CoDesign, 2014
Vol. 10, Nos. 3–4, 171–190, http://dx.doi.org/10.1080/15710882.2014.963125

Establishing shared understanding of product use through collaboratively generating an explicit frame of reference

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(*Received 4 November 2013; accepted 4 September 2014*)

Recent studies have shown that there is a need to improve usability-related decision-making in product development teams to prevent usability problems in the final product. Those decisions are heavily influenced by the knowledge those teams have of future use situations and expected usability issues. Our previous research showed that design team members often implicitly hold this type of knowledge, but do not share it within the team. This lack of a shared understanding of product use negatively influences the decision-making process. In this paper we present the iterative development of a set of guidelines to support design teams in sharing knowledge of product use through the generation of flexible, explicit and evolving frames of reference. A series of studies in which the guidelines were evaluated suggest that particularly the activity of collaboratively creating the explicit frame of reference contributes to a shared understanding of product use.

Keywords: user-centred design; design method; design representation; industrial design; collaborative design

1. Introduction

Knowledge of product use is an essential component of user-centred design. Designing a product or service that is particularly aimed at solving the user's needs requires a thorough understanding of who the user is, why he or she would use a product or service, what the circumstances of use will be and how all these 'use situation aspects' influence the usability or user experience of certain design proposals. Designers can gather this knowledge from numerous sources including on the one hand 'primary' user research such as user observations, interviews and focus groups (Sharp, Rogers, and Preece 2007), ethnography (Blomberg, Burrell, and Guest 2003) and contextual inquiry (Beyer and Holtzblatt 1998), and on the other hand use evaluations as described in, for example (Nielsen 1993; Rubin 1994; Cushman and Rosenberg 1991). Although this shows that plenty of proven techniques are available to gather knowledge of product use, the design process is complicated by the fact that products are often used by diverse kinds of users, for different purposes in different contexts of use. This dynamics and diversity of use situations make the generation of a complete 'picture' of product use practically impossible, and can result in an overwhelming amount of data that designers have to deal with.

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In a preceding retrospective study, we investigated how design teams dealt with the dynamics and diversity of use situations in professional design practice (van der Bijl-Brouwer and van der Voort 2014). We found that the design teams indeed conducted user research and use evaluations to gain insight into varying use situations and how these situations influence product use. However, they also applied knowledge of product use of similar previous projects that were documented in the organisation, and personal knowledge of product use, such as their own experiences with a certain product or experiences of friends or families. Particularly this personal, implicit knowledge was often not shared within the team.

Not sharing design information will lead to an incomplete or even inaccurate shared understanding of product use within the design team. In our study we focused on two consequences of a lack of an adequate shared understanding of product use. First, failing to share knowledge of product use can result in an inaccurate or incomplete overview of use situations, which in turn will make it more difficult to design user tests with ecologically valid test conditions. These user tests influence the quality of recommendations for improvement of solutions, which in turn influence the quality of the solution generation process. Second, a lack of a shared understanding of product use can negatively influence collective team decision-making with regard to usability or user experience. Recent studies have shown that usability problems can be traced back to such decisions in the design process (Harkema 2012) and that they might be caused by a lack of sharing knowledge of product use (van Kuijk 2010).

It is generally acknowledged in the design research field that design team members need to establish a 'common ground' or 'common frame of reference' when codesigning (Visser 2006, 122). The need for sharing the more specific type of knowledge of product use was discussed by Buchenau and Fulton Suri (2000) who state in their work on user experiences that to work effectively as a design team, it is important to develop a common vision of what the team is trying to bring into being. This common vision relates to the construct of 'team mental model' which is a recent topic of study in the design research field, as discussed by Badke-Schaub et al. (2007). Team mental models have been investigated primarily by organisational psychologists from the 1990s, and are defined as team members' shared, organised understanding and mental representation of knowledge about key elements of the team's relevant environment (Klimoski and Mohammed 1994). The general thesis of the shared mental model literature is that team effectiveness will improve if team members have an adequate *shared understanding* of the task, team, equipment and situation (Mohammed and Dumville 2001). Note that the notion of having *a* shared understanding is slightly different from the *process* of shared understanding from which a shared understanding emerges.

Badke-Schaub et al. (2007) assume that mental models for design can relate to knowledge about the task, the process, the group, the competence and the context. Knowledge of product use would fall into the category of task models. The level of 'sharedness' of a team mental model is the extent to which team members have overlapping, or shared, knowledge and belief structures (Dong, Kleinsmann, and Deken 2013). Since design teamwork is dynamic in character (Visser 2006), individual mental models, and consequently the team mental model, emerge over the course of a design project. The sharedness of (task) mental models in design is, therefore, not fixed (Dong, Kleinsmann, and Deken 2013). Boos (2007) argues there exists an optimal level and degree of sharedness of individual mental models, depending on the task and the phase of task fulfilment. A certain level of sharedness is necessary to make collective decisions. However, when creativity is needed to generate new solutions to a given design problem, it

is essential that team members have diverse individual mental models. Furthermore, a level of sharedness of individual mental models that is too high might result in 'groupthink' (Janis 1972), which means that when there is too much cohesion, team members tend to develop a mindset where unanimity in the team overrides the motivation of team members to realistically evaluate alternative decisions, resulting in suboptimal solutions. Van Kuijk (2010) extensively studied user-centred design practices and showed that this optimal level is currently far from being reached when it comes to usability-related decision-making. We therefore aimed our research at supporting design teams in increasing this sharedness of mental models of product use to come closer to the optimal level.

We assumed that an explicit representation of knowledge of product use would support design teams in generating a shared understanding of product use. To support design teams in this process, we developed a workshop technique to generate the representation (van der Bijl-Brouwer, Boess, and Harkema 2011), guidelines that explain how existing user research techniques can be applied to add knowledge to the representation, and recommendations for the organisation of the representation. In this paper, we present the results of a series of studies in which we explored the effect of the workshop technique and the resulting explicit representation of product use, by having student design teams and professional design teams apply the workshop technique and guidelines in a design project.

In this paper, we first set out the objective of the development of the workshop and guidelines through a literature analysis of existing methods and tools and a summary of our studies on the application of these methods and tools in design practice. Next we describe the iterative development method of the workshop and guidelines, and we introduce the final design of these 'design supports' (Blessing and Chakrabarti 2009), as resulting from the iterations. Then we show the results of the effects of the workshop and guidelines with regard to the generation of a shared understanding of product use. We conclude the paper with a discussion of the effect of the activity of jointly creating a representation of product use on a shared understanding of product use.

2. Design support requirements

For the development of the workshop and guidelines, we first analysed the necessary content and characteristics for the explicit representation of knowledge of product use. Subsequently we conducted a literature analysis of existing formats for this representation and existing methods to gather content for the representation. By comparing these insights to our own studies of design practice, we could formulate an objective for the development of the workshop and guidelines.

