11 Scaffolding visualization and mental rotation in designing and crafting

Marte S. Gulliksen and Camilla Groth

Introduction

Visual mental imaging has been studied largely in the field of cognitive science (cf. Kosslyn, 2005) and relatively less from a design or craft perspective. As opposed to visual perception – which is what we see when we look at an object – mental imaging is the visualization of an object when we do not look at it. We can imagine the visual appearance of something that we have not seen yet and what it would look like when rotated in different angles. Mental imaging is one of the most important aspects when designing and crafting 3D forms, and in this chapter, we open some of the issues that researchers talk about in relation to imaging, while also sharing some insider perspectives from a craft case.

Much attention is currently being devoted to the concept of imagination in relation to general embodied cognition (EC) and issues in action knowledge or skilled work (Ingold, 2021; Koukouti & Malafouris, 2020; Rucińska & Gallagher, 2021; van Dijk & Rietveld, 2020). The idea of mental representations and mental models is contested in EC theories (Baber, 2021; Newen et al., 2018, p. 8; van Dijk & Rietveld, 2020). However, researchers have lately discussed imaging as other than visual representations and generated insights into how such visual mental images are, to a large degree, grounded in a person's previous kinaesthetic and cultural experiences that also enable the imagining of future scenarios (Gallese & Lakoff, 2005; Iachini, 2011; Ingold, 2021; Schilhab, 2011, p. 319; van Dijk & Rietveld, 2020). Schilhab (2011), for example, proposed that "understanding is obtained by borrowing and transferring embodiment in the form of re-enactment from previous first-person experiences" (p. 311).

In our approach, we acknowledge that the issue of mental images is too complicated to be discussed from only one theoretical perspective. Rather, it is helpful to take on several perspectives to make a more comprehensive image. As Chemero (2013, p. 149) held, it seems "prudent to adopt a pluralistic stance" towards theorizing, and doing so might give a fuller image of complex issues, welcoming the fact that an extreme view of cognition might not give all answers. Thus, we have here related to research on a broad spectrum while giving a background for the discussion of the case example.

The idea that visualizations are grounded in previous experiences is not new as several researchers have pointed to this connection earlier (Ahsen, 1984; Keller & Keller, 1999). Even researchers writing within a representational theory of mind agree that visual mental imagery is based on stored memory of previous visual perception (Kosslyn, 2005; cf. Koukouti & Malafouris, 2020, p. 39). Also, cognitive linguistic researchers have argued that some of the same parts of the brain used in seeing are also used in visual imagination

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(Gallese & Lakoff, 2005). Mental images are according to Keller and Keller (1999) building on previous experiences of joint activities and cultural connotations. Even aspects that have not been experienced personally may be imagined based on previous encounters of visual images or stories told by others. This is not to claim that there would not *also* exist imaginative creative assemblages and views that are entirely made up, such as dreams. However, when it comes to crafting in a material, imagination is often related to the restrictions of the material reality, that is, the material properties and their limitations in terms of affordances, something that especially the experienced craft practitioner is aware of (Koukouti & Malafouris, 2020). Enacting and simulating possible material and real-life constellations help imagine future actions; for example, a chess player might better imagine the consequences of a move by lifting the chess piece and moving it in the air to the planned place (Kirsh & Maglio, 1994).

Mental images are not necessarily just visual but can also be multimodal and somatosensory, for example, haptic or kinaesthetic, auditive or olfactory (Kosslyn, 2005). We can imagine what something might feel like or what kind of movements we could do with our bodies. By enacting possible bodily actions, it is easier to foresee future actions such as dancing steps or routes for climbing a wall. Rucińska (2021) discussed the manner in which climbers preview their routes for climbing a rock wall and showed how they engage in what she called "enactive planning" as they make their "corporeal imaginings" by visualizing their bodily positions on the route before and during their climb. Rucińska further proposed that such visualization is a form of "doing" even if the body is not in motion at the time. Similarly, when designing a coffee cup, it is important for designers to imagine what the cup should feel like in the hand, how heavy or light it should be, how it is balanced when lifting, and the best size for it.

We will not get deeper into the *general* discussion on creative and freely unfolding imagination here. Rather, we will in this chapter particularly discuss the imaging and visualizing of shapes for making 3D objects. We broadly define our topic of visualizing images as the ability to generate, recall, maintain, and manipulate visual or multimodal shapes in an imagined space (Hawes & Ansari, 2020, p. 466). We claim that when foreseeing future material engagements, it is equally important to draw on previous experiential knowledge of material properties, affordances, and construction to make realistic mental visualizations. The reason for such a visualization and imaging activity is closely connected to the ideation stage in the very beginning of a design or making process and the inspirational sources that give a spark to the ideation.

The image takes shape

When inspired to make something, the idea does not pop up in the head of the designer or craft practitioner out of the blue; rather, the process starts much earlier than that, in previous personal experiences and an inspirational source (Laamanen, 2016, pp. 12–13). Whether the inspiration is drawn from an interesting material, a concept, a poem, or someone else's creative work, the practitioner develops ideas for how to realize this in a material form. Mental images, or visualizations of ideas for shapes or functions, feels or atmospheres, colours, and tastes, are thus fundamental for craft and design practices. The imagined visualization is something that the practitioner keeps in their mind during the process, even if the realized artefact seldom turns out as the first imagined visualization due to the situated and reflective process that unfolds in the material interaction when making it (Ingold, 2013, 2021; van Dijk & Rietveld, 2020).

