Boundary Negotiating Mock-ups

Master Thesis by Thibaud Gentil

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Abstract

Designing usable smart products is a multidisciplinary effort that requires people with very diverse knowledge to collaborate. Collaboration is challenging because knowledge from various design stakeholders with different needs and constraints has to be integrated in a design. Design mock-ups are used by designers to facilitate the collaboration. Design mock-ups help integrate different perspectives because they evoke different things to different stakeholders and help them negotiate the limits within which they can agree on a design. Literature suggests the analytical boundary object concept as a theory to explain how mock-ups support the integration of knowledge in design collaboration. I review the literature on the boundary object concept and iterate it with the data collected from a one year ethnographic study of a multidisciplinary product development project to design a smart usable device. I discuss that the boundary object concept fails to conceptualize how mock-ups support negotiation and suggest the concept of dynamic boundary objects as a more appropriate concept for the role of mock-ups in design collaboration. Design mock-ups iteratively support the boundary negotiation activities of self-explanation, inclusion, compilation and structuring. They act as a scaffold for the creation of a shared understanding.

Introduction

Background

Designing smart usable devices is by nature a multidisciplinary design process in which designers will collaborate with a wide range of design stakeholders belonging to different layers of an organization such as management, marketing, sales, engineering, manufacturing and research, and with stakeholders outside of the organization such as external clients, sponsors and end users.

Collaboration between individuals with specialized knowledge and continuous user involvement is essential in order to cope with the tight technological limitations of smart devices and articulate them with the needs of the user. Collaboration between design stakeholders with different points of view is problematic; although specialized knowledge supports innovative problem solving it can also be a barrier for collaboration.

Mock-ups can be used for several purposes such as idea generation and the evaluation of ideas. They always serve as tools to support communication between different design stakeholders. A few authors in the design field have investigated the role of mock-ups in design collaboration and point to the analytical concept of the boundary object (Star and Griesemer 1989) to conceptualize how mock-ups help the integration of knowledge.

The concept of the boundary object describes artifacts that span across the boundaries of collaboration between participants with different viewpoints, needs and knowledge. This concept is somewhat confused as it has been applied to design prototypes that do not really fit the definition of the boundary object concept. The concept of the boundary object is suitable to explain how artifacts support cooperation in scientific work where there is a set task, structure and collaboration method. Boundary objects are not flexible enough to explain how design mock-ups support design collaboration, in particular how mock-ups support negotiation between design participants. This research reviews design collaboration, design prototypes and mock-ups. This research explores the concept of boundary objects and alternative concepts and aims to use them to develop a practical understanding of the role of mock-ups in design collaboration.

Method

This work uses a one-year ethnographic study of a product development project to understand how mock-ups support the evolving collaboration between designers and engineers. The project is used to analyze how characteristics of mock-ups such as attributes, prototypologies, purpose and stakeholders interact with each other and influence the collaboration. I participated in the project as an Industrial Design student and focused on promoting the use of mock-ups for articulating the needs and constraints on different functions and on documenting the process.

Ethnographic methods such as participant observation and formal and informal interview were used. The use of the prototypes and the mock-ups in the project were documented taking notes and pictures. Data was collected from September 2009 to April 2010. A great quantity of pictures of notes, project documentation, meeting briefings and pictures were collected.

The use of terminology to define the representations used in design is blurry. Terms like prototypes, mock-ups, model and representations mean different things in different projects and to different practitioners. Research works on the role of representation in collaborative design work are few and can be focused on specific types of representations such as the role of sketches in design engineering and the role of mock-ups in co-design. For this reason the term 'prototype' will be used as an umbrella term for all the forms used to represent the product the user and its context. This approach is used to collect a wider range of information on the role of prototypes in collaboration.

Through this literature research I gathered articles that identified the analytical concept of the boundary object as the most promising theory to explain how prototypes support the integration of knowledge in design. I reviewed literature from various fields such as sociology, computer supported collaborative work, knowledge management and design research, and iterated it against the data from the ethnographic study.

The iteration took the form of informal conversations with previous team members, reading notes and meeting briefs, creating diagrams, charts, tables and scenarios in the attempt to categorize a mock-up or one of its characteristics with a collaborative function.

The iteration supported the orientation of the literature review and helped me to identify an analytical concept that is more suitable to specify how mock-ups support the evolving collaboration in design. The dynamic model of boundary objects and further of boundary negotiating objects is a valid model to understand the evolving role of mock-ups in design collaboration. The analysis of the project data provides empirical data that support this conclusion.

Structure

This work is divided in seven parts:

Part one presents literature on design collaboration, design stakeholders and design for usability. The purpose of this part is to frame what type of project the Weatherway is and what this implicates in terms of collaboration. The purpose of this part is also to introduce how multidisciplinary collaboration is necessary but challenging in design in general, and in particular the design of smart usable devices.

Part two presents literature discussing the use of prototypes and mock-ups. The purpose of this part is to define the notion of prototype and mock-ups, their attributes, their purpose of use and the role they play in communication.

Part three presents literature reviews on the boundary object concept and its criticisms. The purpose of this part is to clarify the boundary object concept and then introduce the claim of this work.

Part four reviews the boundary negotiating object concept and the dynamic boundary object concept to give a deeper background for the analysis of the Weatherway project.

Part five presents a general overview of the Weatherway project and gives the data for the analysis.

Part six analyzes and discusses the Weatherway project in light of the literature review.

Part seven summarizes the findings of this research.

Short introduction to the Weatherway project

Weatherway is a product development project to develop a handheld terminal for use in rough conditions. Vaisala, a major weather instruments company, sponsored the project. The product that was to be developed involved usability and technological considerations. During the project many prototypes (sketches, mock-ups, models) were created. The use and development of the ergonomic mock-ups are the focus of this research. The project lasted one year and ended with the delivery of a working prototype of the product. The project involved ten students from engineering and design backgrounds as well as other partners. The project was held mainly in Helsinki, Finland, as part of the product development project of the Aalto design factory.

I. Collaboration in design of usable smart devices

Consider a well-known parable of blind men and an elephant. The blind men have never seen an elephant before and therefore have to touch it to learn what it is like, but each blind man can only touch one part of the beast. After touching the elephant to get a sense of it, the blind men get together to compare their notes and find out that they agree and disagree. The one who was touching the trunk believes that the animal is like a tree while the one who was touching a massive flank believes that the elephant is like a wall (Wikipedia, 2011).

Collaboration is the act of working jointly for a common goal. The metaphor of the blind men and an elephant (or men in the dark) is often used to demonstrate the relativity of truth regarding complex problems and the challenge of collaboration between individuals who have different points of view on the same problem. Multidisciplinary collaboration is essential to design usable smart products but it can also hinder the design effort when individuals with different specialized knowledge work together to solve a common problem. As design methods move towards a wider co-design, the role of the designer will be to create appropriate tools to support this collaboration (Sanders, 2008).

This part investigates the nature of collaboration in design in general and in particular in the design of usable smart products. The aim of this part is to present the specifics of the collaboration observed in the Weatherway project (see V.4) and to emphasize the importance of multidisciplinary collaboration in design in general. I will first clarify the specificities of collaboration when designing usable smart devices. Secondly I will discuss co-design as an emerging approach to enact multidisciplinary collaboration and how it will push the designer to become a facilitator. Thirdly I present the design process as a tool that roughly structures the collaboration based on the needs and constraints of a specific project. Lastly, I will discuss knowledge boundaries to illustrate one way in which collaboration, although essential, can be problematic.

I.1. Designing usable smart products

The task of the Weatherway team was to design a hand-held terminal with state of the art usability to make it useful in rough conditions (see V.1). The term 'usable' is used to refer to a product designed with usability as a main objective. Designing usable smart devices is better done following a user centered design process and working in close collaboration with a multidisciplinary team (see V.4). Multidisciplinary collaboration will bring insights on the technological constraints, which must be articulated and aligned to the needs of the user.

I.1.1. Collaboration in designing usable smart products

The design of usable smart products demands both multidisciplinary teamwork and continuous user involvement. Säde defines smart products as:

> *'[…] modern, interactive electronic consumer or professional product. They have original hardware and software and a specific set of tasks. Their user interface (UI) is limited when compared to computers.'* (Säde, 2001:7)

Designing usable smart product needs multidisciplinary collaboration (Säde, 1999) to cope with technological complexity and limitations. Smart products consist of a physical product and its interface, both should be considered as a *'[…] whole-product user interface'* (Säde, 1999:66). Designing the physical product and the interface demand different experts who must collaborate together to solve the dependencies that exist between the two components. When designing usable smart products, the technological constraints must be put in synergy with the user needs through multidisciplinary collaboration and continuous user involvement throughout the project (Säde, 1999).