2.1 Content and characteristics of the representation of knowledge of product use

Our research is focused at the types of team decisions that relate to usability and user experience. This decision-making involves the choice of solution proposals and the development of criteria to use in the activities of evaluating and choosing solutions (Visser 2006). Such criteria for product use include on the one hand the desired occurrence of usability (ISO 1998) and user experience issues (Roto et al. 2011). We will further refer to both types of issues as 'use issues'. On the other hand the criteria concern the use situations in which the issues will occur. For example, for the design of a bicycle, you have to decide whether it is important that cyclists can comfortably transport their luggage (use issue) and which different types of luggage (use situations) they would be allowed to transport.

It is then important to find which 'aspects' of use situations are relevant. This relevancy depends on the solution. A very simple example is that when you design a bicycle with hand brakes, you need to know something about the use situation aspect 'hand size', because that is going to influence the usability issues 'comfort' and 'effectiveness' of the hand brake. But if you design a bicycle with pedal brakes, hand size is not relevant anymore. Designers therefore need a 'frame of reference' which reflects both those use situation aspects and related use issues (Figure 1). Visser (2006, 16) states that a frame of reference is a representation that concerns agreements, especially on the definition of tasks, states of the design, references of central notions, and weights of criteria and constraints. It is the frame to which designers refer when taking decisions and evaluating solutions with regard to product use.

An important characteristic of such a frame of reference is that it needs to be flexible. Rigorous studies of the design activity have shown that design can be seen as a process of co-evolution of problem and solution (Dorst and Cross 2001; Wiltschnig, Christensen, and Ball 2013). This also applies to problems related to product use. It means that a solution and the problem, reflected in the frame of reference, are inter-dependent, as we have shown above. If a solution and frame of reference are inter-dependent, and a solution evolves over the course of a design process, the frame of reference necessarily needs to be able to evolve as well. Thus a flexible frame of reference is required.

Based on the idea that things should be made visible so 'that they can be seen, talked about, and potentially manipulated' (Suchman 1995, 63), we furthermore assumed that a frame of reference needs to be *explicit* to be able to support a shared understanding of product use. When we refer to an explicit frame of reference in this paper, we mean an external, visible, representation of a frame of reference, for example a storyboard, a mind map or a visualisation of a persona.

2.2 *Existing types of frames of reference of product use*

In the user-centred design field, several formats have been developed for a frame of reference that reflects both use situations and related use issues, including user requirements, user profiles, contextual models and scenarios. Traditional user requirements do not make relevant use situations explicit but are mainly focused at the

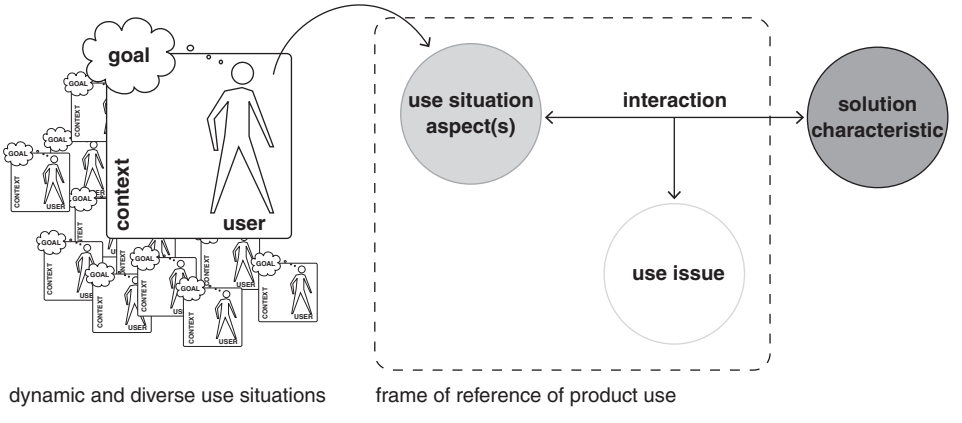

Figure 1. A frame of reference of product use represents relevant use situation aspects and how they are connected to use issues.

specification of measures of effectiveness, efficiency and satisfaction – such as the maximum acceptable number of user errors (ISO 1998; Nielsen 1993), or only represent quantifiable constraints about the limitations of user characteristics such as the minimum body length that should be supported by the design (Cushman and Rosenberg 1991).

Frames of reference that do make use situation aspects explicit are the different types of models that show commonalities in information about specific categories of use situation aspects. For instance, user characteristics can be represented in 'user profiles' (Rubin 1994; Sharp, Rogers, and Preece 2007) or 'personas' (Cooper 1999), and use situation aspects related to the context of use can be captured in, for example, the different types of contextual inquiry models developed by Beyer and Holtzblatt (1998), such as the flow model and the physical model. Both personas and contextual inquiry models are based on large quantities of verified data about users and other use situation aspects, which are translated into models by a thorough interpretation step to reveal similarities (see, e.g. Pruitt and Grudin 2003). This suggests that they might not be flexible enough to adjust during the design process and are particularly useful for design projects in which the design team can reuse knowledge of previous, similar projects and that are aimed at incremental innovation.

Although personas can also be applied in a 'lighter' mode without the underlying data, they often do not connect use situation aspects (the persona characteristics and goals) to use issues. A more integrated way then to represent use situations and related use issues is the use of scenarios, whether combined with personas or not. They are deliberately incomplete and easily revised or elaborated: in a few minutes, a piece of the scenario could be rewritten or elaborated (Carroll 2000). Scenarios therefore seem an appropriate type of representation in terms of their flexibility and the extent to which they represent both (varying) use situations and use issues.

2.3 Gathering knowledge of product use for the frame of reference

To generate the frame of reference, insight is needed both into future use situations and into use issues that can be expected or are desired to occur in those use situations.

Insight into relevant use situation aspects can be gathered through either direct studies of use situations or the use of self-reports. Direct studies of use situations include user observation, interviews and focus groups (Sharp, Rogers, and Preece 2007), ethnographic studies (Blomberg, Burrell, and Guest 2003) and contextual inquiry (Beyer and Holtzblatt 1998). In self-reports, users report their user experiences themselves. They include retrospective interviews (Rosson and Carroll 2002), after sales feedback (van Kuijk et al. 2007) and probes (Gaver, Dunne, and Pacenti 1999; Mattelmäki 2005). These studies give insight into the current use of products and can be extrapolated to future use when similar use situations and use issues are expected, compared to current products and services.

In a retrospective case study, we investigated how three practising design teams dealt with the dynamics and diversity of use situations in a specific design project (van der Bijl-Brouwer and van der Voort 2014). Our results showed that all of the above-mentioned techniques were used to gain insight into current use in those projects. However, additional information about use situations was gathered from personal and organisational sources. One of the studied teams could make use of 'organisational' knowledge gathered in previous projects, because they continuously developed the same types of products, often a new version of a previous design. This knowledge was documented in, for example, personas (Cooper 1999; Pruitt and Grudin 2003). However, the teams that worked on a much more variable product portfolio relied to a much larger extent on their personal knowledge when designing products for new or unfamiliar use situations. Designers, for

example, indicated that they had in some instances used knowledge of their own personal experiences with similar products, or experiences from friends or family.