The image may be fuzzy and inexact to begin with, and further influenced and changed along the way (Baber, 2021, pp. 155–157). Ingold (2013, p. 71) likened this chasing of the imaginary idea to a composer whose musical imagining flies faster than his ability to pin it down in his notes. Mental images rely on working memory, but this memory is short lived and cannot keep up with the evolving pace of what is imagined – the image, feel, or notion is easily lost. This is not to say that it is necessarily unrealistic. Koukouti and Malafouris (2020, p. 40) reminded us of the materiality of imagining and that imagination happens in a dynamic relationship with the world, rather than just inside the head, always in relation to the ways in which we actually relate to aspects of our material environment. When meeting the material constraints in the actual making of an artefact, the imagined image again needs to be refined and better aligned with the material reality (Zeisel, 1981/2006, p. 26). New affordances that are "unlocked" along the process of making may inspire new directions for the image to reshape (Kimmel & Groth, 2023). Not only is the imagined shape invisible to others, but it may also be lost even to the practitioner. Therefore, making a drawing of the imagined shape is common for externalizing the mental image.

However, the process of externalizing an image is not exact either. Novice practitioners, especially, may experience difficulties in drawing the envisioned image before their eyes, possibly due to the fluctuating, temporality of the visualized image that they are unable to keep constant until it is drawn, their untrained hand-eye coordination or drawing skills, or their inability to imagine the materiality of the idea (cf. Frisch, 2010). It is also well-documented that drawing is a form of thinking in itself, during which shapes that are drawn also start influencing the drawing in a new direction, and thus the engagement with the drawing is not following a predetermined plan even if the practitioner would aim for a certain shape that they have in their mind (Ingold, 2013, p. 128; van Dijk & Rietveld, 2020).

Within design research, there has been extensive work put into communicating design thinking processes, from broadly describing the entire process to specifically examining the embodied dimension of designers' or architects' professional practice (Groth, 2017; Höök, 2010; Hummels & van Dijk, 2015; Rietveld & Brouwers, 2016) and how thinking, imaging, and making are not consecutive actions, but combined (Gedenryd, 1998; Poulsen & Thøgersen, 2011). Rietveld and Brouwers (2016) especially described the skilled intentionality of an architectural team searching for an *optimal grip* on the imagined designs the team is visualizing, i.e., forming a clearer understanding of the best possible solution to the design problem.

This search for a *grip* as in a better understanding of the optimal design is familiar; especially, design students know the importance of material exploration, both in the ideation and formation of embodied knowledge of materials and related affordances (Laamanen, 2016). Novice practitioners may feel discontentment when their mental image of a design is not working out in practice, meaning that their expectations are not met (Groth & Mäkelä, 2016; Zeisel, 1981/2006, p. 23). In renegotiating one's expectations through material manipulation and experimentation, the visualized image becomes better aligned with the material reality (Zeisel, 1981/2006, p. 26). Laamanen (2016) found that bodily experiences were part of creating mental images in design ideation. Also, Ahsen (1984, as cited in Laamanen, 2016) rejected purely representational theory in his triple code model that he called the *ISM* (Image-Somatic-Meaning) as without the bodily response in the experience of the image, the world would appear as a mere surface impression (p. 22).

As noted already, imaging is developed through physical interaction with and through activities and materials, such as drawing, prototyping, or material explorations

(Hengeveld & Frens, 2013; Koukouti & Malafouris, 2020; van Dijk & Rietveld, 2021). But what happens if your ability to imagine a 3D shape is fading away?

Several studies have explored the role of the body in interaction with the material environment as support of mental imaging. For example, Kirsh and Maglio (1994) studied participants doing mental rotations in an interactive video game called *Tetris*. They found that the participants started rotating before they anticipated the best fit for the falling shapes into the relief of the game, thus actively exploiting the environment to make the most of their limited cognitive resources, rather than relying on a "planning first" strategy. By "changing the world" through "epistemic actions", the participants were able to simplify the problem-solving task (Kirsh & Maglio, 1994, p. 515).

Similarly, acting in materials by making material mock-ups or prototypes helps externalize and thus supports mental imaging and visualization (especially mental rotating) by offloading cognitive capacities in the environment – a proposition that is aligned with the extended mind thesis and distributed cognition (Baber, 2021, p. 38; Clark & Chalmers, 1998). Craft and design practitioners use a wide variety of techniques to support mental imaging and especially rotation throughout the entire process of making, such as drawing and prototyping, or through using 3D computer-aided design (CAD) software. In this chapter, we focus on *human* abilities of mental rotation in manual craft practice and examine mental imaging and visualization in direct material manipulation by hand and hand tools. We further discuss how the visualization and mental rotation ability in humans differs among persons and how it can be trained, or even lost.

Visualization, mental imaging, and mental rotation

Before we present the case example and describe its activities and experiences, the following concepts need a short introduction: spatial visualization; mental rotation; sense of space; spatial modelling; and visuospatial working memory.

Spatial visualization becomes important because mental imaging is linked to our *sense of space* (Groh, 2014), as what we visualize often has three dimensions or are imaged in a virtual space. While spatial visualization describes the ability to imagine moving ourselves and objects in a three-dimensional space, sense of space is used as a broad term to incorporate both mental imaging of a space and our physical being in a physical space here-and-now. In the case example, the practitioner's ability to envision both her arm and the piece she was carving on was compromised, and thus she reported having issues with these aspects of spatial visualization.

