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## Material knowledge in collaborative designing and making

A case of wearable sea creatures

### **Abstract**

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

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

### **Introduction**

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

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

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

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

Creative collaborative efforts to build knowledge and to design artefacts are often associated with the adaption of new *vocabulary*: Proper nouns replace common nouns, and more accurate terms and professional terms replace vague and descriptive expressions (Kangas, Seitamaa-Hakkarainen, & Hakkarainen, 2013); vocabulary grows with the adoption of more specific expressions. Yet, in design conversation, the words one uses reveal many things, not just the level of material knowledge: the level of detail with which the team is working (that is, a measure of progress); if the planned features are easily translated into material form (i.e. shiny vs. fearsome); if the aspired-to expression is tacit or lexical in nature. The selected expressions could even be a part of the negotiation tactics or indicate the level of

agreement that the team members have reached (or failed to reach). In design, decisions are made, and immature details—whether from the viewpoints of design premises, (material) knowledge or group processes—remain open; meanwhile, working hypotheses are established and worked with. The process requires both general and specific expressions.

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

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

## **Setting: Designing and making wearable sea creatures**

### ***Structure and approach of the assignment***

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

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

The support structure, on the one hand, assured that the novice teams focused their attention on pertinent aspects of designing and making, but, on the other hand, granted the teams a degree of autonomy to innovate and prioritise the given premises. The support

structure, as well as designing and making assignments in general, can be considered a manifestation of the *design mode*, where knowledge and ideas are approached as objects of creation and advancement, extension and application rather than as objects with a given truth value (which is characteristic of belief mode, typical of traditional educational activities) (Bereiter & Scardamalia, 2003). In design mode, the pivotal concern is the usefulness, improvability and developmental potential of ideas in relation to the design challenge at hand (Bereiter & Scardamalia, 2003).

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

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

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

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

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

Table 1. Data corpus for the present study.

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

### Analysis methods for shared material knowledge

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

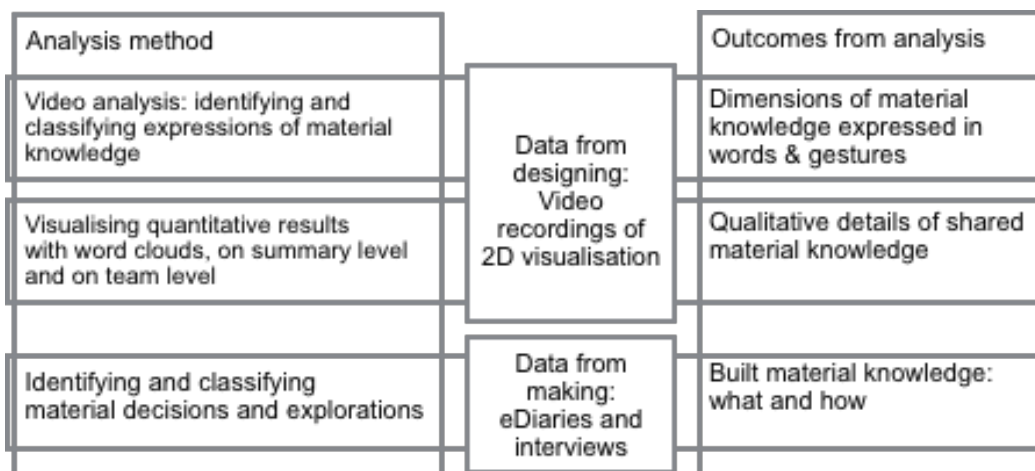


Figure 1. Analysis methods, target data and outcomes.

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

#### ***Analysing the teams’ expressions of material knowledge while designing***

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

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

(e.g. turn-at-talk responding to the gesture), and (4) the purely kinesic characteristics of the gesture (Enfield, 2009, p. 9).

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

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

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

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

In our data, ‘naming’ also occurred by referring to objects (e.g. ‘we could use a non-slip bathtub mat’) and techniques (e.g. ‘like crocheted’) or by gestures (e.g. by pointing). Our

class of ‘behaviour of material’ includes both original categories of ‘technical qualities’ and ‘behavioural qualities’, as behaviours were usually derivatives of technical properties. Instead of holding just one class, ‘sensory’, we divided it into two parts—‘sensory-visual’ and ‘sensory-tactile’—to understand more clearly the types of experiential knowledge expressed. A third part, ‘sensory-spatial’, accounted for the strengths of gestural expressions. Our teams made ‘valuations’ rather than expressed ‘emotions’, and no statements described the ‘typical use of the materials’.