To complete the frame of reference with use issues that can be expected for solution proposals in certain future use situations, designers can apply use evaluations. For use situation aspects that set 'boundary conditions' (Green, Kanis, and Vermeeren 1997), it can be predicted how they will influence the future user–product interaction. Boundary conditions define the limits of the use situations in which a product can be used. For example, knowledge of the physical dimensions of the target group allows predicting if the future users and solution will match physically. However, the only way to gain insight into how use situation aspects that are not boundary conditions influence usability and user experience is to execute user tests (Kanis 1998). We indeed found that design teams for this reason conducted user tests early and throughout the design process. On the one hand these tests concerned formal evaluations with end-users that were well documented. On the other hand designers indicated they applied informal ways of user testing such as testing a quick mock-up themselves or testing it opportunistically with colleagues. Similar results with regard to informal testing were found by Boess (2009).

Our study showed that this knowledge gathered in informal use evaluations, as well as implicit personal knowledge of current product use, was often not shared between design team members, particularly in the teams that had to design products for use situations they had not worked on before. Although this can lead to a lack of shared understanding, which in turn can negatively influence decision-making, the implicit knowledge was useful to the designers because it was always readily available for application in their iterative design process.

2.4 Research objective

Based on the above insights, we concluded that many techniques are available to gather insights for a frame of reference of product use. What is lacking is a technique that allows the addition and sharing of implicit knowledge of product use. We developed a workshop technique for that purpose. Furthermore, there is a need for guidance on the generation of an explicit and flexible frame of reference that represents the knowledge gathered by means of those techniques, and that can evolve in the course of the design process. We assumed that the generation and application of the explicit frame of reference would support the creation of a shared understanding of product use. Our research objective (Figure 2) is to investigate the assumed influences of the developed design support (1 and 2), as well as the influence of the explicit frame of reference of product use on a shared understanding of product use (3). An additional assumed effect of this explicit frame of reference is the influence of its application in use evaluations on the external validity of these evaluations (4). This influence is outside the scope of this paper.

In our studies we posed open research questions with regard to which aspects of the workshop and guidelines worked well and which did not. Furthermore, we specifically evaluated the effect of the workshop and guidelines with regard to our objectives. In this paper we will focus on the research questions of if and how an explicit frame of reference of product use contributes to a shared understanding of product use.

3. Research methods

In our research we chose an iterative approach in which we could explore and evaluate the success and appropriateness of different versions of the workshop technique and

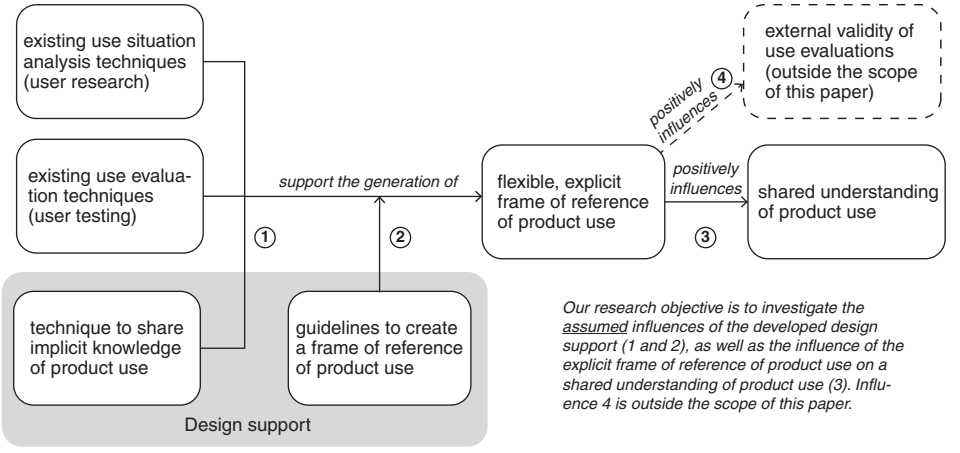

Figure 2. A visualisation of our research objective.

guidelines, as advocated by Blessing and Chakrabarti (2009) in their *Design Research Methodology*. In this approach, we evaluated and adjusted successive versions of these design supports by applying them to both fictional and real design projects with design students and design practitioners. Those studies can be summarised as follows:

- To answer the research question 'how can we support the transfer of implicit knowledge of product use to a shared explicit frame of reference?', we went through five iterations of the workshop technique in which we applied the workshop to fictional design cases with practising designers.
- To answer the research question 'how does an explicit frame of reference of product use support sharing knowledge of product use in a complete design project?', we evaluated the application of successively a first and revised set of guidelines by, respectively, four and three student design teams to a design brief offered by two different clients.
- In the previous study, we found indications that the activity of generating the explicit frame of reference contributed largely to creating a shared understanding of product use. We therefore posed a third research question: 'How does the joint creation of an explicit frame of reference contribute to creating a shared understanding of product use?', and answered it by applying and evaluating the final workshop technique in three real product development projects of consumer products in industry.

The student design teams consisted of master students industrial design engineering with bachelor degrees in various courses including industrial design, mechanical engineering and human technology. Although we acknowledge that the external validity of working with student teams is lower than studying practising design teams, it did allow us to closely study the process and effects of the workshop and explicit frame of reference, over the course of a design project. The additional interventions with the workshop in natural design situations allowed for a more valid – but shorter – study of the effect of the workshop on a shared understanding of product use.

Data were gathered by means of group interviews after the application of the workshops and the guidelines. The workshops were also recorded on video. For the

evaluation of the guidelines in the student projects, we furthermore gathered data about their design process through document analysis, which included a portfolio of the design proposals and frames of reference, a log of the design process and a written process evaluation by the design teams. The interviews were transcribed completely. We observed the workshop videos and generated workshop summaries of the process and most salient aspects. The triangulated data for the studied student design projects were translated into a summary of their design process which showed how the different design and research activities connected to different versions of the solution proposals and frames of reference. Relevant sections of the transcriptions and design process summaries were subsequently identified and assigned to the research questions.

4. Results: supporting design teams in sharing knowledge of product use

4.1 Workshop

The iterations of the workshop development led to the design of a half-day workshop in which all members of a design team are brought together to share knowledge of product use (van der Bijl-Brouwer, Boess, and Harkema 2011). For this purpose, we iteratively explored a combination of techniques. We did not just focus on eliciting what designers already knew of product use, but also used the workshop to have them explore what different use situations potentially could mean for future use of a product. For example, we provided them with a large collection of images of possible users and contexts and had them think about how the product would interact in those instances. Some of the techniques we used were borrowed from existing techniques such as storytelling (Erickson 1996) and role-playing (Iacucci, Kuutti, and Ranta 2000; Simsarian 2003). The uniqueness of the final format of the workshop is that it combines techniques to explore and elicit knowledge of both current use and future use, that it records this knowledge successfully in a pre-defined, flexible representation (see next section) and that it has designers reflect on which assumptions need to be verified and which gaps need to be filled in their collective knowledge by means of additional research activities. In the first five iterations of the workshop with practising designers, it became clear that the added value of combining the techniques, as opposed to using single techniques, was that it stimulated eliciting personal knowledge of related use situation aspects and use issues, through having participants associate between stories of current use and scenarios of imagined use (see van der Bijl-Brouwer, Boess, and Harkema 2011). We named the final technique the 'Envisioning Use workshop' (van der Bijl-Brouwer, Boess, and Harkema 2012). Its steps can be summarised as follows (Figure 3):

- Remembering: a story-telling technique in which team members share their knowledge of current product use.
- Imagining: provoking assumed stories of user experience by means of providing random images of users and context of use.
- Structuring: organising the gathered knowledge in an explicit representation.
- Experiencing: a role-playing technique in which team members explore what effects a current product or solution proposal has on selected role-play scenarios.
- Targeting: selecting use situation aspects and use issues that form opportunities to design solutions.
- Envisioning: translating the gathered insights into solution proposals.
- Questioning: identifying and prioritising gaps and assumptions in the representation and translating them into required research activities.