Spatial visualization skills include *visuospatial working memory* – the ability to recall spatial information, i.e., drawing upon knowledge of and experience with an existing object in the world, or manipulating knowledge of a viewed object or illustration to imagine how the object will look when turned upside down or seen from behind (Hawes & Ansari, 2020). They also include *spatial modelling* – the ability to generate spatial information, i.e., imagining shapes not yet there or generating novel constructional solutions.

Mental rotation is a task-specific type of mental imaging where the imagined object is rotated or turned around some axis in an imagined three-dimensional space. It can also refer to processes where tangible objects we physically interact with are imagined as seen from the other side. Mental rotation skill is highly dependent on working memory, because, in order to mentally rotate, we need to keep in mind one position of the imagined object while also thinking of how it would look in another position (Zacks, 2008).

Next, we present a concrete example of a fluctuating ability to visualize and rotate 3D shapes, through an autoethnographic case of an experienced wood carver and the first author of this chapter, Marte S. Gulliksen, who temporarily lost parts of her ability to do mental imaging and mental rotation.

Case presentation

The events took place from December 31, 2017, to September 1, 2022. The most crucial part of the case happened in January and February 2018. A full-length description of this phase in a narrative inquiry style has been published in Gulliksen (2021). As this case is based on autoethnographic data, we switch to tell the story from Marte's first-person perspective.

In my artistic work, I have for a long time been inspired by the shapes of neural structures in the brain. Also, this time, I began my carving process with the ambition to develop two sculptural objects with interlocking forms inspired by the Purkinje cells in the cerebellum. These are neurons that are characterized by a highly complex dendritic arbour shape. In my imagined design, each object would have small golden bowls in the centre, hinting towards a cell nucleus. A thin form, like an axon, would stretch out from the centre-bowl in one end and from the other end, interlocking forms would meander out like the Purkinje cells' dendritic arbours (Figure 11.1). My aim in this project was to

Figure 11.1 Purkinje #2 and Purkinje #3, the two carved objects in *Purkinje Serie* that I was working on during this period. Photographs by Marte S. Gulliksen.

explore how I could create this complex dendritic shape in the chosen material – aspen wood. These objects would be part of a planned *Purkinje Series*.

I had always mastered mental imaging, in particular spatial visualization, to a high degree. So, when embarking upon this process, I was used to ideating in a three-dimensional space and visualizing what my ideas could look like in a material, and I had always relied on that skill throughout to successfully carve intricate forms.

During the first weeks in the wood shop, after splitting a 25-cm-diameter aspen log in two halves, I was carving on the first half based on my initial idea, negotiating with the wood's hidden branches and fibres. I then drew a tentative design on the top of this piece of wood with a pencil and started carving according to the lines. Within only a few days of carving, I realized that something was wrong with my mental imaging skills and my sense of space. I especially struggled to follow one form around the log when turning it around, i.e., my mental rotation was much more challenging than usual. By the second week, I got "lost" when I turned the sculpture upside down and could no longer recognize the form at all. Usually, this is how I check if I am on the right path in my carving – I turn the piece around, and as I remember what I just saw on the front side, I can make plans for how the shapes would continue and look like on the back side. Now, finding the guiding directions of the grain in the wood was gradually more challenging, leading to making rookie mistakes while cutting in the material with the gauge tools. Later, in analysing successive video and audio documentation of my other carving sessions, it is possible to understand that there was something fundamentally wrong with my mental rotation and my visuospatial working memory at this time (see also Gulliksen, 2021).

At the time I did not know why this was happening, I was confused but still insisted on continuing carving. The pragmatic solution I chose for overcoming the problem was to copy the form as seen from above the object onto a paper and mirroring it by holding the drawing up to a window. This drawing aided me in my visualization of how the shape would look from below – something that I was unable to imagine unaided at the time. As this was still not enough for making decisions on the cuts with my tools, I cut out the drawn shape from the paper, making a template that could be attached to the underside of the half-log and drawn onto the wood by following the edges of the paper template. This action "scaffolded" my process in the sense that the template functioned as a form of distributed cognition, helping me through cognitive offloading. Figure 11.2 shows one of the paper templates used as well as part of the work in progress. Despite this scaffolding, I got tired much more easily than normally from the effort of doing these spatial visualization tasks. I decided to stop working on this first object and instead begin carving on another, using the second half of the log. I purposely made this second piece less complicated, so that I would need less effort when imaging it.

At the same time as I experienced these visualization problems in the wood shop, I also started to experience spells of dizziness in other situations too. These intense spells, occurring about once a week and lasting only five to 15 minutes in the beginning, were accompanied by disturbances in my right visual field and I had the perception of my right hand being dislodged 15 centimetres to the left from its actual physical location. Within the next month, I was diagnosed with a brain tumour. As I was to find out later, an oedema covered my sensorimotor and visual cortices as the tumour grew in the left parietal lobe of the brain, all of which are central parts of the neural correlates of visual imagery vividness (Fulford et al., 2018) and mental rotation (Zacks, 2008). Shortly after

Figure 11.2 Purkinje #2 in-progress and a paper template used as a scaffold to aid in mental rotation, January 2018. Photograph by Marte S. Gulliksen.

the surgical removal of this tumour, both the dizziness spells and the error in sense perception were gone and my mental rotation skill was restored. The experience was naturally shocking; however, my method for recovering from this experience was to do what I love the most and so I returned to finishing both sculptures that I had left unfinished (cf. Gulliksen, 2023).