I.1.2. Design for usability

Design for usability of an industrial product is the action of focusing the process of creation towards a product that has to satisfy specific usability needs. Usability of an emerging product is:

> *'[...] the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.'* (ISO 9241 DIS 1994)

The user should be able to use the device with a certain level of comfort (satisfaction) to achieve his desired task (effectiveness) and with the minimum amount of effort and time (efficiency) (Säde, 2001). Satisfaction is especially important when designing products that are voluntarily used, such as consumer products.

Usability is part of a series of factors that influence the product acceptability. In the utility theory, usability and likeability are balanced with cost support product acceptability. Nowadays usability is an implicit requirement of the user, and a product with a good usability will no longer be a pleasant surprise (Säde, 2001). Poor usability will be a disappointment for the user and prevent him from enjoying the utility of the product. Usability played a big part in the Weatherway project and for this reason many ergonomic mock-ups were created to evaluate whether the user could interact with the device while wearing heavy-duty equipment (see V.3 and V.5).

I.1.3. Designing usable products

The ten heuristics by Nielsen (1993), the height golden rules of Schneiderman (1998) or the ten principles of usable design from Jordan (1998), serve as a guideline to design usable products, in particular interactive interfaces (Säde, 2001). A common approach to designing usable products is to use the principles of human centered design (ISO 13407), which provides a framework to guide the design. Following a user centered design process minimizes the risk that the outcome does not match the users' requirements. While Sanders (2008) describes user centered design as scientific observation of the user, Säde (1998) takes a broader definition that also includes active participation of the user:

> *'The main principles of user-centered design include an iterative design process and continuous end user involvement, which requires effective way of communication'* (Säde 1998:561)

I.2. Co-Design

The type of collaboration observed in the Weatherway project can be described as co-design. Sanders (2008) describes co-design as collaborative creation of designers and other stakeholders, not trained in design, working together in the design development process. The Weatherway team members worked individually or in small specialized groups on their own task, often meeting in small or large multidisciplinary groups. During meetings they generated ideas and elaborated the needs and constraint of the project together. While specialized work and punctual interdisciplinary meetings describe standard design collaboration, the collaborative generation of ideas fits the broad definition of co-design by Sanders. Co-design emerged from an interest in the user and is a successor to user centered design and participatory design. Current co-design practice is user centric but in the future it will be more multidisciplinary and involve all the stakeholders in the design process in a tight cross-cultural collaboration. As Sanders states: *'Future co-designing will be a close collaboration between all the stakeholders in the design development process'* (Sanders, 2008: 17). The emergence of co-design will change the role of the designer into a facilitator for the different stakeholders involved. This future evolution of design described by Sanders can be witnessed in the Weatherway project where collaborative creativity between designers and engineers is punctually used as a natural way to foster collaboration in the design process.

I.2.1. Evolution of Co-Design

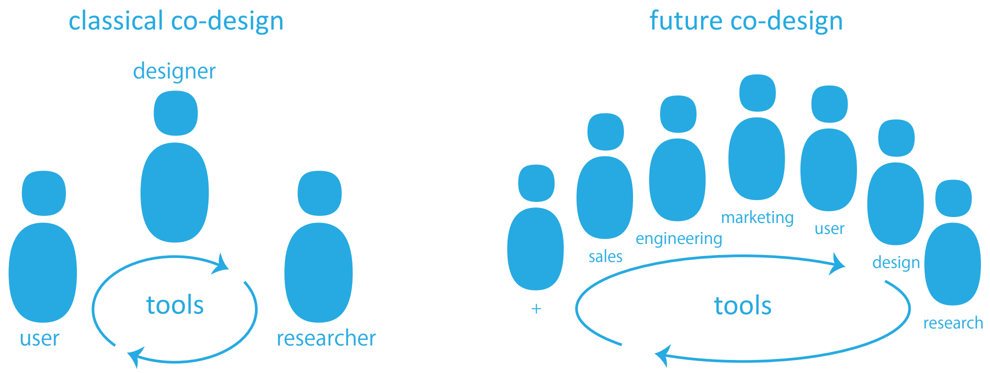


Figure 1. Future co-design will involve all the stakeholders of the design process.

Nowadays companies see a source of competitive advantage in the user. In the field of smart products the technological superiority alone can no longer grant competitive advantage. Product manufacturers want their products to provide superior user experience (Sanders, 2008) and we can understand that the idea of co-creation appeals to that purpose. Co-creation in this case describes a situation where the manufacturer involves the user in the creation of a product. We can see this practice applied with Nike ID where the customer can customize his own shoes before their production. The early phase of design where objectives are blurry and questions are unclear is called the fuzzy front end of the design process. The practice of co-creation in the industry currently happens mainly in the late phase of the design process but it is when applied in the fuzzy front end of design, it can have more positive, long-range consequences (Sanders, 2008).

Co-creation is not a new concept. Over the last sixty years design professionals have increasingly included the user in their design processes. This aperture gave birth to user centered design and participatory design. In user centered design the researcher studies the user and reports his findings to the designer. Participatory design, often described as the Nordic approach to design (Sanders, 2008), involves the user in the design process rather than studying him.

Faced with the complexity of interactive products and the present challenges of our society new design disciplines have emerged. These disciplines, such as interaction design, product design and service design, are product-centric. In phase with the growing interest in companies and from designers for the user, new design disciplines will emerge. The traditional disciplines of design are centered on products, the new design disciplines will be for the purpose of the user such as design for experience, emotion and sustainability (Sanders, 2008).

I.2.2. Role of the designer in Co-design

The change of focus in design from a product to a purpose perspective and the move from user-centered towards co-design is changing the role of the designer. In the classical user-centered design approach the user is the object of studies. The researcher observes and interviews him then reports his findings to the designer. In a co-design approach the user plays a role in idea generation, the designer gives form to ideas and provide tools to support ideation with the user (Sanders, 2008).

The role of the designer and researcher get mixed up as they act as facilitators for the user. Designers are skilled at *'[…] visual thinking, conducting creative processes, and finding missing information'* (Sanders, 2008:12). These skills will be necessary to solve complex design problems such as designing environments and systems for delivering healthcare. The designers will contribute their expert knowledge to the design development process. In co-design practice, designer will '*[…] make tools for non-designers to use to express themselves creatively'*. (Sanders, 2008:12)

I.2.3. Multidisciplinary Co-Design

New disciplines of design, according to Sanders, will emerge that are focused on purpose rather than product (Sanders, 2008:7). The fuzzy front end of design will see more involvement of the user in generating ideas and the designer will take the role of the researcher and facilitate the participation of the user. Co-design will not be limited to a tight collaboration with the user but will include a diverse range of design partners and tools to facilitate the cross-cultural communication will become highly valued. Sanders sums this up in the following statement:

> *'Future co-designing will be a close collaboration between all the stakeholders in the design development process together with a variety of professionals having hybrid design/research skills. These team players will vary across many types of culture simultaneously: disciplinary culture, company culture, ethnic culture, worldview, mindset, etc. […] In the future, the new co-design languages that support and facilitate the many varieties of cross-cultural communication will become highly valued.'* (Sanders 2008, p. 13)

I.3. Collaboration in the design process

Design of new products starts with the desire to identify a new opportunity for design, to solve a specific problem and ends with the release of a product to the market (British Design Council, 2007). Within this framework different partners – be they individuals, departments or organizations – participate in a collaborative cross-cultural effort. This cross-cultural collaboration is made of separate and common activities, which are arranged within the structure of the design process. Each design project is specific with its own goal and necessarily the partners vary according to the needs of the project. In this context all design projects have their own specific design process. Despite that there is no standard design process, there is core of four phases – as defined by the British Design Council – that can be used as a base for most projects and adapted in function of the needs and constraints to make a project specific design process.

Collaboration between the different project stakeholders can only be structured on a project basis, as the way stakeholders relate to each other and the problems that they solve together or individually depend on the needs of the specific project. Collaboration in the design process is often structured along the way as needs and constraints of the project are revealed (British Design Council, 2007).

I.3.1. The design process

Clarkson and Eckert (2004) have written extensively about the design process, surmising that the design process is a succession of activities and methods, which are arranged together depending on the requirements of a project. The purpose of the design process is to manage the different stages of the design and its related activities. They argue that the design process is usually represented as a linear succession of steps that organizes the activities of the designer through time. However, while the general overview might be a linear chronological flow, it serves more as a guideline and the design team may have to loop back on previous activities or start again. They conclude their findings by stating that there is no standard design process because the type of design process will vary depending on the scale, the size and the nature of the project.