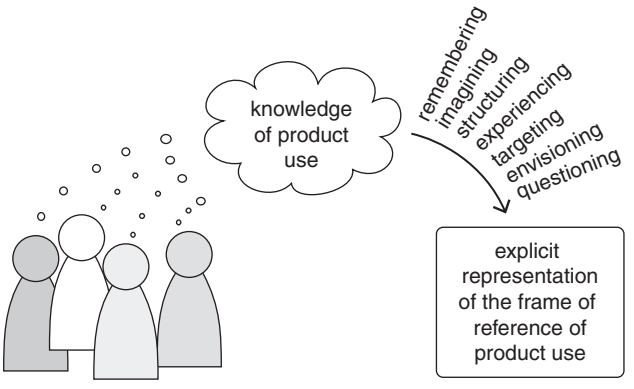

Figure 3. In the Envisioning Use workshop, members of a design team are brought together to share their knowledge of product use through a combination of techniques.

4.2 Format of the frame of reference of product use in the workshop

From our literature review of existing frames of reference of product use, we concluded that scenarios would provide a flexible and integrated means to record knowledge of product use. However, within the workshop, scenario representations would not allow participants to flexibly record the stories and scenarios that were shared. We, therefore, looked for a format that would prevent the recording process from hampering the sharing of stories and scenarios. Therefore, only the most relevant aspects of the stories and scenarios were written down on sticky notes and posted on a wall of flip charts. In the workshop iterations, we investigated different formats for the organisation of those sticky notes. The first representations were very (pre-)structured, and included a matrix and pre-defined use situation categories. However, they turned out to be too complex to handle by the workshop participants and hampered the thinking process of associating from one story to other stories and scenarios (van der Bijl-Brouwer, Boess, and Harkema 2011). The final format simply categorises sticky notes in use situation aspects and use issues by means of a colour code (see Figure 4). Distinguishing use situation aspects and use issues forces the team members to always contextualise the occurrence of usability or user experience issues within the gathered stories. Participants are then asked to categorise the gathered information based on their own preferred structure. This organisation of the frame of reference served its purpose within all the subsequent workshops we facilitated. We named the final representation of knowledge of product use the 'product use mind map' (Figure 5).

4.3 Guidelines

In the student projects we could evaluate how the Envisioning Use workshop and working with an explicit frame of reference of product use would function in a complete design project. We found that an approach which involved both the exploration of how use situations would potentially influence product use and the validation of those assumptions by means of evaluations with end-users was very effective in generating an evolving frame of reference of product use throughout the design process. This approach is visualised in Figure 6.

The centre of the model shows that the frame of reference of product use guides the generation of solutions. The design team needs to choose a 'target' in this frame of

use situation aspects *use issues*

taking picture in cold weather — buttons are difficult to control with cold fingers

wanting to take a picture of you and someone with background — it is nice to have a picture of you together

wanting to take a picture of you and someone with background — it is difficult to get everything in the picture

Mieke's story:
"This picture was taken in January 2010 in the Haute-Savoie in France. It shows my husband and I and Mont Blanc. The picture was taken by my husband with a Canon compact camera. I love the picture, since it reminds me of the wonderful time we had skiing in the mountains and enjoying the beautiful scenery together. However, taking this picture was not that easy. The temperature was about -20 degrees Celsius, but the buttons on the camera are too small to be able to control them while wearing gloves. This made the camera very uncomfortable to use. Also, taking a picture of ourselves and Mont Blanc was difficult because my husband could not see the preview screen when he aimed the camera at ourselves. A closer inspection of the photo reveals that the summit of Mont Blanc is not even in the picture!"

This story would be recorded in the workshop in the format as shown on the left: relevant use situation aspects are connected to related use issues.

Figure 4. Example of how a story of the first author would be translated in a representation which connects use situation aspects to use issues in the Envisioning Use workshop.

reference: the desired use issues that should occur in selected use situations. The team furthermore needs to choose solutions based on this frame of reference. The generation of the frame of reference is supported by internal and external design research activities. Internal activities are those that do not involve actual end-users, such as self-testing a prototype, and that consequently generate content for the frame of reference based on assumptions. External activities on the other hand do involve potential end-users and can, therefore, be applied to verify the assumptions created in internal design research activities. We furthermore distinguish on the one hand activities aimed at analysing or exploring the use issues of current solutions, and on the other hand activities aimed at evaluating solution proposals for future use.

The guidelines do not prescribe a certain order of activities. Instead the design team can choose which activities are necessary as input to the frame of reference based on an analysis of the knowledge gaps. These activities can then be used to add knowledge and assumptions to the frame of reference, which consequently evolves over the course of a design project. To illustrate this we summarise the design process of one of the teams that

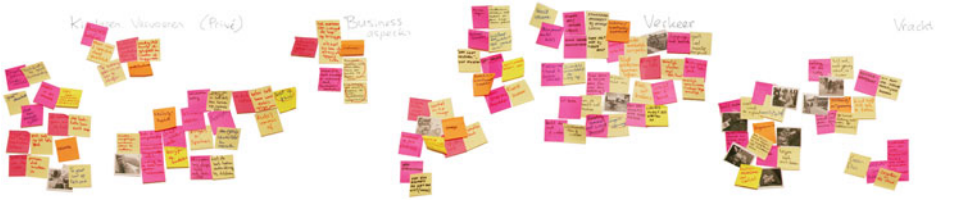

Figure 5. Product use mind map generated within an Envisioning Use workshop.

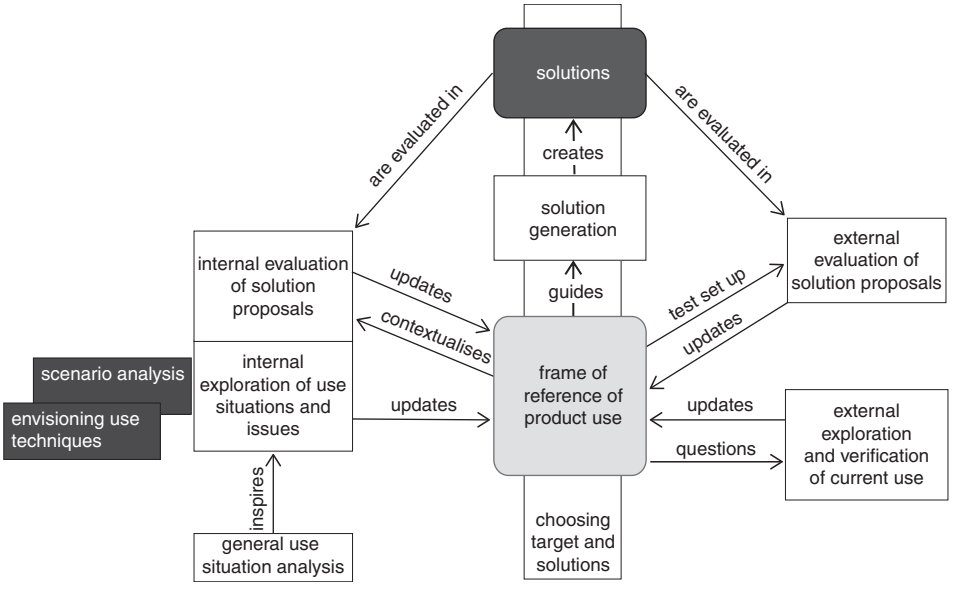

Figure 6. Model of the design process as explained in the guidelines.