In the video and audio data of woodcarving that I, as a craft researcher, collected from this post-surgery period, one main topic for me was about explaining how "natural" it felt to do mental imaging, to do spatial visualization, and to mentally rotate objects. If these abilities had not been temporarily gone, I would never have realized that they were skills I normally mastered well. They were elusive and only became apparent to my conscious self when they were absent.

In the years after these first two intense months, I continued to study my own spatial visualization ability and to train my mental imaging skills. To date, I have finished six single and three interlocking sculptures in *Purkinje Series*. As seen in Figure 11.3, the forms in the series have become increasingly more complex – from the fourth sculpture, the dendritic branches have begun moving freely over and under one another. Purkinje #7 and Purkinje #8 have two interlocking parts, a "bottom" and a "lid" for the centre "nucleus" bowl, each made from one singular log. Purkinje #9 is also an interlocking form but has three parts and two hollowed out bowls or "nuclei". All three parts are made from one single log.

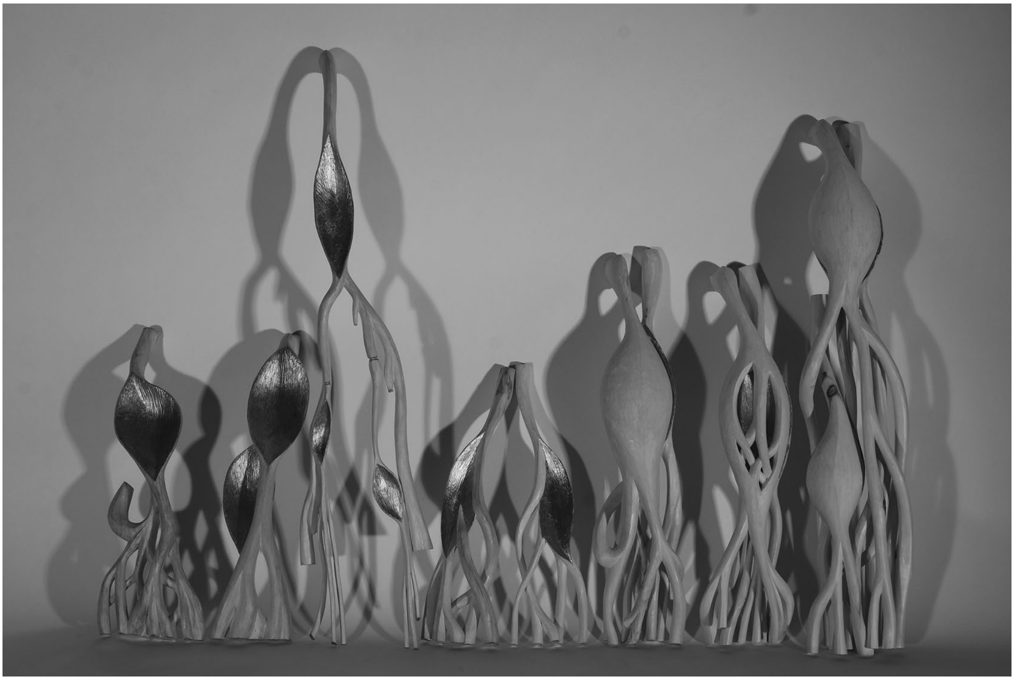

Figure 11.3 Purkinje Series, from left: Purkinje #2, #3, #4, #5, #6, #7, #8, and #9, carved in 2017–2021. Photograph by Marte S. Gulliksen.

In the last period of this case example from February to September 2022, I carved sculptures inspired by the star-shaped astrocyte cells that live adjacent to the Purkinje neurons in the brain. In this series, I took three-dimensional mental imaging to its extreme, carving out star forms across the grain of the wood. These objects are also carved from one log and are split into two parts: a "bottom" part with a "lid" part on top (Figures 11.4 and 11.5). The cancer has not yet come back despite the gloomy outlook, and I have managed to carve these complex forms without any major problems.

Discussion

In our woodcarving case, Marte reported losing her ability to visualize what she was doing in three dimensions and said that she "got lost". This incorporated *both* her ability of carving in the physical world *and* that of forming and maintaining the mental image of what the form should look like and how it would look when turned, in her "mind's eye".

More specifically, she experienced problems when attempting to mentally rotate the piece she was working on. She could not act on this lack of "grip" on the situation as it was a physiological condition she could not change. Her most acute problems occurred when she turned the wood to see it from the yet uncarved backside and needed to visualize how to carve it in order to correspond to the shapes on the front and how they would move and turn around on the backside.

Marte usually experienced quite vivid imagery and was confident in her ability to mentally imagine shapes when working with wood. That was also her inspiration and the reason why she began such a complex task – she liked to challenge her skills in this

Figure 11.4 Astrocyte #1 and Astrocyte #2, both carved in 2022. Photograph by Marte S. Gulliksen.

regard. However, when this ability suddenly disappeared, she was surprised. The fact that she was surprised is a relevant point, as even though she knew she was competent in mental imagery, she was not consciously aware of the ability as such – this was just a part of who she was. When the skill returned, she felt it natural to be able to do mental imaging as before. She could realize that she had such an ability only because it had temporarily been missing.

There is now research documenting that the cognitive process of mental imaging plays out differently for different people. For some, such mental imaging is vivid and almost like viewing an internal video where you can move around and zoom in to see details. Others have aphantasia, meaning that they do not experience internal images at all (Fulford et al., 2018; Zeman et al., 2010). In-between these types, humans live with their varying degree of abilities to visualize or imagine something that is not there right now or yet (Kind, 2017).

