knowledge creation; these could also be interpreted as design moves. Every one of these 'design moves' was understood as contributing to the end result. However, this research does not provide warranted claims of the straightforward consequences of these design moves. Whether these complementary meanings conveyed by the embodied resources invoked any ideas that otherwise would not have emerged, is of course impossible to prove, regardless of the methods used or the levels of analysis.

To reach a fuller picture of the roles of the embodied resources these 'design moves' could be consolidated to 'a multimodal Linkograph'. To eliminate at least a part of the critique related to the subjectivity of the links, designers' eye movements could be tracked with eye-tracking glasses and some suitable software. This additional, observable modality could provide design researchers with new insights on linkages between the design moves of various modalities, as well as on the division between explicit and inexplicit design thinking. 'The multimodal Linkograph' could also bring new insights to the inspiractional properties of gestures.

As a contribution to design research, this research (Publication II) summarised three (families of) factors that influence both if and how gestures are used for designing:

(1) How collaboration is organised (the level and immediacy of sharing);
(2) Characters of the design situation (e.g. level of pre-structuring the work, environmental props and customer involvement); and
(3) Designers' personal preferences and skills.

I also suggest that the above-mentioned factors influence the use of design tools and embodied resources in general, not only the use of gestures. In section 8.6 I utilise this three-fold structure for suggestions for future research.

From the viewpoint of gesture research, I see my research as opening up methodological discussion. In many gesture research publications, methods are rarely discussed. As an independent field of research, gesture research is relatively young. For instance, the journal Gesture, the only scientific peer-reviewed journal focusing solely on gestures, was founded as recently as 2001. In the future, as the research domain matures, I expect discussions on methods and methodologies to become more common. I do not subscribe to the idea of one methodology that solves all questions, yet I believe that the field could benefit from more explicit and rigorous treatment of its analysis methods. For instance, research publications rarely touch upon the selection of data and

research participants, even though gesturing is a highly individualised practice, both quantitatively and qualitatively. Due to this, generalisations over phenomena are more obtainable than generalisations over populations. All in all, systematic discussion on methodological issues could yield approaches with evolved argumentative power as well as a wider consensus on the limits and possibilities regarding gesture studies.

A subset of methodological aspects not widely discussed in gesture studies is the use of parallel coding during analysis. This could be related to the above-mentioned individual differences in interpreting gestures. Not all analysis methods include coding, yet all gesture research methods do include interpretation: gestures are ambiguous and often fulfil several functions simultaneously. Thus, it is in the character of gestures to obtain at least slightly different interpretations from different researchers. This might be considered slightly inconvenient for the 'gestures as communication' approach, but for the inspiraction approach this is an advantage. This is not to say that inspiraction is more valid than the communication approach. Rather than replacing it, I consider that the inspirational approach complements the established ones as every approach, method and research has its own limitations.

8.5 Limitations of the research

This research was carried out in the context of design learning in higher education, and in particular, the craft teacher education programme. Limitations of this research arise from three different sources: the setting, the data and the analysis methods. As the previous section covered methodological concerns, the following focuses on the setting and the data.

The setting comprised two collaborative design and make projects following the LCD model. The projects were included in the first-semester courses mandatory for students; little latitude for extra (data collection) arrangements existed. The projects had a two-fold aim: to provide an opportunity to learn collaborative design, and to provide future teachers with an experience of a pedagogical setting, namely an example of how to scaffold design learning. Each project was based on a design brief and, as the students were novices in design, rather detailed tasks that introduced basic design practices. The order of the tasks was progressive: the first ones required less material effort than the later ones and simultaneously, the teams' level of commitment to selected ideas were to increase as cancelling a (materialised) decision became more laborious. The pre-specified nature and order of the tasks obviously had an effect on the teams' use of sketching and materials, yet the tasks had pedagogical grounds and were specifically planned to support ideation at the novice level.

The teams designed three-dimensional textile objects (puzzles and accessories) for real-world users and were required to complete their designs to

material artefacts. The latter requirement could well have led to the teams' strongly emphasising structure and materials, creating in turn a potent ground for sketching and gesturing. The requirement to make could have yielded simplified designs. However, the carefully considered and inventive details of the final artefacts showed little evidence of the students lowering the bar. All in all, the projects were ambitious yet realistic in the field of textile (artefact) design and craft education; they served as pedagogical examples. Researchwise, more abstract or functionally more complicated artefacts could have induced different volumes and dimensions of sketching and gesturing. However, no grounds exist to speculate on the additional dimensions these changed conditions could produce to the classification scheme identified in Study II.