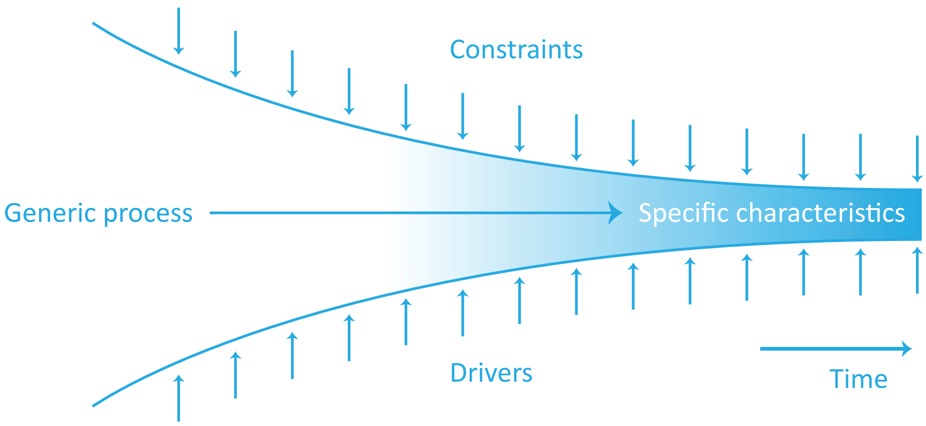


Figure 2. There is no standardized design process but generic steps that can be customized for a specific project.

The British Design Council (2007) has made an extensive study of the design process using case studies of leading global companies such as Lego and Whirlpool. Although the companies use different processes, the design processes themselves actually have similar stages. There is no 'best practice' design process but it is argued by the Design Council that there is a common central core. The core is adapted to the drivers and constraints of the project and becomes customized. It is generally agreed that there are four main stages in a design process.

Based on the findings of the 2007 study into the design process, the British Design Council developed its own 'double diamond' design process model. The process has four stages and emphasizes the fuzzy front end of the project and the divergent and convergent thinking activities of the design team: Discover, Define, Develop and Deliver. The four steps are illustrated below with the activities that were observed within them in the Design Council case studies:

- 'Discover' is where the needs of the user or the business opportunities are identified. In this phase the designers and researchers try to get inspired and to identify a design opportunity by immersing themselves in the world of the user or analyzing market research. This phase usually involves market research, user research, and managing information and design research groups.
- 'Define' is where the previously identified ideas are synthesized and a concept is proposed. The idea is defined and a plan of how to develop the product is made. The end of this phase and the start of the development phase are marked by corporate sign-off where the project is given corporate and financial support. This phase usually involves project development, project management and project sign-off.
- 'Develop' is where the idea is refined and made ready for production through multidisciplinary teamwork. The design team and other stakeholders get together to adjust the idea until it reaches a stage where a product is ready for production. This phase includes multi-disciplinary working, visual management, development methods and testing.
- 'Deliver' is where the first production article is tested and then the product is launched on the market. If necessary the product will be modified after the test. The success of impact of the product must then be reported to the organization. This phase involves final testing, approval, launch, targets, evaluation and the feedback loop.

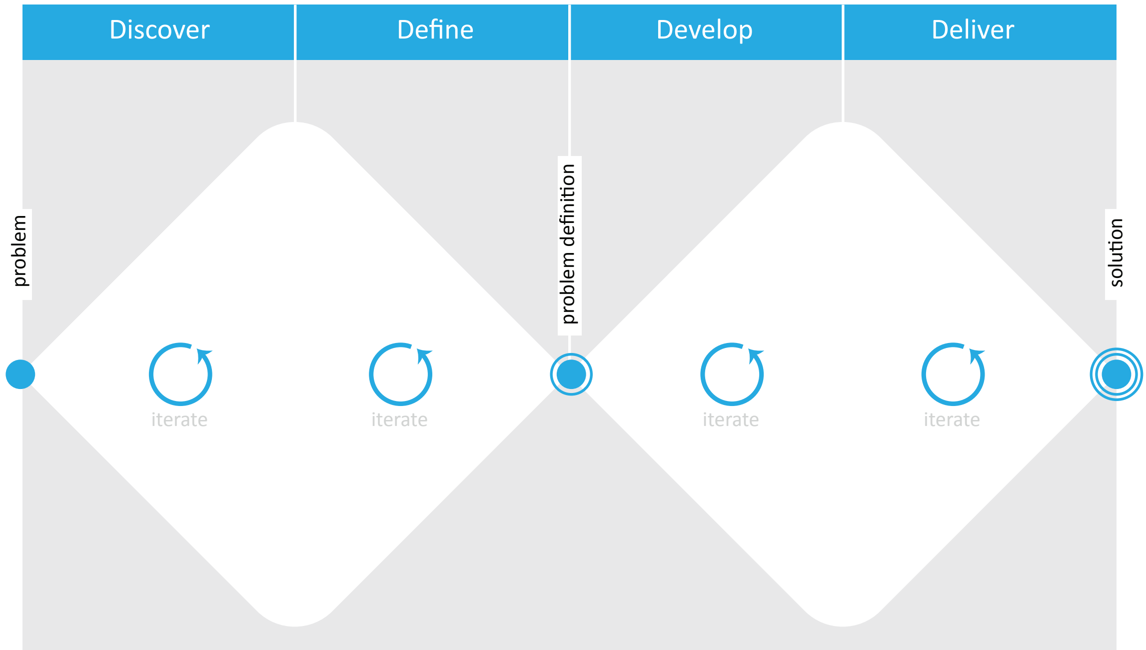


Figure 3. Design Council's Double Diamond design process.

I.3.2. Design stakeholders in the design process

The designer is involved in all stages of the process. At each stage the designer will collaborate with different disciplines to gather information, insights on feasibility or expertise. In Whirlpool's innovation process, designers and other stakeholders are involved from the beginning to the end of the project in tight collaboration (British Design Council, 2007).

In the initial phase of the project, the 'discover' phase, the designer will interact with the researchers and the users. The involvement of the designer is in user research and helping to clarify project objectives and identify problems and solutions straight from the observation scene or data.

In the ‘define’ phase it is important that the design team has a general overview of the factors such as a company’s financial situation, technological or production capabilities, social and economic context, sustainability issues and so on, that could affect the possible solution. As the British Design Council puts it: *‘[a] designer must engage with and understand the wider context in which this problem or opportunity sits, both within and beyond the company.’* (British Design Council, 2007:15)

This ‘define’ phase will engage the designer in internal communication with other specialists or departments, such as engineers, developers, material experts, research and development teams and product managers. Depending on the product type or company priorities some specific specialists will also be present. This is the case with Virgin Atlantic, a company that needs to comply with strict air safety regulations and requires input from an expert about these regulations (British Design Council, 2007: 15).

In the ‘develop’ phase multidisciplinary work with internal partners such as engineers, developers, programmers, marketing teams or external design agencies is essential to finalize the product. Input and advice from engineering and manufacturing experts is essential to identify problems early.

In the ‘delivery’ phase the design team will collaborate closely with internal partners such as marketing, communications, packaging, and brand managers to prepare the product for launch and identify any final problems before manufacture (British Design Council, 2007).

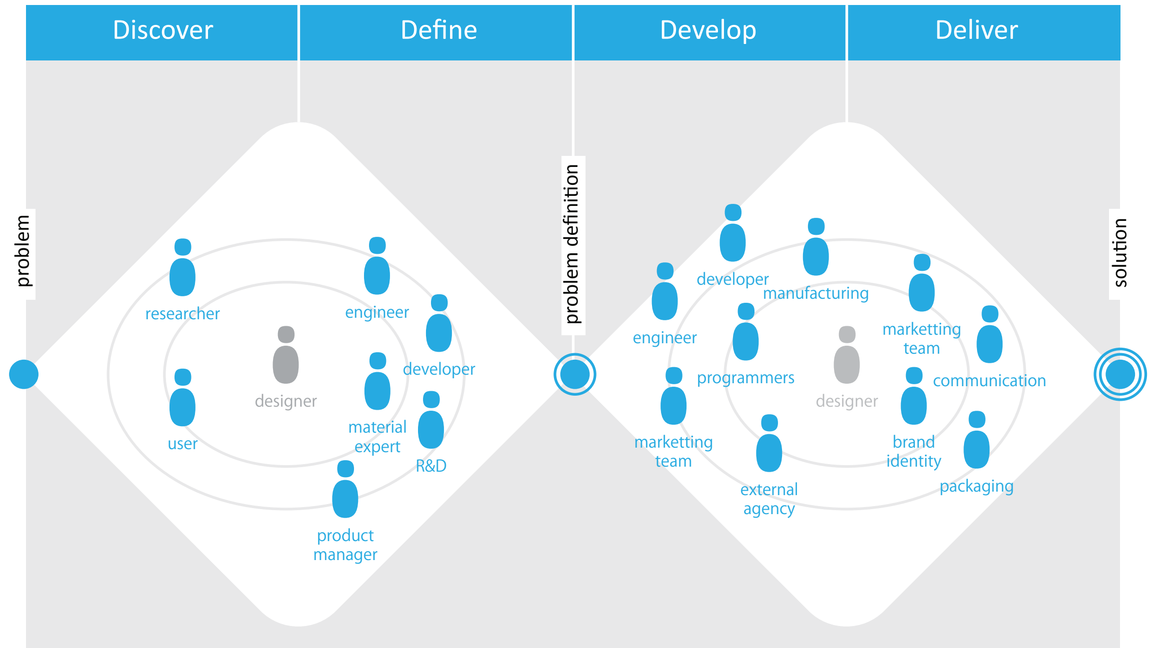


Figure 4. Design stakeholders with whom the design interacts in the different phases of the design process.