Doing mental visualization is generally a complicated and exhausting task; however, much mental imaging skills can also be *trained* (Moreau et al., 2012). The trainability of such skills is relevant to understanding mental imaging as an embodied process in design practice. For example, when spatial modelling can be trained through neuroplastic processes, it is likely to assume that the experienced wood carver or ceramicist would be skilled in their mental imaging of carving or throwing, similarly to what is found in Maguire et al.'s (2000) well-known example of taxi drivers in London who had an enlarged part of the hippocampus related to spatial navigation, or Elbert et al.'s (1995)

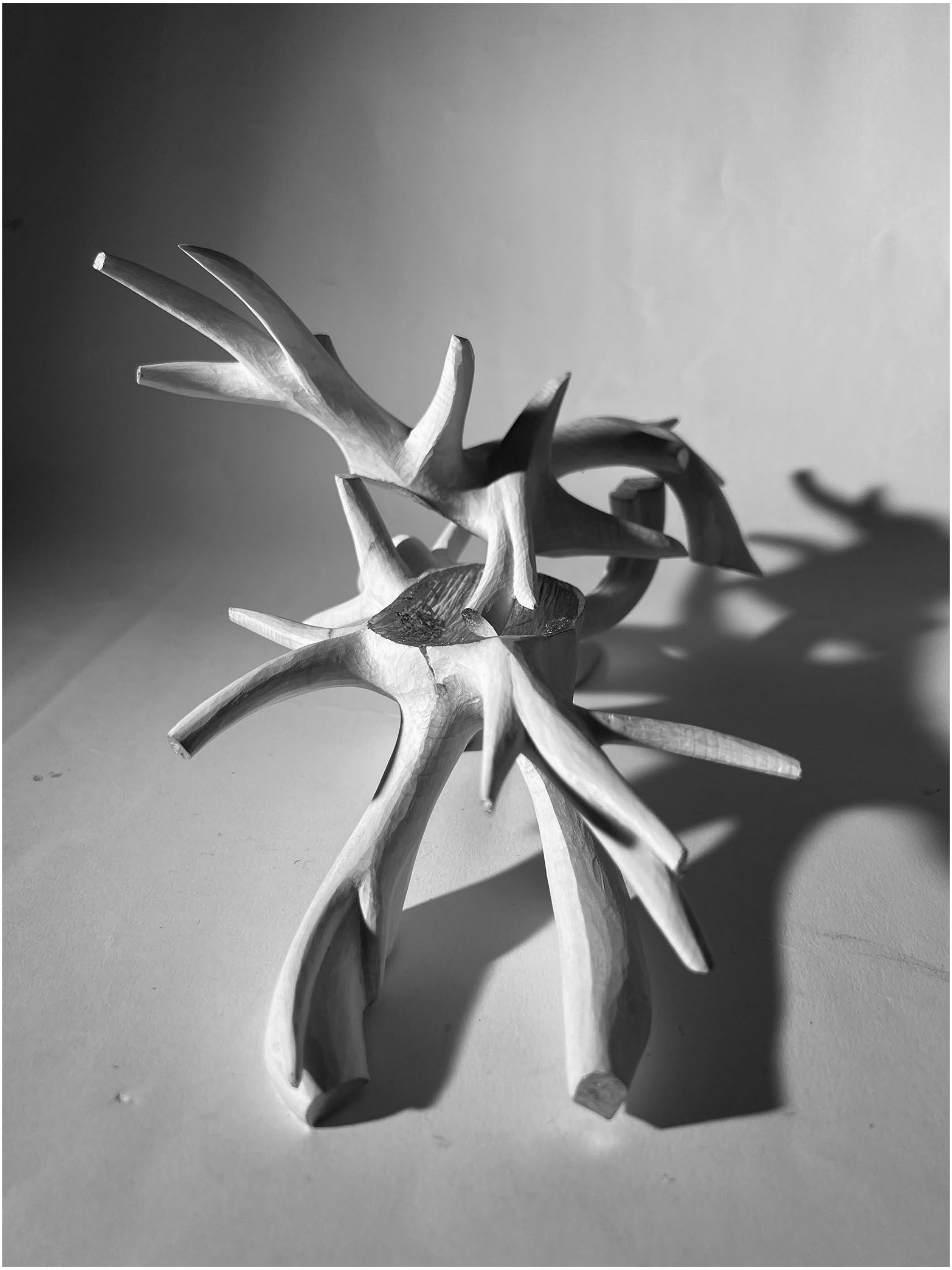

Figure 11.5 The side view of Astrocyte #1 showing an open "lid". Photograph by Marte S. Gulliksen.

study of string musicians who had increased cortical representation in the areas tasked with sensorimotor activity in the left hand. Pietsch and Jansen's (2011) study even finds that people who often do physical training or play a musical instrument are better at mental rotations too, just because they activate similar skills in their other hobbies. Based on these studies on neuroplasticity, we would expect differences in individual practitioners, as every maker has unique life and making experiences that consequently change their plastic brains.