designed a carrier bike in the first evaluation of the guidelines. This is a bike with a box in the front, which Dutch parents mostly use to transport their children. The team first executed an external exploration of current use by interviewing parents about their experiences with their current bike. One of the things they found was that parents wanted to protect their children from wind and rain. Their first explicit frame of reference included these insights. They then did some literature search of the social and emotional development of children (general use situation analysis is shown in Figure 6) and used this as input to an Envisioning Use workshop. One of the things they found was that for children it is important to 'explore the world' and for parents it is important to guide their children in this exploration. In the workshop (internal exploration), they assumed that, therefore, for the carrier bike it is important that children can keep observing the world around them and that parents can at the same time keep contact with their children. Based on these assumptions they generated a design for a rain hood that was transparent, so children could look outside, and that was open on the parent's side, so parents could still communicate with their children (Figure 8). They added this reasoning to their explicit frame of reference. Subsequently they conducted an external evaluation with parents in which they verified this solution and the accompanying frame of reference.

The guidelines do not prescribe a specific format for the explicit frame of reference for use in the complete design process. This flexibility of the guidelines allows design teams to adjust the format to their needs. The guidelines do recommend using a representation that connects use situation aspects to use issues (as explained for the product use mind map in Section 4.2). The studies with student teams showed that an explicit frame of reference which connected use situation aspects to use issues was most useful to set up use evaluations (van der Bijl-Brouwer 2013). The student teams worked with different types of analogue and digitised formats. The most practical formats were scenario representations and (digitised) textual models based on the product use mind map. Figures 7 and 8 shows examples of how these two types of representations were

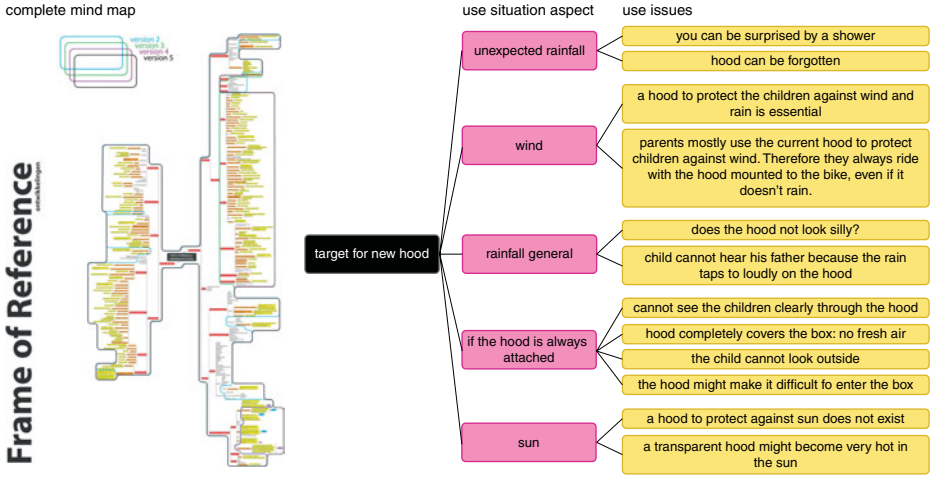

Figure 7. The complete frame of reference created by one of the student teams is an extensive structured textual model (left). The right shows a prioritised view of this frame of reference with the most important use issues to focus on in different weather conditions.

used in the above-mentioned design project of a carrier bike. The final guidelines are explained in a workbook which is available online (van der Bijl-Brouwer 2012).

5. Results of the evaluation of the guidelines and workshop

The application of the Envisioning Use workshop in actual product development projects in design industry in addition to the application of the guidelines in the student projects led to insights into the effects of these design supports on first the *generation* of a shared understanding of product use, and second on the *content* of this shared understanding. We also found indications that the shared understanding positively influenced usability-related decision-making.

5.1 Generating a shared understanding of product use

Our assumption was that the explicit frame of reference of product use would support a shared understanding of product use in the design teams. However, an unexpected result of the application of the guidelines within the student projects was that students indicated that the approach was particularly strong in getting knowledge 'in the head' and thereby taking it into the design process. The following quote illustrates the importance of this 'mindset':

> Researcher: "how did this project differ from other projects? User centred design is not new for you."
>
> > Student A (team 2): "that's right, but usually a lot later, only when you have a solution and you do a user test [. . .], but not from the beginning."
> >
> > Student B (team 2): "yeah, now you design more for them, you are really from the beginning, with the workshop and all that, *in your mind* dealing with use situations and issues."

The importance of this mindset can be seen in the work of the team that designed the hood for the carrier bike. They executed multiple Envisioning Use workshops to explore use

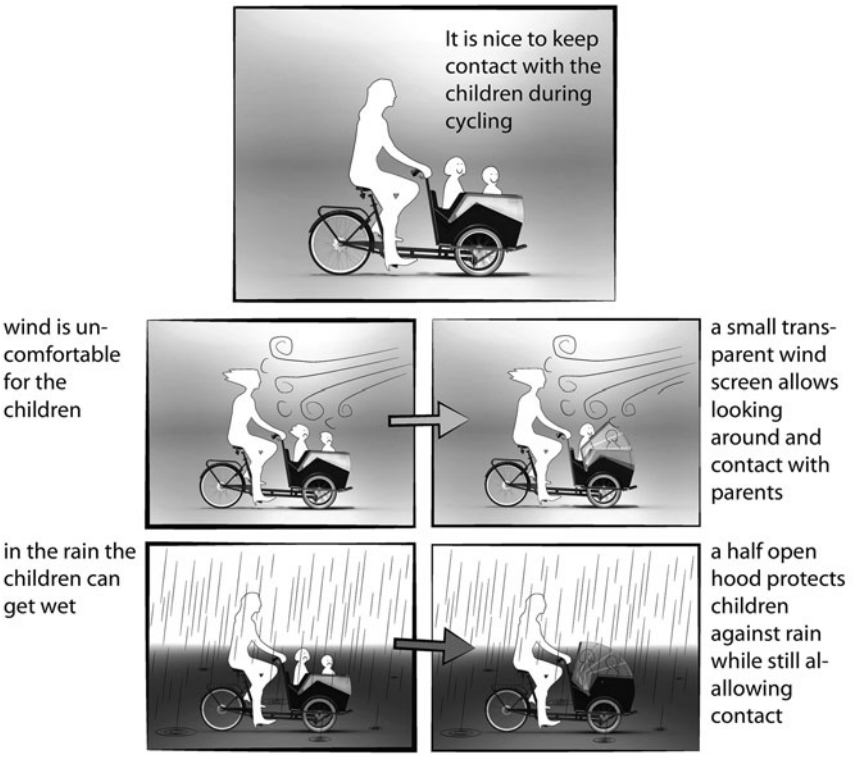

Figure 8. Frame of reference for the same team in the format of a storyboard. This shows how the proposed solution leads to different use issues (in text) in the different use situations (sketched weather conditions).

situations and issues, but they acknowledged they did not really *use* the explicit frame of reference in their design process:

> Student (team 2): "eventually the [explicit] frame of reference is something we only made for [this research], and not something we experienced as a convenient tool to structure our design process."