I.4. Boundaries of collaboration

Multidisciplinary collaboration and user involvement are necessary to design successful smart devices but this same collaboration can also hinder the design effort (Carlile, 2002). Different communities of practice bring their specialized knowledge to articulate the technological constraints that are typical of such a project. Specialized knowledge supports innovative problem solving within a field but when different communities of practice work together to solve a common problem their specialized knowledge can be a barrier to successful collaboration. In specialized fields, knowledge is localized, embedded and invested. Collaboration barriers will appear when collaborating disciplines lack a shared language, interpret meaning differently and feel that their knowledge is put at risk by the other discipline (Carlile, 2002).

I.4.1. Knowledge is a competitive advantage but can be problematic

In the design process many communities of practice collaborate with the designer to solve a problem or create a new product. Each community of practice contributes its specialized knowledge such as electronic engineering, ergonomics, material engineering, manufacturing, mechanical engineering and so on. Specialized knowledge is necessary but also a challenging source of competitive advantage for an organization. Specialized knowledge drives innovative problem solving within a specialized field but can be an obstacle in collaboration across different fields (Carlile, 2002).

I.4.2. Knowledge as localized, embedded and invested

Carlile argues that there are three types of knowledge that *'[…] drive innovative problem solving'* (Carlile, 2002:442) within the activities of a specialized community: localized, embedded and invested knowledge (Carlile, 2002: 442). When collaborating across the activities of those specialized communities, knowledge boundaries form that are problematic for the organization. There are three different approaches to work across knowledge boundaries: syntactic, semantic and pragmatic approaches.

Carlile expands on his idea of knowledge that is localized, embedded and invested in practice:

– Localized knowledge: Companies need to employ individuals from specialized fields to solve complex problems. Individuals are specialized with specific problems therefore knowledge is localized but not limited to that problem.
– Embedded knowledge: Knowledge accumulates with experience and is also enclosed in the tools that a specialized field uses. Embedded knowledge is the tacit knowledge of how we do something. Embedded knowledge is difficult to communicate to outsiders because 'we know more than we can tell'.
– Invested knowledge: Knowledge takes time and efforts to acquire, it represents an investment for the person who developed it and is therefore hard to give up. If individuals have to replace a method that they are experienced with and knows that it works with a method proposed (and developed) by another community then individuals *'[…] will face the cost of altering what they do to develop new ways of dealing with the problems they face.'* (Carlile, 2002:446)

I.4.3. Syntactic, semantic and pragmatic knowledge boundaries

According to Carlile, there are three types of knowledge boundaries that arise when individuals from different specialized communities collaborate across practice (Carlile, 2002: 443):

– A syntactic boundary arises when communities use a different syntax or language to describe a common problem. Developing a shared language will support communication across the communities.
– A semantic boundary appears when meaning is interpreted differently. Meaning of a shared

language can be interpreted depending on the context of use or based on the experience of specialized individuals.
– A pragmatic boundary surfaces when the hard won knowledge of an expert is at risk. To solve a pragmatic boundary knowledge needs to be transformed. This means that a known method to solve a specific problem needs to be changed and a new method needs to be developed.

Design of salable smart devices necessitates multidisciplinary teamwork to articulate the technological constraints, the production challenges and the user needs. Collaboration between all actors can be problematic. Specialized knowledge, different goals and motivations can create collaboration barriers when individuals from different backgrounds collaborate together. Prototypes can be used to face the challenges of design collaboration by facilitating the communication between all the different stakeholders and allowing them to express their point of view to the rest of the team. The next chapter will review literature on prototypes and mock-ups, their uses and attributes and their role in design collaboration.

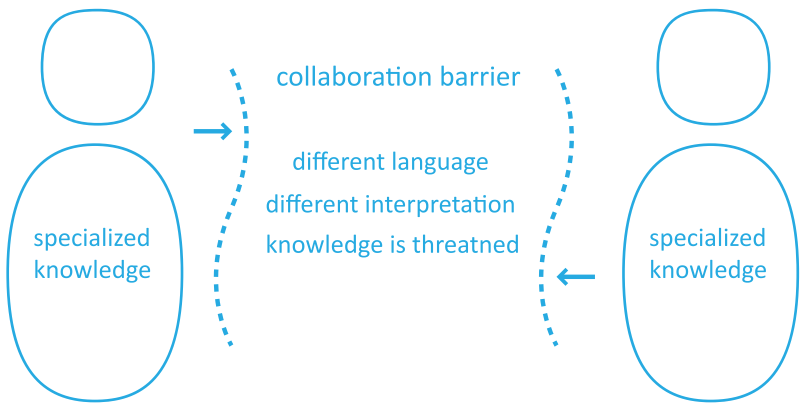


Figure 5. Boundaries between stakeholders with different specialized knowledge.

II. Prototypes and mock-ups

Prototypes are good tools to support the design of usable smart devices. Prototypes can be used for different purposes such as idea generation, testing, communication and political purposes. Prototypes always support communication. Different prototyping media and attributes can be selected to better support a particular purpose but it is better not to be too focused on one particular purpose. This allows other design stakeholders to bring up whatever a mock-up evokes to them.

This part gives a comprehensive overview of the nature of prototypes and mock-ups and focuses on the use of prototypes as communication media. At first I will clarify the notion of prototype. Secondly I describe the different types of prototypes and explain how mock-ups relate to this ensemble. Thirdly I present the attributes that are specific to prototypes and also to mock-ups. The fourth part documents different approaches to prototyping. The fifth part presents different purposes for which prototypes are used. The sixth part is about understanding prototype as media. The final part explains how prototypes can be used for communication.

II.1. Definition of 'prototype'

In product development prototypes are tangible representations of a product or part of a product and its context. Säde argues that these representations support the design process as they are *'[...] the physical process of capturing the design'* (Säde, 1999:66). These supporting representations are usually referred to as models or prototypes. Prototyping is the process of creating these representations.

A model is any description of the product being developed such as mathematical formula or a sketch of a working prototype. *'Model'* in product development is usually used to refer to 3D representation of a product as opposed to a drawing. However, the term *'model'* also includes other types of representations, such as a mathematical formula, and is more abstract than the term prototype (Keinonen *et al.*, 1996).

A prototype originally refers to a representation in which all the properties of the product are represented (Keinonen *et al.,* 1996). In fact the term prototype has different meanings in different organizations. In some it stands for *'[...] every product model built, no matter how rough'* while in others *'[...] only the working model that the organization has actually figured out how to manufacture'* (Schrage, 1993:59).

Previously, it would have been simpler to define clearly the difference between '*model*' and '*prototype*' but now their meanings are blurred. These terms are interpreted differently by different disciplines. The distinction between these terms is becoming less and less meaningful, they cannot really be used interchangeably but the meanings converge: they are *'flavors'* of the same thing (Schrage, 2000).

Ulrich and Eppinger (1995) say prototypes are approximations of the product along one or more dimensions of interest. In this work the term *'prototype'* is used in the sense of Bucheneau and Fulton-Suri (2000). This sense uses the term to refer to any of the representations of a design including sketches and mock-ups up to the first production unit of the final product. While for Schrage (2000) *'prototype'* carries the load of communicating how organizations use media to manage their innovation process, in this work it emphasizes how media works as a shared language amongst design participants from various origins. This definition is surmised by Bucheneau and Fulton-Suri:

> ‘ ‘*Prototypes’ are representations of a design made before final artifacts exist. They are created to inform both design process and design decisions. They range from sketches and different kinds of models at various levels — ‘looks like,’ ‘behaves like,’ ‘works like’ — to explore and communicate propositions about the design and its context.’* (Buchenau and Fulton-Suri,2000:1)

Prototypes have attributes from the product they represent and attributes of their own. These attributes include measurable properties like weight or size, less measurable ones like lifetime or ease of assembly and subjective ones like the ease of use. The attributes of the product that are represented in the model are the chosen properties such as performance, size, colour and reliability. The properties belonging to the prototype itself are attributes that derive from the prototyping technique such as the weight of a clay model of the finish of a rough foam model. The attributes of a product that a model excludes are also important as it allows the user to focus on specific features (Keinonen *et al.*, 1996).