In our extreme case, Marte employed deliberate, external techniques to "keep in mind" and remember what is on the other side of the object since her working memory could not support her mental rotation. She drew lines on the physical object to hold her ideas, and when that failed, she created a template on paper. The physicality of the template provided a kind of mental crutch or scaffold, grounding her mental rotation in a physical world and making the rotation of the mental image tangible. Although this paper template only held information in two dimensions, it sufficed, at least to the point that she could continue the process of carving, thus offloading her strained mental capacities and offering a way forward through epistemic action (Kirsch & Maglio, 1994). By doing so, she explored the environment for opportunities to distribute her cognition to a physical object which could facilitate her process (Clark & Chalmers, 1998; Kirsch & Maglio, 1994). Things like paper templates are used to scaffold cognitive tasks both individually and in groups (for a discussion of the use of physical objects to scaffold sense-making in groups, see van Dijk's Chapter 13 in this book).

Experiential knowledge is needed in the imagination and ideation processes of new designs

As mentioned earlier, experiential knowledge of material properties and affordances are important for a successful ideation process that yields realistic outcomes. This includes recalling not only a mental image but also physical properties and social connotations of materials and their feel in the selection of materials for a design. For example, Groth and Mäkelä (2016) documented a student reporting, "I was imagining mostly in my mind what the different materials would look and feel like" (p. 16). The student in question had prior experiences with other materials, due to a previous artisanal degree, and could bring the experiences to the forefront of her mental imaging and use them to choose materials. However, another student in the same group was unable to imagine how the materials he planned to use would work and as such failed to make a concrete artefact based on his idea. This second student admitted he had very little prior experience with making anything in material (p. 18). This thought about the importance of experiential knowledge in imagination and ideation processes is supported by Koukouti and Malafouris' (2020) understanding of material imagination and the relation between the craftsperson's knowledge of material affordances and the real world that is present even in the craftsperson's imaginative wanderings.

Knowing that some of our mental imaging abilities are malleable and thus possible to train and develop, there is no surprise that some people are better than others in different practical skills. Another issue related to how we access this prior experiential knowledge when doing mental imaging is that, even though it is always available, it might not always be accessible to our conscious selves. What steps could we do to support access to such types of elusive knowledge? Studies in other fields, such as gestures, have found that if subjects had their hands restrained from doing physical movement, like making gestures or manipulating objects, they score lower in mathematical thinking and verbal accuracy (Novack et al., 2014). Similar studies have been done within design and craft; for example, if we give students materials to think with, they get more concrete in their discussions, both when working alone and in groups (Härkki et al., 2016). This suggests that priming with material would help enacting and accessing experiential material knowledge in the process of imagining possible constructive solutions or ideation and gaining an "optimal grip" on the situation. The need for scaffold-thinking through external physical aids is especially clear in research into children's craft and design processes (Kangas, 2014, p. 61), as they have generally less experiences with material interaction. However, this is equally important for design students (Lawson, 2004).

What does this mean for design education?

Understanding the embodied nature of the phenomenon of mental imaging is critical in today's digital era. The materiality of our environment is changing rapidly, and virtual 3D designing and making processes are becoming the norm. Now, any designer can use 3D artificial intelligence (AI) that allows for the creation of unimaginable images and 3D shapes. However, when it comes to designing utensils for use in our daily life that we handle physically, tangible aspects, such as tactile feel of material surfaces, weight, balance of the piece, and thickness or thinness of it, make a difference for the quality and feel of the product. While digital tools such as 3D programs aid mental rotation, they do not help novice design students anticipate the "right" feel, weight, or size of their designs. If the experiential knowledge of materials is not gained before starting to design in a virtual space, it poses challenges for the mental imagination of the experiential aspects of the design, as the reality of materiality can come as a surprise. Digital tools are also only as accurate as their designers, meaning that the programmes also build on the designer's ability to mimic the real-life experience (Hengeveld & Frens, 2013).

Ramduny-Ellis et al. (2010) worried already more than a decade ago about their students' material knowledge and real-life material interaction skills in relation to the new virtual reality that their design students face. They said, "as hybrid physical/digital products are developed, designers have to understand what is lost or confused by this added digitality and so need to understand physicality more clearly than before" (p. 51). This perspective reveals the necessity of experiential knowledge that is gained through the making of physical prototypes in an iterative manner, even when using CAD tools (Kempton et al., 2017).

Strand and Lutnæs (2022) described five strategies that a teacher can use to support students' development of mental imaging in architecture, or what they call "spatial literacy", including (a) "facilitating embodied experience", (b) "activating memories and dialogue on spatial relationship", (c) "encouraging three-dimensional visualizations", (d) "introducing points of reference", and (e) "connecting floor plans to standards and measurements" (pp. 43–49). Although Strand and Lutnæs did not address EC as such, these strategies incorporate embodied experiences and material interactions, helping novices to cope with the complexities of their designs. Also, Lawson (2004) specified how novice designers differ from experts, in the way that experts can utilize their matured "schemata" and "gambits", which novices have not yet developed, to solve problems.

Such stored repertoires of experiential knowledge and well-tested ways of doing things that experts have built up over time underlie their ability to imagine design situations realistically (See also Baber, 2021, pp. 168–169; Rietveld & Brouwers, 2016).

Consequently, sufficient experiences of material explorations leading to experiential knowledge of material properties and affordances help novice designers and craft practitioners visualize their design or craft ideas better and more realistically before and during their making, even when using CAD or other 3D modelling programmes. The current trend of replacing physical workshops with computer-aided tools and software might be cost efficient but does not help students get the correct training and exposure to materials and their resistances, affordances, feels, and atmospheres.