However, their solutions are clearly based on the issues that resulted from these workshop sessions. For example, the issue 'keeping contact with children while protecting them from different weather conditions' is clearly integrated in their solution of a hood.

This suggests that the mindset was created by exploring issues in 'internal design research activities', for example 'imagining' in the Envisioning Use workshop. Apparently this leads to an addition of use issues both to the explicit frame of reference and to a mindset that supports solution generation. This in turn suggests that creating and exploring the *explicit* frame of reference supports creating an *implicit* frame of reference. An implicit frame of reference is the individual mental representation of the frame of reference in the design team members' minds. Since this creation and exploration of the frame of reference is done collectively within the Envisioning Use workshop, we assumed that the workshop could potentially directly lead to a shared implicit frame of reference, or a shared understanding of product use.

We subsequently set up an additional study in which we were invited to apply the Envisioning Use workshop technique to three real product development projects of different

consumer electronics products in industry (van der Bijl-Brouwer, Boess, and Harkema 2011). In each of these projects we facilitated a workshop for the concerned multidisciplinary design team. In all three workshops, there was consensus amongst the participants that doing the workshop together indeed led to the creation of such a shared understanding of product use. In the following section, we illustrate this by means of quotes from these participants about the different components of a shared understanding of product use.

5.2 The components of a shared understanding of product use

In our studies we found that the shared understandings of product use consisted of knowledge of product use in general, a shared view on which issues were considered important and a shared view on which knowledge was lacking and should be gained.

5.2.1 Shared knowledge of product use

During the workshops we observed several instances at which knowledge about (current) product use or the current situation was explicitly shared between team members. This knowledge transfer was also acknowledged by the participants, as can be concluded from the following quotes:

> Project leader (workshop 1): "it is a good means to share knowledge of which you were not aware the others did not know."
>
> Usability expert (workshop 2): "the information that is in the heads and the assumptions are really captured."
>
> Engineer: "true."
>
> Designer: "yeah, do it together."
>
> Usability expert: "so that is for me also the main advantage of this approach, even though you already know quite a lot."

Participants mentioned that sharing knowledge was stimulated by the interactive character of the workshop:

> Participant (workshop 1): "if someone tells you something, do you know it then? Maybe you do not know it exactly. And somehow, this is different than telling. It is more experiencing and therefore for me things now are just the way they are, more than when the project leader told me."

This can also be concluded from the following comments in which participants compare the interactive character of the workshop to more passive group sessions, for example a risk analysis session (here participants refer to an failure mode and effect analysis [FMEA] session):

> Usability expert (workshop 2): "in for example a user FMEA it is sometimes really difficult to get the team on this level."
>
> Project leader (workshop 2): "because, I think therein actually these techniques add a lot of value [...]. We sometimes facilitate FMEAs with other companies and always try to have them, to be active instead of staring at a screen, which is usually what happens with FMEAs. That really doesn't work, you never get to this level of thinking."

5.2.2 A shared vision on future use

The second aspect of the shared understanding is the extent to which team members agree on what are the most important issues to take into account in the solution or what the desired future use is. This is illustrated by the following quote:

> Participant (workshop 1): "by doing the workshop, you get a more common view on what is important within the team."

The added value of the workshop for the shared vision on future use can also be derived from a comment of the system architect of the second workshop who mentioned that he regretted that the product designer did not attend, because they would now have to convince him of some of the decisions that were made. For example, they reconsidered the appropriateness of a certain sub-solution about which some use issues emerged during the workshop. This suggests that a shared vision is created within the workshop, but is expected to be difficult to transfer to team members who were not present.

5.2.3 A shared understanding of important questions

The third part of the shared understanding was the sharing of what was not known and prioritising these knowledge gaps to decide on necessary research activities. This is illustrated by, for example, a quote of the usability expert of workshop 2:

> [The workshop stimulated] to come to one page with everybody, to what do we know, what don't we know and how important is it to find out, to get answers for things we don't know.

And by the following quote of one of the development engineers of workshop 3:

> Doing it together results in that it becomes apparent what you do not know together. This works better than just telling each other.

5.3 Added value of the shared understanding in decision-making

The former paragraphs described the different aspects of the shared understanding. Our assumption was that the shared understanding would support usability-related decision-making in the teams (Figure 2). Although we could not directly observe this decision-making process, several comments of participants suggest that this is indeed the case:

> Participant (workshop 1): "if you would do this with ten people, then after one afternoon you would have the idea of, this is what we are going to make, this is the problem we are dealing with. And somehow I think this will often play a role in future decision making. You get a more common view on what is important."

And in a survey that was held a couple of weeks after the workshop, the usability expert from the second workshop indicated:

> Targeting helped setting the mindset and influenced decision making in value engineering sessions.
>
> We now have a shared experience (role-play) to fall back on in discussions.

5.4 The role of the explicit frame of reference in generating a shared understanding of product use

In a final study we again applied the guidelines and the Envisioning Use technique in a student project. This allowed us to analyse and compare how the workshop and explicit frame of reference would contribute to a shared understanding in a complete design process, as opposed to the previous study in design industry in which we could only analyse the shared understanding at one moment in the design projects.

In this study students again mentioned the contribution of the Envisioning Use technique to a shared understanding of product use. With regard to the role of the explicit

frame of reference in generating a shared understanding, one team mentioned that the frame of reference simplified communication, because everyone had the same ideas about the context of use. However, a student of another team indicated that it only works for this purpose when the frame of reference is created together. He mentioned:

> If I would not have joined the Envisioning Use technique, I would not have understood the explicit frame of reference.

Furthermore, a student of the third team indicated how the shared understanding contributed to their communication process:

> We started with the Envisioning Use workshop and that particularly helped, because together you look at product use and then in the course of the project it is mainly in your head. We did put it on paper, but it was not brought into the discussions by means of really looking at that paper.

These results suggest that the shared understanding indeed supports communication and that that influence is potentially at least as large as the influence of the explicit frame of reference itself. The added value of the explicit frame of reference for communication seems, therefore, to be rooted in its joint creation.