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

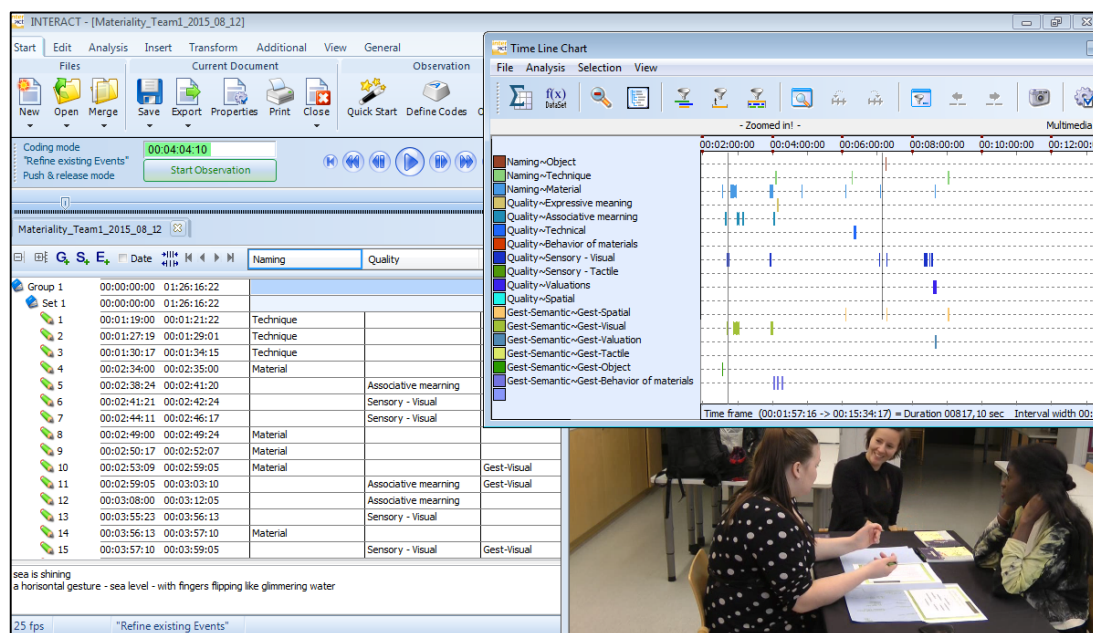


Figure 2. Using INTERACT software for the video analysis.

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

### ***Analysing the building of material knowledge via material decisions and explorations***

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

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

### **Findings on material knowledge shared within the novice student teams**

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



### ***Shared material knowledge expressed in words and gestures***

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

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

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

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

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

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

### ***The ‘naming’ dimension in detail***

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



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

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

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

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

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

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

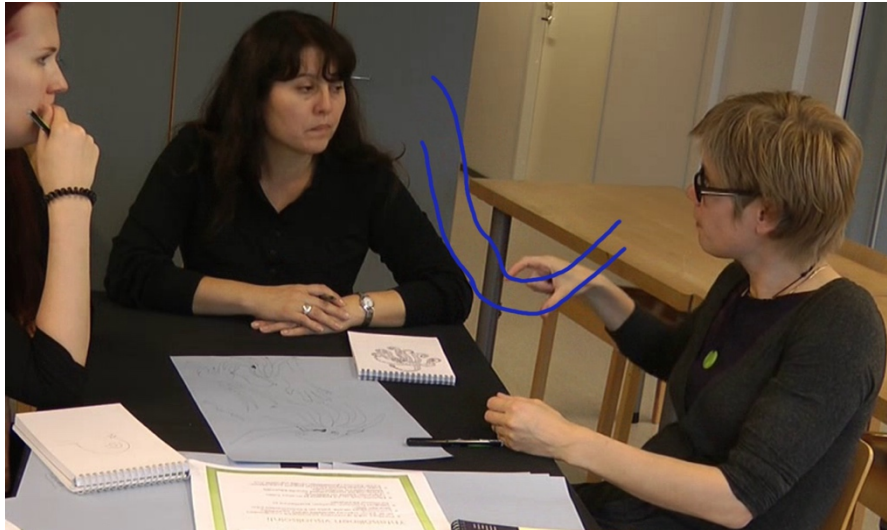


Figure 5. Team 3, a proposal of a strip representing octopus ink, 0:14:13–0:14:16.