Conclusion

In this chapter, we have presented theory and an empirical case example of how visualization, mental imaging, and mental rotation play a major role in design and craft practices. However, we have also found that individuals vary in the degree of ability or skill which depends on their prior experience and that mental imaging skills and visualization can be trained. Based on the case presented, we show that this skill can be lost because of an injury or illness – a loss that may be permanent or temporary pending the nature of the injury. There are also several situations in design and craft practice where mental imaging and mental rotation are not enough and where scaffolds or externalization of mental capacities or tasks are needed, even for healthy individuals. For example, for children who have relatively less experience of manipulating materials and visualizing shapes, such external scaffolding might be useful.

The understanding of how important this ability is for design and craft processes makes it necessary to allow students to train such abilities through sufficient material manipulation, rather than move on to using computer supported aids too soon. While 3D and CAD software can do all the mental rotations we need, this technology is also limited in its interface and affordances and does not allow for multimodal aspects of imagining materials and their feel. The immediacy and the ease with which the proposed materials and designs are produced in such programs might actually be deceiving for novice designers who do not have enough real-life experience with material resistance and construction. Further research into the topic of the influence of new technology on and the implications of making realistic mental images and visualizations is necessary.

Reference list

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

Baber, C. (2021). Embodying design: An applied science of radical embodied cognition. *The MIT Press*. https://doi.org/10.7551/mitpress/12419.001.0001.

Chemero, A. (2013). Radical embodied cognitive science. *Review of General Psychology*, *17*(2), 145–150. https://doi-org.ocadu.idm.oclc.org/10.1037/a0032923.

Clark, A., & Chalmers, D. (1998). The extended mind. *Analysis*, 58(1), 7–19.

Elbert, T., Pantev, C., Wienbruch, C., Rockstrosh, D., & Taub, E. (1995). Increased cortical representation of the fingers of the left hand in string players. *Science*, *270*(5234), 305–307. https://doi.org/10.1126/science.270.5234.305.

Frisch, N. S. (2010). *To see the visually controlled: Seeing-drawing in formal and informal contexts: A qualitative comparative case study of teaching and learning drawing processes from Vega* *in Northern Norway* [Doctoral dissertation, Norges teknisk-naturvitenskapelige universitet – NTNU]. NTNU Open. http://hdl.handle.net/11250/270213.

Fulford J., Milton, F., Salas, D., Smith A., Simler, A., Winlove, C., & Zeman, A. (2018). The neural correlates of visual imagery vividness – An fMRI study and literature review. *Cortex, 105*, 26–40. https://doi.org/10.1016/j.cortex.2017.09.014.

Gallese, V., & Lakoff, G. (2005). The brain's concepts: The role of the sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology*, *22*(3–4), 455–479. https://doi.org/10.1080/02643290442000310.

Gedenryd, H. (1998). *How designers work – Making sense of authentic cognitive activities* [Doctoral dissertation, Lund University]. Internet Archive. https://archive.org/details/HowDesignersWork -MakingSenseOfAuthenticCognitiveActivity.

Groh, J. M. (2014). *Making space: How the brain knows where things are*. Harvard University Press.

Groth, C., & Mäkelä, M. (2016). The knowing body in material exploration. *Studies in Material Thinking*, *14*. https://materialthinking.aut.ac.nz/sites/default/files/papers/0176_SMT_V14_P02_FA.pdf.

Groth, C. (2017). *Making sense through hands: Design and craft practice analysed as embodied cognition*. Aalto ARTS Books. http://urn.fi/URN:ISBN:978-952-60-7130-5.

Gulliksen, M. S. (2021). There and back again: A carver's tale of losing and regaining sense of space due to a brain tumour. *Craft Research*, *12*(1), 127–152. https://doi.org/10.1386/crre_00043_1.

Gulliksen, M. S. (2023). What I learned by doing craft when I got terminal cancer: On woodcarving and psychophysical wellbeing from an insider perspective. *FormAkademisk*, *16*(4). https://doi.org/10.7577/formakademisk.5378.

Hawes, Z., & Ansari, D. (2020). What explains the relationship between spatial and mathematical skills? A review of evidence from brain and behaviour. *Psychonomic Bulletin & Review*, *27*(3), 465–482. https://doi.org/10.3758/s13423-019-01694-7.

Hengeveld, B., & Frens, J. (2013, August 26–30). To make is to grasp [Paper presentation]. In *The 5th international congress of International Association of Societies of Design Research*, Tokyo, Japan.

Hummels, C., & Van Dijk, J. (2015). Seven principles to design for embodied sensemaking. In *Proceedings of the nineth international conference on tangible, embedded and embodied interaction* (pp. 21–28). https://doi.org/10.1145/2677199.2680577.

Härkki, T., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2016). Materials knowledge in collaborative designing and making – A case of wearable sea creatures. *FormAkademisk*, *9* (1). https://doi.org/10.7577/formakademisk.1480.

Höök, K. (2010). Transferring qualities from horsebackriding to design. In *Proceedings of the sixth Nordic conference on human-computer interaction: Extending boundaries* (pp. 226–235). https://doi.org/10.1145/1868914.1868943.

Iachini, T. (2011). Mental imagery and embodied cognition: A multimodal approach. *Journal of Mental Imagery*, *35*(3–4), 1–66.

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

Ingold, T. (2021). *Imagining for real: Essays on creation, attention and correspondence*. Routledge.

Kangas, K. (2014). *The artificial project – Promoting design learning in the elementary classroom* [Doctoral dissertation, University of Helsinki]. University of Helsinki Open Repository. http://urn.fi/URN:ISBN:978-951-51-0401-4.