6. Discussion and concluding remarks

In this paper we discussed the importance and difficulties of generating a shared understanding of product use, for usability-related decision-making in multidisciplinary design teams. The main research question was if and how an explicit frame of reference of product use contributes to a shared understanding of product use. Our studies showed how our assumptions on how to create a shared understanding of product use in a design team shifted from a focus on sharing an explicit representation of this knowledge to a focus on the *joint creation* of this representation. It seems that it is particularly the *activity* of jointly creating the explicit frame of reference of product use that contributes to the shared understanding of product use.

In our research we could study this joint creation of a frame of reference of product use most closely in the evaluations of the Envisioning Use technique in the design industry. We could not study the lasting effects of the workshop on a shared understanding of product use, and we acknowledge the limitation of having to rely on subjective self-reports of a shared understanding by a small number of teams. However, the feedback from the members of these three teams clearly showed that, for them, the workshop was an effective moment for sharing knowledge of product use, including knowledge of current product use, a vision on future use and gaps in the collective knowledge of product use. Some participants in these workshops indicated that the knowledge transfer seemed to be stimulated by the active character of the workshop. This corresponds to the work of Mohammed and Dumville (2001) who argued that information should not only be *mentioned*, but also be *actively considered* to create a team mental model. It remains unclear, however, how the different workshop activities contribute to this knowledge transfer, or which existing types of user-centred design techniques would lead to similar levels of sharing knowledge. One research field which discusses the influence of 'activities' in knowledge transfer is educational research about active learning (e.g. Prince 2004). These studies showed, for example, that students remember more content when brief activities are introduced to a lecture. These insights suggest that the activation character of the workshop itself, rather than the explicit representations of the shared knowledge, contributed most to the creation of a shared understanding.

This suggests further that other kinds of knowledge transfer, such as from team member to team member, might also benefit from an active approach. For example, usability assessment and development are often separate activities in industry, which challenges the connection between usability and the development process (Hornbæk 2010). Knowledge transfer between usability experts and product developers is, therefore, essential to make sure usability assessment and user research have any influence on the design process. The formal reports that are often used to communicate this information in current design practice are probably not the best means for knowledge transfer because of their lack of richness in data and their focus on a research audience (Bruseberg and Deana 2002; Norman 2010). To overcome these issues, an active approach as suggested in this paper through joint 'internal design research activities' as the Envisioning Use technique, or through similar methods proposed by others such as the 'participative communication tools' by Sleeswijk Visser, van der Lugt, and Stappers (2007) might be an essential precondition for this knowledge transfer to succeed. Whether and which activities are needed to raise the level of knowledge transfer, in particular with regard to the level of sharedness of the understanding of product use, needs more dedicated research on a social and cognitive level.

We deliberately chose to support design teams in generating flexible frames of reference which could *evolve* over the course of a design project, and which explicitly represented the co-evolution of problem and solution. A document analysis of the student projects showed that their frames of reference indeed evolved. The teams presented two (one team), three (two teams), four (two teams) or five (two teams) iterations of a frame of reference (see van der Bijl-Brouwer 2013). A dynamic explicit frame of reference requires that this frame of reference is also dynamically shared. In some of the student projects, this was done successfully through repetitive executions of the Envisioning Use workshop at different stages of the design process. However, for practical reasons we could not gain insight into how this could be applied in design practice, where contextual requirements regarding time, investment and efficiency will have a larger influence on the success of such a technique (Wixon 2003). Future research should, therefore, be aimed at further investigating the trade-off between joint and active team sessions on the one hand, and individual research activities that are shared through explicit representations of product use on the other. These studies should then include a further analysis of appropriate formats for this representation, including, for example, a comparison between structured textual models and visually richer representations such as collages and storyboards. A specific issue with regard to flexible formats of the frame of reference is the suitability of scenarios. Within the workshops, scenarios could not be recorded fast enough to flexibly represent information about product use. We, therefore, just recorded the relevant scenario elements on sticky notes. However, it remains unclear whether either the holistic scenarios as shared through storytelling, or their deduced elements, contributed most to the shared understanding. It remains a challenge to find formats of a frame of reference that offer both flexibility and a richness that arguably supports communication and shared understanding.

Future studies would require conducting a more objective and longitudinal analysis of the sharedness of mental models, to compare the team mental model at different stages of the design process, as well as to compare the content of the explicit frame of reference to individual mental models. In our studies, we had to rely on subjective indications by designers of a shared understanding of products use. Dong, Kleinsmann, and Deken (2013) state that established methods to measure team mental models of design teams are still lacking. They propose a sophisticated and objective assessment of sharedness of mental models through linguistic communication, but indicate that their method has limitations

with regard to application in natural design settings. Overcoming these challenges is essential for further understanding of the role of (the joint creation of) explicit frames of reference of product use in influencing a shared understanding of these issues.

In this paper, we focussed on sharing knowledge of *product use*. This knowledge is characterised by the dynamics and diversity of use situations, and the interdependency of use issues, use situations and solutions. This variance of contexts, and interdependency between solution, context and performance, can be found in other aspects of the design problem as well. For example, issues occurring in other phases of the product life cycle such as sales, maintenance and disposal, and issues that are not related to usability or user experience, such as technical, social, economic and environmental issues are not uncommonly contingent upon dynamic and diverse contexts. For future research, it would, therefore, be interesting to extend our studies beyond product use, and explore a more general application of frames of reference and the activity of their joint generation in a co-design context.

Acknowledgements

We would like to thank all students of the University of Twente who participated in the design projects for their enthusiasm and valuable feedback on the guidelines. We also thank Bongo Innovations BV and Philips Consumer Lifestyle for providing the cases for these projects. Furthermore, we would like to express our gratitude to all design practitioners who participated in the iterative development and evaluation of the Envisioning Use workshop. Finally we thank Stella Boess and Christelle Harkema for their indispensable contribution to the development of the Envisioning Use technique.

Funding

This work was supported by the Netherlands Ministry of Economic Affairs, Agriculture and Innovation [grant number IOP IPCR 0631].

References

Badke-Schaub, Petra, Andre Neumann, Kristina Lauche, and Susan Mohammed. 2007. "Mental Models in Design Teams: A Valid Approach to Performance in Design Collaboration?" *CoDesign* 3 (1): 5–20.

Beyer, Hugh, and Karen Holtzblatt. 1998. *Contextual Design: Defining Customer-Centered Systems*. San Francisco, CA: Morgan Kaufmann.

Blessing, Lucienne T. M., and Amaresh Chakrabarti. 2009. *DRM, A Design Research Methodology*. Springer. Original edition, A Design Research Methodology. London: Springer.

Blomberg, Jeanette, Mark Burrell, and Greg Guest. 2003. "An Ethnographic Approach to Design." In *The Human–Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications*, edited by Julie A. Jacko, and Andrew Sears, 964–986. New York, NY: Lawrence Erlbaum.

Boess, Stella. 2009. "Experiencing Product Use in Product Design." Paper presented at the International Conference on Engineering Design ICED'09, Stanford, CA, USA, August 24–27.

Boos, Margarete. 2007. "Optimal Sharedness of Mental Models for Effective Group Performance." *CoDesign* 3 (1): 21–28.

Bruseberg, Anne, and McDonagh-Philp Deana. 2002. "Focus Groups to Support the Industrial/Product Designer: A Review Based on Current Literature and Designers' Feedback." *Applied Ergonomics* 33: 27–38.