II.2. Prototypologies

The heterogeneous ensemble of prototypes that lives within a design project is described by the term ‘*prototypologies*’ (Schrage, 1993). Prototypologies refer to a different combination of representations depending on the project. A prototype is designed to answer questions and as every project is unique in its scope the questions asked in that project will also be unique. Prototypologies will be different when designing usable smart products, services or designing for experience. Each organization will answer questions in its own way and will have a specific set of prototypes. The prototypologies of an organization is called the prototype portfolio.

Säde defines seven classes of prototypes that describe the emerging product, its user interface and the interaction between the user and the product: use scenarios, drawings and storyboards, UI maps, physical 3D models, paper prototype and computer modeling. Different prototypes represent the user, the events of use and the designed objects (Säde, 1999).

- ‘*Use scenarios*’ tell the story of a fictive person using the product in certain situations. It is made to evaluate how the user reacts to the product in a given situation.
- ‘*Drawings and storyboards*’ group many kinds of two dimensional representations from sketches to detailed renderings addressing the product, the user and the use environment.
- ‘*User interface maps*’ represent the structure of the user interface in the form of a diagram.
- ‘*Physical 3D models*’ are tangible mock-ups of the product. First rough mock-ups are made then more finished mock-ups of the appearance appear towards the end of the project.
- ‘*Paper prototypes*’ are used to evaluate the interaction between the user and the user interface early in the project. The UI is drawn on paper, the user ‘uses’ it by pressing the buttons and a designer manually changes the image of the UI.
- ‘*Interactive prototypes*’ are on-screen computer simulations of the user interface that can be interacted with through the human interface of a computer.
- ‘*Computer modeling*’ makes three-dimensional digital representations of the product hardware to inform manufacturing and evaluate the appearance.

Prototypologies can consist of any number of these seven classes, depending on the specific scope of the project.

II.2.1. Mock-ups

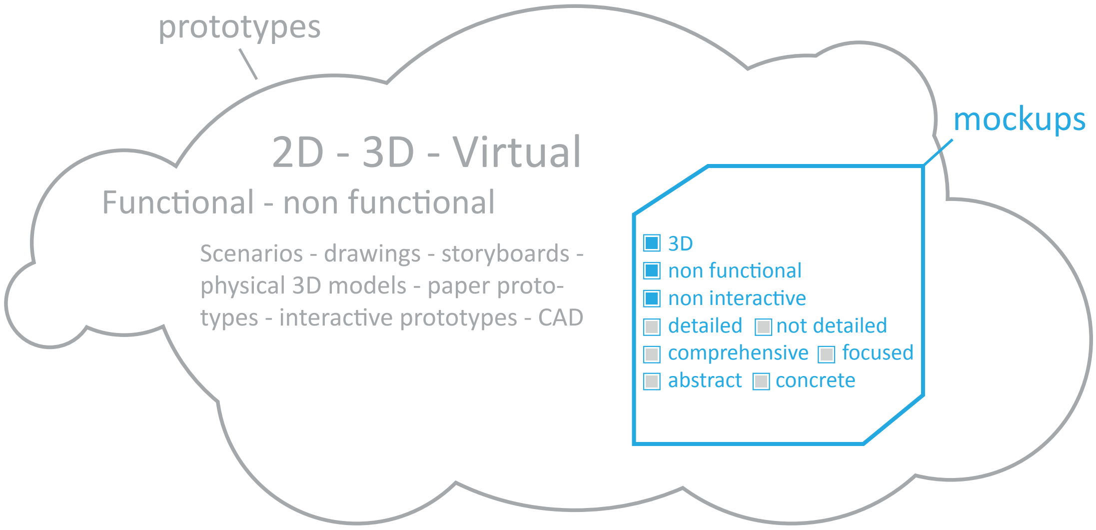


Figure 6. Positioning of mock-ups in relation to the concept of prototype.

Mock-ups are non-functional three dimensional representations of the design (Leonard-Barton, 1991). They are indispensable for designing physical 3D models and their environments because they are representations with volume and therefore truly tangible. They can be produced manually or using CAD and can be built of many materials, for example cardboard, clay foam, plastic, metal. They can be true to scale and represent most of the design related attributes of a product such as shape, color, size, surface and weight. As such they can be studied from any angle; they can be felt and touched. Mock-ups facilitate the analysis of ergonomics and usability the in real context of use (Säde, 1999).

Only some of the following prototype attributes relate to this definition of mock-ups. These are the level of fidelity, abstraction, focus and detail. This indicates that mock-ups are more specifically grouped than prototypes. For this reason mock-ups will form the basis of the case study presented in Chapter 6, as this grouping means that deeper analysis and comparison can take place.

II.3. Prototype attributes

Prototypes and prototyping techniques have many attributes and dimensions. Several authors have studied the different attributes of prototypes. Ulrich and Eppinger (1995) say that prototypes can be analytical or analytical and focused or comprehensive. Preece et al. (1994) divide prototypes in two categories of low-fidelity and high fidelity. Keinonen et al. (1996:71) make a comprehensive list of the most important prototype attributes. Keinonen states that a prototype can be:

– High-fidelity (finished, polished) or low-fidelity (rough): high-fidelity resembles the final product than more the low-fidelity one. A rough mock-up is low-fidelity while a 1:1 scale model of a car is high-fidelity.
– Concrete or abstract: is defined through the similarity of the technique to produce the prototype and the product. A user interface map is very abstract because it represents the structure of the interface in a schematic way as opposed to an interactive prototype of the interface, which has a close resemblance and behavior to the final interface.
– Comprehensive or focused: comprehensive prototypes represent most aspects of a product whereas a focused prototype goes deep into one attribute of the product. Focused prototypes separately explore what the product looks like or how it works, and are used together to evaluate the overall performance of a product.

- Detailed or undetailed: is the number of details in which one aspect is described. A detailed concrete model can represent all the aspects of the product, which is the same as being horizontal. An abstract model can also be detailed or undetailed. For example a technical measured drawing can include all dimensions for manufacturing or only overall dimensions.
- Interactive or non-interactive: the ability to get feedback from the model. A mock-up is usually not interactive in the sense that it does not give any feedback, whereas an on-screen user interface prototype allows the user to interact with the interface through the computer.
- Physical or virtual: physical prototypes are tangible, they are made of materials like a mock-up. Virtual prototypes are non-tangible and exist only in bits in a computer like a CAD model.
- 2-dimensional or 3-dimensional: A 2D prototype like a drawing is flat; a 3D prototype like a mock-up allows product attributes to be explored in more depth.

Additionally, there are other attributes that characterize prototypes: functioning or non-functioning, dynamic or static, using a common code or specialized code, modifiable or non-modifiable, early phase or late phase, communicating or private, exploratory or experimental, time-consuming or fast, expensive or cheap, complicated or easy, firm or fragile and external or internal (Keinonen *et al.*, 1996).

II.4. Prototyping

Several authors have searched for guiding principles for prototypes in design. Ulrich and Eppinger (1995) state some principles of prototyping for product design, discussing what type of prototype to build and how to integrate it into the project development plan. Säde (1999) summarizes important points and proposes a suitable process for prototyping when designing usable smart product. Schrage (2000) creates ten heuristics of how to approach and manage prototyping in organizations that want to be innovative.

Ulrich and Eppinger (1995:261) say that prototyping should be done by choosing the suitable type of prototype and considering its impact on the development process as a whole. They list five prototyping principles, which also illustrate the importance of prototyping:

1. Virtual prototypes are more flexible than physical prototypes because they can be easily modified and they allow for larger changes. For this reason they will usually come first and be used to limit the range of possibilities for the physical prototype. The physical prototype will be used to refine the design.
2. Physical prototypes are required to detect unanticipated phenomena. Physical prototypes intended to check to geometry might reveal something about the optical or thermal properties of the product. These might or might not be relevant for the final product.
3. A prototype may reduce the risk of costly iterations. If a molded part does not fit, the mold may have to be rebuilt. However, if a prototype is made of this part first the problem will be identified earlier and building the mold for nothing will be avoided.
4. A prototype may expedite other development steps. Short prototyping of a part may make the following steps easier and faster.
5. A prototype may restructure task dependencies. A software test is dependent on the existence of a physical circuit-board, therefore making a prototype of the circuit may allow the team to test the software while the circuit is being created.