One of the main tenets of my research is that embodiment, the use of embodied resources, is a social phenomenon with indisputable connections to individuals' experience and knowledge. Thus, selection of participants influences the unfolding of the events and the reseach results. However, even if the details, such as the embodied conceptualisations that surfaced, could be specific to these participants and these settings, at the level of the phenomena (identified epistemic roles, characteristic uses of the embodied resources, classification schemes) extrapolation is a possibility.

The participants of each project represented one third of the first-year students of craft teacher education. The criteria for the participants and creating the teams were pragmatic: from volunteers, teams of three were formed based on their availability. In most cases little choice was left, as the first year students' course schedules are tight. The teams were fresh, with no experience on working together or knowledge of each other's skill sets or preferences; we caught the teams with collaborative practices in emergence. In regard to the studied phenomena, the students were novices in designing with varying self-reported sketching habits, yet they had years of experience in sewing and handling textile materials—an experiential embodied background against which to produce and interpret models be they sketches, gestures or material explorations. In these respects, they represented typical craft teacher students. The students were eager to share their ideas already at a predefined stage and build on each other's ideas—in other words, to collaborate. With less collaborative teams the results could have been very different. Further, had we been able to gather video data from the making, qualitative differences—additional roles for sketching, gesturing and material explorations—could have surfaced.

My primary data was captured in video format. Mondada (2006) discusses the possibilities and limitations of video production: the camera is both a resource and a constraint. In real-life, the data collection is not only constrained by the camera but also by the facilities (space, time) required for good-quality video. For this qualitative research, two data sets (two projects) with four teams in each were considered sufficient. As confirmed by the students in the

stimulated recall interviews, our cameras managed to capture all their design activities. However, without having bird's-eye view cameras, all the detailed analysis of the sketched content would not have been possible. For gesture analysis, one camera angle from the tripod was sufficient: only a couple of gestures were not in full view.

Apart from the data collection, the criteria of selecting the data for analysis could have affected the results. For Study I, three of the four Puzzle project teams were selected. The fourth used a pattern book and skipped the structural planning, thus they were not regarded as comparable with the other three. For Study II, only one of the teams that participated in Study I was selected: the team which exhibited the most elaborate and spontaneous ways of sketching and gesturing. Based on my analysis for Study I, I doubt whether any additional patterns of gesturing would have been identified if other teams had been included. For Study III, all four Wearable sea creature teams were included, as in Study IV. However, at least as powerful as the selection of the team-level data was the decision to include all events of sketching, gesturing and material explorations in the analysis. This approach is radically different from the approaches suggesting that the micro-level analysis should focus on selected segments of data (e.g. Jordan & Henderson, 1995; Derry et al. 2010), and it yields different kinds of results from the selective approaches, as already discussed in the previous section.

8.6 Suggested topics for future research

Two types of future research streams emerge from my research. One continues to advance design pedagogy within the realm of higher education and craft teacher education. The other advances an understanding of gestures in creative work while at the same time carrying my methodological propositions further. The two streams are not totally unrelated. Suggestions regarding pedagogy continue to scrutinise students' understanding and the use of design practices, and include variations of LCD-model-based research settings introduced in this research. This does not imply that these topics could not be investigated within other kinds of collaborative arrangements. The suggestions are reported below in the order of the three families of factors that influence the use of design practices: organisation of collaboration, characters of the design situation, and designers' personal preferences and skills.

Studying possible practice-specific features of organising collaboration, especially regarding the level and immediacy of sharing, requires utilisation of the developed micro-level analysis method. During the Wearable sea creature project I already saw some indications of mobile devices having an impact on collaboration patterns but the setting did not permit rigorous analysis and comparisons between free-hand sketching and photographing for documenting.

Thus, questions like 'Do the identified collaborative patterns appear regularly also with other design practices, tools and participants?' and 'Are there differences in the overall flow of the designing, in the number of preliminary solutions, or how team members build on each other's ideas?' could be researched to understand the impact of different practices for the quality of collaborative design. These findings could have relevance in higher education but also for design education at the primary level.