Buchenau, Marion, and Jane Fulton Suri. 2000. "Experience Prototyping." Paper presented at DIS'00 the 3rd Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques, Brooklyn, NY, USA, August 17–19.

Carroll, John M. 2000. *Making Use: Scenario-Based Design of Human–Computer Interactions*. London: MIT Press.

Cooper, Alan. 1999. *The Inmates Are Running the Asylum: Why High-Tech Products Drive Us Crazy and How to Restore the Sanity*. Indianapolis, IN: Sams.
Cushman, William Mitchell, and Daniel J. Rosenberg. 1991. *Human Factors in Product Design*. Amsterdam: Elsevier.
Dong, Andy, Maaike Kleinsmann, and Fleur Deken. 2013. "Investigating Design Cognition in the Construction and Enactment of Team Mental Models." *Design Studies* 34 (1): 1–33.
Dorst, Kees, and Nigel Cross. 2001. "Creativity in the Design Process: Co-Evolution of Problem-Solution." *Design Studies* 22 (5): 425–437.
Erickson, T. 1996. "Design as Storytelling." *Interactions* 3 (4): 30–35.
Gaver, Bill, Tony Dunne, and Elena Pacenti. 1999. "Design: Cultural Probes." *Interactions* 6 (1): 21–29.
Green, W. S., H. Kanis, and A. P. O. S. Vermeeren. 1997. "Tuning the Design of Everyday Products to Cognitive and Physical Activities of Users." Paper presented at the annual conference of the Ergonomics Society, Stoke Rochford Hall, April 15–17.
Harkema, Christelle. 2012. "Revealing Unawareness in Usability Related Decision-Making." PhD diss., Faculty of Industrial Design, Eindhoven University of Technology, Eindhoven, The Netherlands.
Hornbæk, Kasper. 2010. "Dogmas in the Assessment of Usability Evaluation Methods." *Behaviour & Information Technology* 29 (1): 97–111.
Iacucci, Giulio, Kari Kuutti, and Mervi Ranta. 2000. "On the Move with a Magic Thing: Role Playing in Concept Design of Mobile Services and Devices." Paper presented at the conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques, Brooklyn, NY, USA, August 17–19.
ISO. 1998. *ISO 9241-11 Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs) – Part 11: Guidance on Usability*. Geneva: International Organization for Standardization.
Janis, I. 1972. *Victims of Groupthink: A Psychological Study of Foreign-Policy Decisions and Fiascoes*. Boston, MA: Houghton Mifflin.
Kanis, H. 1998. "Usage Centred Research for Everyday Product Design." *Applied Ergonomics* 29 (1): 75–82.
Klimoski, R., and S. Mohammed. 1994. "Team Mental Model: Construct or Metaphor?" *Journal of Management* 20 (2): 403–437.
Mattelmäki, Tuuli. 2005. "Applying Probes – From Inspirational Notes to Collaborative Insights." *CoDesign* 2 (1): 83–102.
Mohammed, Susan, and Brad C. Dumville. 2001. "Team Mental Models in a Team Knowledge Framework: Expanding Theory and Measurement Across Disciplinary Boundaries." *Journal of Organizational Behavior* 22 (2): 89–106.
Nielsen, Jakob. 1993. *Usability Engineering*. Boston: Academic Press.
Norman, Donald A. 2010. "The Research-Practice Gap: The Need for Translational Developers." *Interactions* 17 (4): 9–12.
Prince, Michael. 2004. "Does Active Learning Work? A Review of the Research." *Journal of Engineering Education* 93 (3): 223–231.
Pruitt, John, and Jonathan Grudin. 2003. "Personas: Practice and Theory." Paper presented at DUX '03 Designing the User Experience, San Francisco, CA, USA, June 5–7.
Rosson, Mary Beth, and John M. Carroll. 2002. *Usability Engineering: Scenario-Based Development of Human–Computer Interaction*. San Francisco, CA: Morgan Kaufmann.
Roto, Virpi, Effie L.-C. Law, Arnold P. O. S. Vermeeren, and Jettie Hoonhout. 2011. "User Experience White Paper: Bringing Clarity to the Concept of User Experience." http://www.allaboutux.org/uxwhitepaper
Rubin, J. 1994. *Handbook of Usability Testing*. New York: John Wiley & Sons.
Sharp, Helen, Yvonne Rogers, and Jenny Preece. 2007. *Interaction Design: Beyond Human–Computer Interaction*. 2nd ed. New York, NY: John Wiley & Sons.
Simsarian, Kristian T. 2003. "Take It to the Next Stage: The Roles of Role Playing in the Design Process." Paper presented at ACM CHI 2003 Human Factors in Computing Systems Conference, Ft. Lauderdale, FL, USA, April 5–10.
Sleeswijk Visser, F., R. van der Lugt, and P. J. Stappers. 2007. "Sharing User Experiences in the Product Innovation Process: Participatory Design Needs Participatory Communication." *Journal of Creativity and Innovation Management* 16 (1): 35–45.

Suchman, Lucy. 1995. "Making Work Visible." *Communications of the ACM* 38 (9): 56–64.
van der Bijl-Brouwer, M. 2012. "Guidelines to Design for Dynamic and Diverse Use Situations." http://www.designforusability.org/wp-content/Guidelines-DDU_final.pdf
van der Bijl-Brouwer, M. 2013. "Exploring Usability. Design for Dynamic and Diverse Use Situations." PhD diss., University of Twente, The Netherlands.
van der Bijl-Brouwer, M., S. U. Boess, and C. L. E. Harkema. 2011. "What Do We Know About Product Use? A Technique to Share Use-Related Knowledge in Design Teams." Paper presented at the 4th World Conference on Design Research IASDR2011, Delft University of Technology, October 31–November 4.
van der Bijl-Brouwer, M., S. U. Boess, and C. L. E. Harkema. 2012. *The Envisioning Use Workshop*. TU Delft: Faculteit van het Industrieel Ontwerpen.
van der Bijl-Brouwer, M., and M. C. van der Voort. 2014. "Understanding Design for Dynamic and Diverse Use Situations." *International Journal of Design* 8 (2): 29–42.
van Kuijk, J. I. 2010. "Managing Product Usability. How Companies Deal with Usability in the Development of Electronic Consumer Products." PhD diss., Delft University of Technology, The Netherlands.
van Kuijk, J. I., H. Kanis, H. H. C. M. Christiaans, and D. J. van Eijk. 2007. "Usability in Product Development Practice: After Sales Information as Feedback." Paper presented at IASDR07, Hong Kong Polytechnic University, November 12–15.
Visser, Willemien. 2006. "Designing as Construction of Representations: A Dynamic Viewpoint in Cognitive Design Research." *Human–Computer Interaction* 21 (1): 103–152.
Wiltschnig, Stefan, Bo. T. Christensen, and Linden J. Ball. 2013. "Collaborative Problem-Solution Co-evolution in Creative Design." *Design Studies* 34: 515–542.
Wixon, Dennis. 2003. "Evaluating Usability Methods, Why the Current Literature Fails the Practitioner." *Interactions* 10 (4): 28–34.