When prototyping for usable smart products it is important to allow for an early evaluation of the total experience (Keinonen *et al.*, 1996). This can be supported by the iterative loop of idea generation, modeling and evaluation. Prototyping should aim at showing how the many dimensions of use of an interactive product influence each other. Prototyping should be done using a set of prototyping techniques that *'[…] flow into each other in an integrated way'* (Sade 1999:65) and are chosen for the situation at hand based on the approach of the designer. It is also important to find a set of techniques that is justified in the eyes of management and people who are more concerned in resource expenditure than in human factors (Säde 1999).

Prototypes are what an organization does, and what an organization does is more important than what they say (Schrage, 2000:201). Prototypes reveal a great deal about the character of an organization. The most important thing when prototyping is honesty because while prototypes are made to answer a question they often give unexpected answers. As Schrage points out: *' All too frequently, firms don't like what they see. So they ignore it, suppress it, destroy it, or dismiss it as an aberration. '* (Schrage, 2000:201). Schrage (2000:203-212) lists ten heuristics that can improve the benefits of serious play:

1. *'Ask, 'who benefits?' '* The most important question that must be asked when making a prototype is who will benefit from it. A prototype can inspire collaboration but also threaten other departments.
2. *'Decide what the main payback should be and measure them. Rigorously. '* Organizations should measure the desired benefits of their prototype against a metric that they consider critical. This assessment metric should reflect the values of the organization and how the users value the product.
3. *'Fail early and often. '* Prototyping early allows what Leonard-Barton (1991) calls '*fail forward'* which is the ability to unveil problems and solve them early where it is cheaper.
4. *'Manage a diversified prototype portfolio. '* The emphasis of prototyping should be on the interplay between different types of prototypes, which represent the same problem from different perspectives such as *'look like'*, '*behave like*' and '*work like*'.
5. *'Commit to a migration path. Honor that commitment. '* The benefits of a prototype should outweigh the cost of building and using it. The types of prototypes used should integrate into the production and distribution infrastructures of the organization.
6. *'A prototype should be an invitation to play. '* Prototypes should create dialogue. They should incentivize important stakeholders to explore new possibilities and make suggestions.
7. *'Create markets around prototypes. '* Prototyping should help create subsidies for the organization in the form of currency and knowledge.
8. 'Encourage role playing. ' Adopting the perspective of the customer or other team members can reveal the value of a prototype. This will also create cross-functional awareness.
9. *'Determine the points of diminishing returns. '* To avoid iterating too much an organization should have set criteria to make sure that the cost of prototyping does not outweighs the benefits.
10. *'Record and review relentlessly and vigorously. '* Organizations should learn from their prototyping by looking at how they built and used prototypes.

II.5. Purpose of prototyping

The type of prototype depends on its purpose. Ulrich and Eppinger (1995) suggest a process for prototyping in order to avoid what they call the '*hardware swamp*' (Ulrich and Eppinger, 1995:254) or misguided prototyping effort. This process consists of four steps:

1. Define the purpose of the prototypes
2. Establish the most suitable attributes
3. Plan the evaluation of the prototypes
4. Schedule the building and testing

The first step of this process is to define the purpose of the prototype. The morphology of design characteristics made by Buur and Andreasen (1989) can be used to relate the attributes of a prototype to its purpose. For example one can relate a high level of detail to answering a question about production. However, in collaborative setting, it is better not to be too focused on one particular purpose, as a prototype can be used to address different purposes and being too focused *'[...]can unnecessarily limit the designer and the user in their search for better solutions'* (Brandt, 2007)

One prototype can respond to different purposes. Ulrich and Eppinger (1995) suggest four reasons for prototyping: learning, communication between design partners, integration of different components and stakeholder perspectives, and using prototypes as milestones of the design development. All types of prototypes can be used for all four purposes but some are more appropriate than others for certain purposes.

Kurvinen (2007) proposes that prototypes can be used to generate social interaction around it in order to simulate the idea of the future service behind the prototype.

Leonard-Barton (1991) organizes prototypes in five categories. 2D models and non functional 3D models are used to communicate and test ideas. Functional prototypes are used to evaluate how well the product works. User test models are more comprehensive and support user testing. Organization system models allow evaluation of the interaction between the product and the environment in which it evolves.

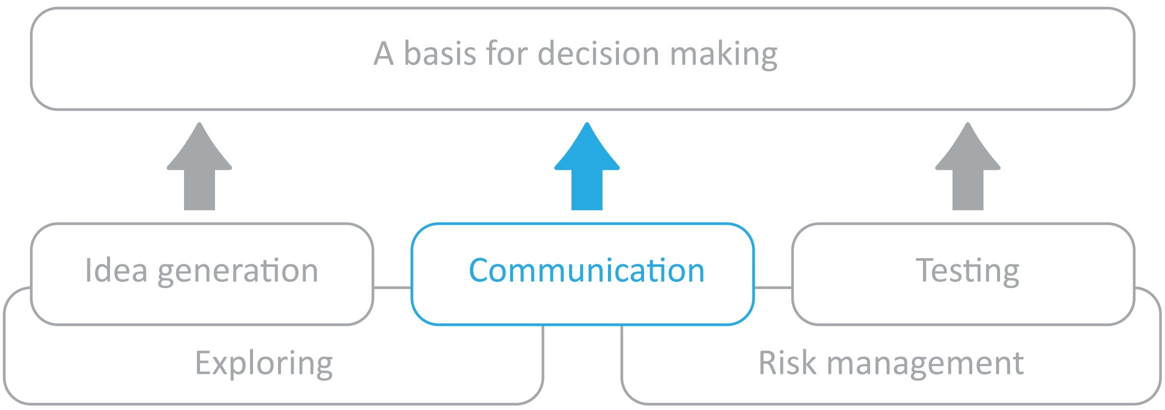


Figure 7. The three purposes of prototypes by Säde (1999).

Säde (1999) suggests that all purposes of prototypes can be grouped in three categories that altogether support decision-making: Idea generation, communication and testing. Designing usable smart products is a mesh of intersecting constraints that need to be articulated. Making a decision is not easy as it can have negative consequences on other aspects of the project or have unknown consequences. Representations support the decision-making process by transforming an idea into a concrete form, by integrating knowledge from different sources and by revealing problems early.

> *'The decision makers in a design process need information on which decisions can be based. The point of interest during the process shifts from exploring the possibilities to managing risks. The various reasons for modeling and prototyping can be categorized into three broad classes: idea generation, communication, and testing. '* (Säde, 1999:66)

II.5.1. Political prototyping

The purpose of prototypes is also political because they must be consequent to the role of the different stakeholders and the relationships of power in the design process. Firstly they act as political representative of the ideological positioning of the designer. Secondly they play a role in the politics of the design development process.

When designers use prototypes to communicate ideas they must be aware that they are actually taking a position on what they stand for. This is illustrated in a case study situation in Chapter 6. Kurvinen (2004) argues that prototypes are political because the essence of design activity is to generate proposals of how things could be. In design we do not study the world as it is but we create prototypes that allow us to study the world as it might be. Prototypes are proposals, they are informed guesses. As such they also take a position; a design that proposes a product that is more sustainable or more user friendly is in fact political. Design prototypes are politically positioned proposals.

Schrage (1993, 2000) says that prototypes are inherently political because they play a role in company politics. In company politics, as in any collaborative product development project, different stakeholders play different roles, some contribute to the idea generation while some give their approval to continue the development of the process. Prototypes are used to satisfy different political purposes:

> *'Sometimes a prototype is presented as a design platform to elicit feedback; at other times it is a sales tool to procure additional funding.'* (Schrage, 1993:59)

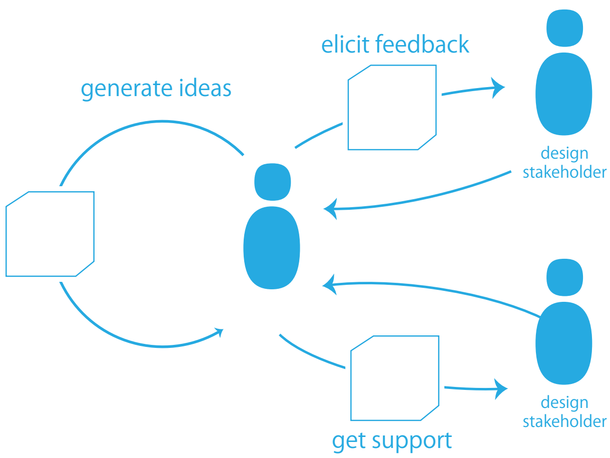


Figure 8. Mock-ups as political tools to elicit feedback and get support.