Keller, C. M., & Keller, J. D. (1999). Imagery in cultural tradition and innovation. *Mind, Culture, and Activity, 6*(1), 3–32. https://doi.org/10.1080/10749039909524711.

Kempton, W., L., Killi, S., & Morrison, A. (2017). Meeting learning challenges in product design education with and through additive manufacturing. *Journal of Systemics, Cybernetics and Informatics*, *15*(6), 119–129.

Kimmel, M., & Groth, C. (2023). What affords being creative? Opportunities for novelty in light of perception, embodied activity, and imaginative skill. *Adaptive Behaviour*. https://doi.org/10.1177/105971232311794.

Kind, A. (2017). Imaginative vividness. *Journal of the American Philosophical Association*, *3*(1), 32–50. https://doi.org/10.1017/apa.2017.10.

Kirsh, D., & Maglio, P. (1994). On distinguishing epistemic from pragmatic action. *Cognitive Science*, *18*, 513–549.

Kosslyn, S. M. (2005). Mental images and the brain. *Cognitive Neuropsychology*, *22*(3), 333–347. https://doi.org/10.1080/02643290442000130.

Koukouti, M., & Malafouris, L. (2020). Material imagination: An anthropological perspective. In A. Abraham (Ed.), *The Cambridge handbook of the imagination* (pp. 30–46). Cambridge University Press. https://doi.org/10.1017/9781108580298.003.

Laamanen, T.-K. (2016). *Generating and transforming representations in design ideation* [Doctoral dissertation, University of Helsinki]. University of Helsinki Open Repository. http://urn.fi/URN:ISBN:978-951-51-1948-3.

Lawson, B. (2004). Schemata, gambits and precedent: Some factors in design expertise. *Design Studies, 25*(5), 443–457. https://doi.org/10.1016/j.destud.2004.05.001.

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S. J. & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences*, *97*(8), 4398–4403. https://doi.org/10.1073/pnas.07003959.

Moreau, D., Clerc, J., Mansy-Dannay, A., & Guerrien, A. (2012). Enhancing spatial ability through sport practice: Evidence for an effect of motor training on mental rotation performance. *Journal of Individual Differences*, *33*(2), 83–88. https://doi.org/10.1027/1614-0001/a000075.

Newen, A., de Bruin, L., & Gallagher, S. (Eds.). (2018). *The Oxford handbook of 4E cognition*. Oxford University Press.

Novack, M. A., Congdon, E. L., Hemani-Lopez, N., & Goldin-Meadow, S. (2014). From action to abstraction: Using the hands to learn math. *Psychological Science*, *25*(4), 903–910. https://doi.org/10.1177/0956797613518351.

Pietsch, S., & Jansen, P. (2011). Different mental rotation performance in students of music, sport and education. *Learning and Individual Differences*, *22*(1), 159–163. https://doi.org/10.1016/j.lindif.2011.11.012.

Poulsen, S., & Thøgersen, U. (2011). Embodied design thinking: A phenomenological perspective. *CoDesign: International Journal of CoCreation in Design and the Arts*, *7*(1), 29–44. https://doi.org/10.1080/15710882.2011.563313.

Ramduny-Ellis, D., Dix, A., Evans, M., Hare, J., & Gill, S. (2010). Physicality in design: An exploration. *The Design Journal*, *13*(1), 48–76. https://doi.org/10.2752/146069210X12580336766365.

Rietveld, E., & Brouwers, A. A. (2016). Optimal grip on affordances in architectural design practices: An ethnography. *Phenomenology and the Cognitive Sciences*, *16*, 545–564. https://doi.org/10.1007/s11097-016-9475-x.

Rucińska, Z. (2021). Enactive planning in rock climbing: Recalibration, visualization and nested affordances. *Synthese*, *199*, 5285–5310. https://doi.org/10.1007/s11229-021-03025-7.

Rucińska, Z., & Gallagher, S. (2021). Making imagination even more embodied: Imagination, constraint and epistemic relevance. *Synthese*, *199*, 8143–8170. https://doi.org/10.1007/s11229-021-03156-x.

Schilhab, T. (2011). Derived embodiment and imaginative capacities in interactional expertise. *Phenomenology and the Cognitive Sciences*, *12*, 309–325. https://doi.org/10.1007/s11097-011-9232-0.

Strand, I., & Lutnæs, E. (2022). Developing spatial skills through design of built environments. *Design and Technology Education: An International Journal*, *27*(3), 36–57.

van Dijk, L., & Rietveld, E. (2020). Situated imagination. *Phenomenology and the Cognitive Sciences*. https://doi.org/10.1007/s11097-020-09701-2.
Zacks, J. M. (2008). Neuroimaging studies of mental rotation: A meta analysis and review. *Journal of Cognitive Neuroscience*, *20*(1), 1–19. https://doi.org/10.1162/jocn.2008.20013.
Zeisel, J. (2006). *Inquiry by design, environment/behavior/neuroscience in architecture, interiors, landscape, and planning*. W. W. Norton. (Original work published 1981).
Zeman, A. Z. J., S. Della Sala, L. A. Torrens, V.-E. Gountouna, D. J. McGonigle, & R. H. Logie, (2010). Loss of imagery phenomenology with intact visuo-spatial task performance: A case of 'blind imagination'. *Neuropsychologia*, *48*(1), 145–155. https://doi.org/10.1016/j.neuropsychologia.2009.08.024.