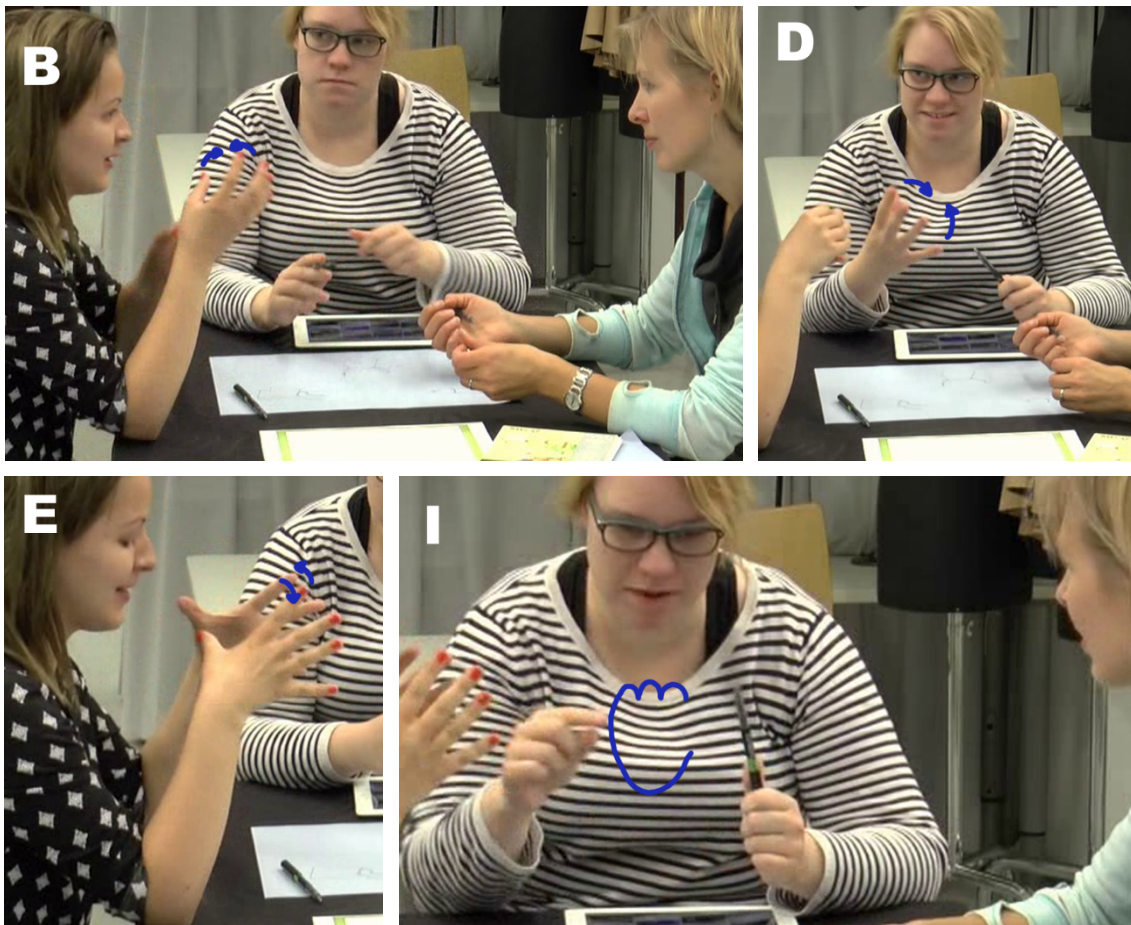


Figure 6. Gestures related to fluffy balls; see transcript on the next page.

Conventions used in the transcript:

(w) = expression in words

(g) = gestural expression

(Sf g) = speech-framed gesture

text in bold = expression of material knowledge

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

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

Laney suggested that they could use some non-textile materials (1.1) and began to describe an object, a fluffy ball. First, she lifted her right hand, pressed her fingertips together, and began to quickly open and close her grip, stretching her fingers (AAA): She identified the object by

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

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

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

### ***The ‘behaviour of materials’ dimension in detail.***

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

Many of the longest expressions came from Team 1. They also produced more gestures to describe ‘behaviours’ than did the other teams, and they used more descriptive language—speech and gestures—than did the other teams. Team 2 was at the other extreme: Their conversations on the behaviours of the materials were rather short and ‘technical’ in nature, focusing mainly on evaluating the looseness and stretchability of the ribs and on how to make sufficiently stiff fins for the shark. The use of different kinds of expressions may reflect, at least partly, the teams’ different approaches to an authentic user experience. Team 1

aspired to a strong impression of the sea, waves and shining water, an impression where materials played *more of a mediating role than a representative role*. Again, Team 2 focused on a sea creature, an epaulette shark, and on how to mould and paint leather to create a leather accessory that looked like a real shark—a very practical and ‘material’ challenge.