II.6. Prototyping media

Any prototype naturally serves a purpose of communication by mediating information from a sender to a receiver (Keinonen *et al.* 1996) Prototypes are media in the sense that they allow us to extend our reach to grasp new things much like a metaphor makes a concept accessible by putting it in a different way.

Maclullan (1964) says that media is an extension of ourselves, which we use to reach new understandings or reach further. Media is the extension of ourselves, like a cowboy is the servo mechanism of his horse. The media is part of ourselves like an extended arm where we do not recognize it as part of ourselves, in the same way that we are numb where we were amputated. When we adopt a new media to extend the reach of one of our senses, our other senses need to adapt so that we do not get overloaded with sensorial information. In the same way the adoption of a new media by society has implications for human relationship and social structures. Internet carries information instantly but what is meaningful is not the information it contains, but the way it changes the way we relate to each other and shapes the dynamics of society by making communication instant.

The role of media is to take information from one side and carry it to the other: media translates information from one form to another. The form of the medium influences how the information that is carried is perceived by the receiver. The perception of a story will be different whether it is told with a picture, in a book or on the radio. The same can be said of prototypes because a rough mock-up and a high-fidelity prototype will be used to communicate with different design stakeholders.

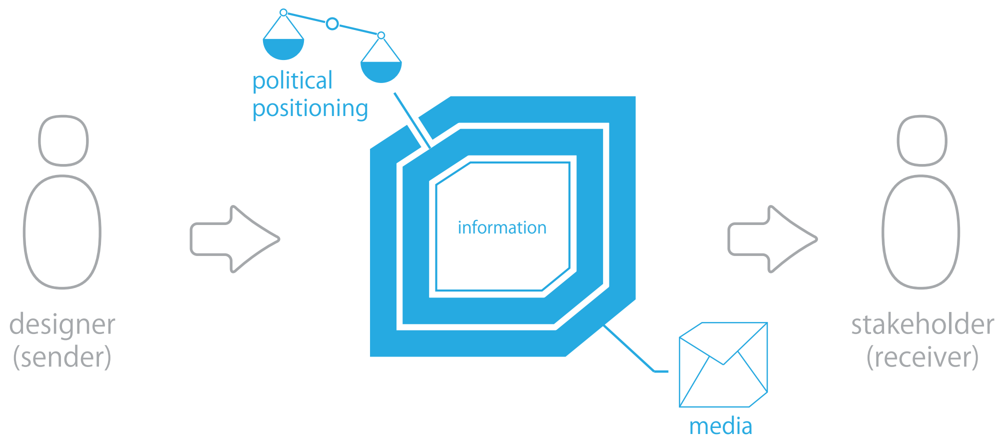


Figure 9. Mock-ups convey information from a sender to receiver. The political positioning of the information and the type of media used by the sender influences the perception of the message by the receiver.

II.7. Prototypes in communication

In design development prototypes can be used for various purposes. Prototypes are media that communicate information from a sender to a receiver. As such they will always be communication tools independent of what the main purpose of the prototype is. Sometimes their main purpose is to communicate with other design stakeholders. Prototypes are made to do something with someone, so when talking about the communication purpose of a prototype we need to define both use and user. Prototypes can be used to generate ideas in collaboration with designers, users and customers, to test an idea with the user, to explore and refine the design specifications with the client or as political tool to get the support of management.

When prototyping it is important to be aware that the prototype media influences the communication in different ways. The prototype media itself depends on the purpose for which the prototype is used. In brief it is important to make it clear what the prototype will be used for and who will be benefiting

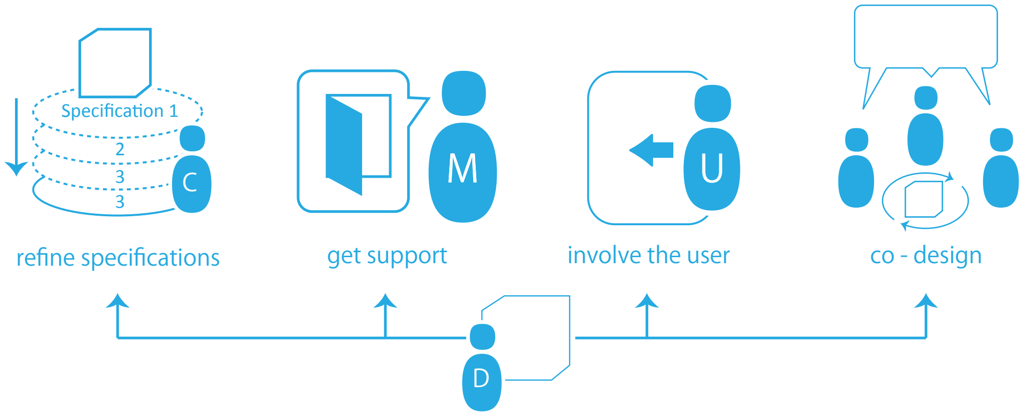


Figure 10.Purpose of prototypes in product development.

from it because this will influence the communication and therefore the collaboration.

Low-fidelity prototypes and iterative prototyping can be used as mean to refine the specifications for the design of software (Schrage 2000). The hardest part of building a software is deciding the design specifications. This problem arises because the designer needs to get the software requirements from the client but the client cannot provide complete and specific requirements. In practice the client often does not know precisely what he wants. Creating a dialogue between the designer, the client and a prototype can help this problem. Low-fidelity prototypes can be made early in the design process because they do not demand much time or expense. Using the specifications from the client the designer can make a quick representation of his idea and get feedback from the client. This will also help the client to get a better idea of what he wants and make him refine the specifications for the product. This loop from specifications to representation then again to specifications and so on is an iterative loop. As low-fidelity prototypes are easy to make or modify the iterative loop can be repeated as often as necessary. Iterations of the specifications will stop when the specifications are clear enough to decide the next steps of the design process.

Concrete prototypes can be used to facilitate the end-user involvement. When designing a usable product the biggest communication challenge is facilitating the user involvement. It will be easier for the user to talk about his needs when he has the mock-up of a device in his hands and can play around with it and simulate its use. Jacucci et al. (2000) show how a simple block of wood can be used to generate discussions with the user. Prototypes act as a common language between the design and the user. The ability of representation to serve as a common language depends on how abstract the representation is. The more abstract the representation the more specialized knowledge is needed to comprehend it, for example verbal documents and diagram. If the purpose of the representation is to communicate with the end-user then it must be concrete (Säde 1998).

High-fidelity prototypes are useful to get support from management. At some stages of the development of a design the designer is dependent on the management side of the organization to bring the idea to the next stage. In an organization, management is often the gateway from concept definition to product development. The designer presents the idea in a way that justifies the investment and the risk that the organization will take in committing to its development (British Design Council, 2007). The designer will create representations that are explicit and cover the points upon which management is concerned. In Toyota the mock-ups of the car interior made by the designers are usually built in foam board to help the designers deal with proportions and structure of the driving system. Foam board is useful for this purpose but it is rough and white and therefore too abstract to present to the department of sales, which needs a more realistic overview of the product. Renderings are good to present the aesthetic qualities of a product but unable to address questions of volume and dimensions. For this reason the presentations of the foam board mock-up of the interior is usually complemented with a rendering of the interior.

Using low-fidelity prototypes such as mock-ups is useful to establish a common ground between users, customers and designers in co-design sessions. The level of details of the mock-up will affect the communication. Simple mock-ups without many details will bring up a wider range of questions while high-fidelity mock-ups will lead to a more focused conversation. In this kind of collaboration it is better not to be too focused on the purpose of the mock-up so that the participants can bring up whatever the model evokes to them (Brandt 2007).

II.8. The concept of the boundary object proposed to theorize the role of mock-ups in collaboration

The boundary object concept and 'inscription devices' are proposed to theorize the role of mock-ups in design collaboration. By acting as boundary objects, mock-ups span the boundaries between the different design stakeholders and act as inscription devices, recording knowledge into a physical product. Mock-ups support co-design because they act as boundary objects and inscription devices (Brandt, 2007). However, this role is not only found with mock-ups in co-design. Research on different types of prototypes and design collaborations have linked prototypes to the theoretical concept of boundary object and also inscription devices (Leonard-Barton, 1991; Henderson, 1998; Brandt, 2007).