The second factor, the characteristics of the design situation, can be externally regulated by changing the design assignment and the task structure. The assignment could have a more abstract character by, for instance, not requesting a specific artefact but instead functionality or user experience. Shifting the primary focus from structure could shed light on new roles for the practices. To continue research on the roles of material explorations, the order of the tasks could be changed so that teams are presented with materials already in the initial and conceptual design stage. In craft, 'stashing' materials (Stalp and Winge, 2008) and ideation starting with the materials at hand is customary. However, Laamanen (2012) found that craft teacher students found material explorations uncomfortable when they did not have a clear goal for the explorations. To avoid the feeling of 'wasting materials', the design project could start, for instance, with a visit to a recycling centre, where teams would delve into the materials. In a place like a recycling centre, the materials could easily become potentials rather than solutions. Additionally, the teams could be encouraged not to discard their most innovative material ideas by giving them more time to explore. Further, to continue comparing embodied resources of gesturing and material explorations, the assignment could emphasise visuo-tactual user experience rather than structure. Also, the differences between engaging in a 2D visualisation or a scenario task before 3D modelling could be compared. Scenarios could invite active and rich gesturing, and reportedly, scenarios can enrich ideation, stimulate divergent thinking and have an impact on collaboration (for an overview of scenarios in design, see Casakin et al. 2016). A scenario could task the students to enact user behaviour in the problematic situation that the design project is targeted to solve. Then, the challenges (or lack of) in the following 3D modelling task and making could be analysed. In an advanced course, the teams could have a choice of practices to select rather than using them in a pre-arranged order. In addition to changes in the design situation, the possibility of collecting video data from the making could yield additional roles for the embodied resources to surface.

The third factor, personal preferences and skills, could be focused on by setting up a reflective task: in the beginning, students write or video record their personal understanding of the design practices and their preferences, and during the course they would continue to reflect on how the practices support their designing. All in all, research on these factors could provide a new

understanding on the epistemic roles of design practices and challenges experienced by students, and have further implications on pedagogical practices.

The above-mentioned changes in research setting support a deepening understanding of the inspiractional qualities of collaborative design. For gesture research, refocusing on inspiractional qualities and gestures in the context of creative work could provide new series of insights. Experimental settings reinforced with stimulated recall interviews could be used to explore how gestures enrich communication to spark new ideas and directions of thought. For instance, selected gestures could be used as 'sources of inspiration' and the sparked ideas recorded to analyse the (variety of) ideas, or if more abstract gestures spark more ideas than more specific ones. One topic to analyse could also be whether a variety of interpretations reflects individuals' backgrounds, especially involvement with (or lack of experience on) different embodied practices and craft techniques. Further experimental settings could follow.

In addition to experimental research, naturalistic settings are necessary to understand how gestures contribute to the creation of the final design artefact. As Goodwin (1986) recognised, the lack of a clear affirmation whether a gesture has been noticed or not hinders research on the conversational roles of gestures. This problem could be partly tackled by including eye-tracking technology. The introduction of yet another observable embodied resource could provide a means to construct linkages between proposed ideas and their role in the design process, as briefly mentioned in section 8.4. The study objects could include participant responsiveness (if they are actively considering each other's suggestions or only engaged with their own ideas, cf. van der Lugt, 2005), as well as the linkages between ideas, their further development and how they relate to the creation of the final design object. However, even if eye-tracking sounds promising, the results need to be approached with caution. On the one hand, gaze is heavily involved with the social aspects of interaction, influenced by sociopsychological and cultural factors. On the other hand, the relationship between the fixation of the gaze and information uptake is complicated: fixation does not necessarily signal information uptake, and information uptake from a gesture is not limited to fixations but can occur within the area of peripheral vision (Gullber, 2016, p.118; Gullberg & Kita, 2009). Moreover, when studying gestures in collaborative designing—in interaction focused on the creation of the emerging design artefact and spiced with sketching or material modelling—the direction of the gaze does not necessarily follow the rules of a conversation pure. Future research will reveal if the latter point complicates or simplifies interpreting the results. In any case, I believe that eye-tracking could provide new insights, in addition to the insights relevant for gesture research, on linkages between design moves of various modalities, as well as on the division between explicit and inexplicit design thinking. The challenges encountered and the new insights gained would then guide research in further directions.

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