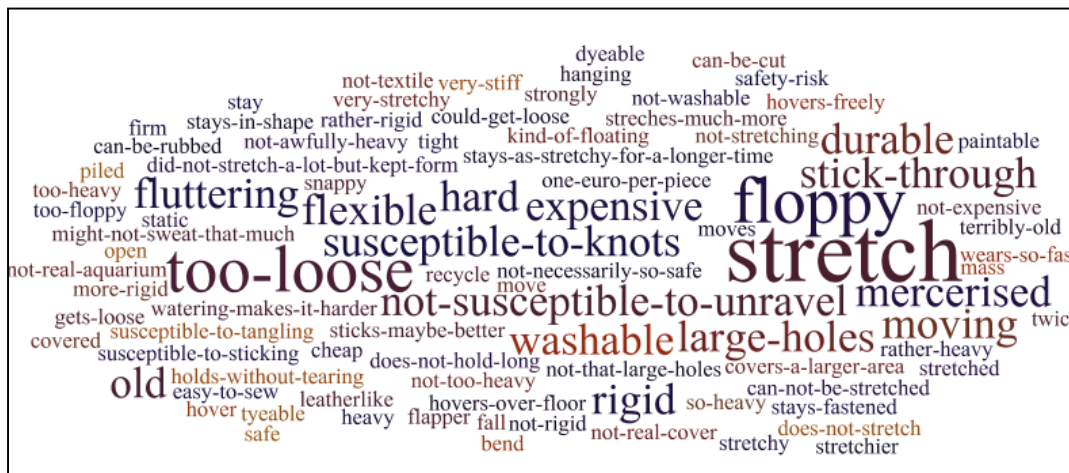


Figure 7. Word cloud visualising shared material knowledge in the ‘behaviour of material’ dimension.

### ***Building material knowledge during making***

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

Table 6. Objectives for material decisions and explorations.

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

The reported objectives (Table 6) suggest that the teams focused most of their attention on ‘selecting a material’. The second place involved ‘practicing a technique’, while a fairly small amount of attention was focused on tools (usually a notorious overlock sewing machine) and combinations of materials. *This order reflects the nature not only of the new material knowledge needed but also of the material challenges the teams took upon themselves*: Most

ideas focused on creating authenticity with the materials themselves, not heavily processing them. An interesting trend in material selections was that even if all of the teams discussed—whether only briefly or in more detail—non-textile materials, such as ‘led strips’, ‘optical fibre’, ‘plastic pipes’, ‘iron wire’ and ‘Styrofoam balls’, none of the materials named were tested or used in the making phase. Only a few solutions outside the world of textiles and beads, such as pipe insulation for creating the 3D form of the shark (Team 2) and soap pads for the octopus’ suction cups (Team 3), were tested. The techniques selected were either familiar (e.g. Team 1 with fish netting; Team 2 with crocheting; Team 4 with using a glue-water mixture to stiffen yarn) or taught at the time of the assignment (sewing and sewing with an overlock machine). The one exception was Team 2, with their techniques of leather moulding and painting. In other words, the teams approached material knowledge as a tool to address the challenges of making, not as an end in itself.

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

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

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

*Usually the solutions were accepted because the ideas were considered fit for purpose.* The teams did not, in general, specify in detail the criteria applied during evaluations, which might implicate that at that point—in the making phase—the team members had already internalised the criteria so well that they saw no point in explicating them. Yet, the selection process could be rather pragmatic, especially *when materials were not a key part of the user experience*: The teams often selected materials that were *easily available and fitting enough*. Such pragmatism



is understandable considering the tight timeframe under which they were working. On the other hand, they laboriously hunted for key materials across the metropolitan area, from diverse flea markets to the Reuse Centre, and tested key features again and again; the teams possessed ample ambition when it came to pursuing important parts of the aspired-to user experience.

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



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

## Discussion

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

We found that material knowledge was frequently expressed in conversations, and practically all material aspects of any importance were tested prior to their actual implementation; the student teams used material knowledge as a tool for designing and making, and they took on the challenge of building new local material knowledge seriously. Furthermore, in our results, modalities indeed became specialised: Words contributed mostly

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

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

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

conclude, the teams took on the challenge of authenticity and created demanding 3D structures on a small budget and within a tight timeframe while pragmatically prioritising the number of challenges they took on and the resources available to them.

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

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