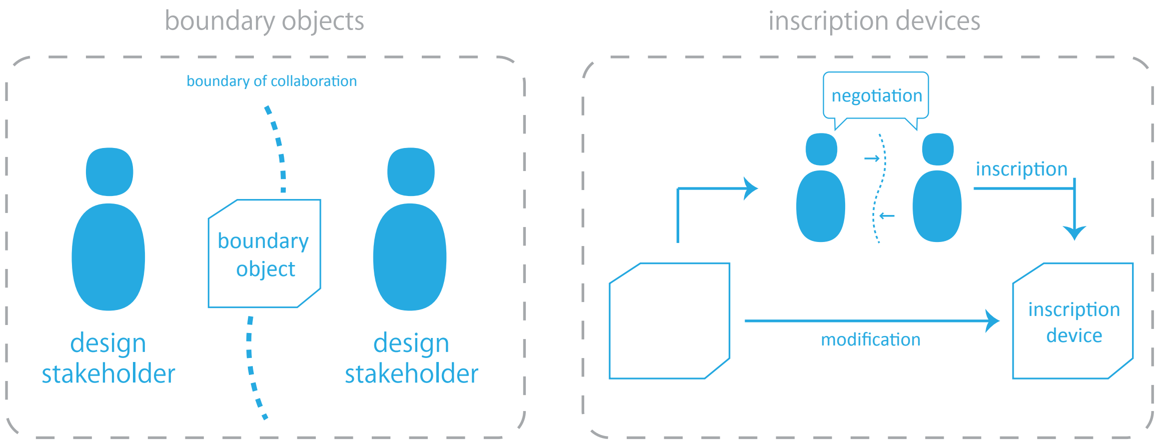


Figure 11.Mock-ups support design collaboration by acting as boundary objects and inscription devices.

Brandt (2007) states that mock-ups act as boundary objects because they allow participants to bring up their own perspectives and help them figure out how they can all agree. A mock-up will be interpreted differently depending on the perspective of the different design stakeholders. When customer, user, and designer interact with a mock-up they will bring up different issues. In collaboration the different perspectives need to be negotiated to find the limits within which each participant can agree. This is not an agreement in the sense that all the different stakeholders will come to adopt the same perspective, but in the sense that the design will make sense to the different points of view according to their interest in the product.

Mock-ups are inscription devices after they have been modified to reflect the comments and the decisions made by the different stakeholders. The process of inscription means that information is transferred from one setting into another. In this case knowledge from different design stakeholders is materialized into a mock-up.

Henderson (1998) has described how engineering drawings serve as boundary objects. Design sketches and drawings act as boundary objects because designers and engineers can understand them on multiple levels. The sketch of a welded joint makes the designer think about how this part fits into the structure of the product. On the other hand, workers in the shop think about the labor that will be needed to realize it. The sketch becomes an inscription device when it is modified after discussion to reflect the suggestions of other participants.

Keinonen et al. (2008) say that prototypes in design act as boundary objects that links the realities of the user and the designer.Leonard-Barton (1991) also suggests that prototypes work as boundary objects because they act as bridges that span the language boundary between different disciplines. The complexity of design needs different disciplines such as engineering, manufacturing, marketing and sales. All these disciplines use their own specialized terms to express their understanding of a problem. Representations work as a lingua franca spanning the language boundary between the different disciplines and allowing communication that does not need specialized terms. This aspect of representations has the advantage to allow stakeholders who have a less specialized and scientific background to contribute to the project. Representations that span language boundaries also work as a symbol of the target product that keeps the team members focused on their objectives. These are all very important aspects of a collaborative process.

The concept of boundary object is important to understand how design mock-ups support the sharing of knowledge, the negotiation of points of view and the recording of reached agreement in multidisciplinary design collaboration. The next chapter will review literature on the boundary object concept.

III. Boundary objects

The purpose of this literature review is to explain the boundary object concept, to document its evolution and to present the main criticisms – such as the concept of boundary negotiating objects and dynamic boundary objects – to the concept. Two amendments in particular: the concept of a boundary negotiating object (Lee, 2007) and the concept of a dynamic boundary object (Pennigton, 2010) will be presented.

Firstly I will introduce the original the boundary object concept supporting it with examples. I will then document literature using the concept in a variety of fields, followed by literature criticizing the concept. I will list the main criticisms and amendments and then present the boundary negotiating object concept (Lee, 2007) that led Pennington to create her dynamic model. The following part will detail how Pennington re-interprets the boundary object concept .

Note on terminology :

Throughout the evolution of the concept of the boundary object, different authors use the term *'boundary object'* to refer to different concepts, or use different terms to describe the same concept. For the sake of clarity the following terms will be used:

- *'Boundary object'* refers to the original conceptualization of boundary objects by Star (1989)
- *'Dynamic boundary object'* is coined to refer to the reinterpretation of the boundary object concept by Pennington (sensu Star and Griesemer, 1989). Dynamic boundary objects are all *'[...] artifacts that bridge different viewpoints'* (Pennington, 2010:176). Dynamic boundary objects include two subclasses: boundary negotiating objects and boundary specifying objects.
- *'Boundary negotiating object'* will always be used to refer to the concept of boundary negotiating artifacts (Lee, 2007) and to the sub category of dynamic boundary objects with the same characteristics. Boundary negotiating objects *'[...] negotiate the interaction between viewpoints'* (Pennington, 2010:176).
- *'Boundary specifying object'* will be used to refer to the subcategory of dynamic boundary objects having the same characteristics as the original concept of the boundary object of Star. Boundary specifying objects, *'[...]specify viewpoints and fully mediate their interaction'* (Pennington, 2010:176).

The term *'boundary'* will be used in a geographical sense where we understand knowledge, needs, constraints, working methods and motivation as territory of a stakeholder or a community and boundary as its border. Boundary negotiation between two stakeholders should be understood as the act of pushing and pulling these boundaries.

The term *'object'* will be used in the sense of Star (2010) to refer to something people interact with that is not necessarily physical. For example a theory can be considered an object.

III.1. Boundary objects

Star and Griesemer (1989) study how individuals with different backgrounds and perspectives successfully collaborate for a common endeavor. They establish that two activities are essential for this: method standardization and boundary object creation. Their findings are documented by a case study of the creation of the Berkeley Museum of Vertebrate Zoology in California. In this study scientists and animal collectors worked jointly together. The scientists needed precise documentation and proper preservation of the animal specimen captured by the collector who was not used to such practices.

Method standardization is an agreed method of work across different allies. In the study, sample collection standards were used that fitted the needs of the scientist for accuracy and preservation whilst remaining simple enough for the collector to comply with. One example of a boundary object is the standardized forms that the collectors had to fill out. The forms meant that the specimen collected was accompanied by the information needed by the scientist.

III.1.1. Definition of boundary objects

Boundary objects describe artifacts that act as bridges between the perspectives and activities of different individuals working jointly. Different individuals with different purposes can use the same objects. A boundary object has a standard structure that is understood by all its users. It conveys sufficient information so that one individual can use it for his own activity and doesn't need to negotiate its use with the other users. Start and Griesemer (1989) define boundary objects as such:

> *'Boundary objects is an analytical concept of those scientific objects which both inhabit different social worlds and satisfy the information requirements of each of them. Boundary objects are objects that are plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use and become strongly structured in individual site use. They can be abstract or concrete. They have different meanings in different social worlds but their structure is common enough to make them recognizable, a mean of translation. The creation and management of boundary objects is a key concept in developing and maintaining coherence across intersecting social worlds.'* (Star and Greisemer, 1989:383)

III.1.2. Types of boundary objects

Star and Griesemer study how animal collectors, scientists and other actors collaborate for the creation of the Berkeley Museum of Vertebrate Zoology and identify four types of boundary objects. These four types form a list that is not intended to be exhaustive:

1. *'Repositories'* contain objects that can be found using a standard index known to all the individuals. They are like libraries; the objects contained can be used by different individuals for their own activities without having to negotiate how they will use them with other users.
2. *'Ideal Type'* has general or vague content. The Ideal Type is like an atlas that contains many different maps that can be used by the different individuals for their own activity. The individuals can all use the atlas because it uses a standard representation system that makes it understandable by everyone.
3. *'Coincident Boundaries'* is suited to describe abstract objects such as the boundary of the state of California. It represents the same thing but its internal content is different depending on the individuals using it.
4. *'Standardized Forms'* are just like forms. They can be filled with information from the activities of the different individuals but their structure is standard so all individuals can understand them. They support the communication of information across different communities.

III.2. Boundary objects amended

The concept of the boundary object (Star and Griesemer, 1989) has an important role in theorizing the workings of collaborative work. In Computer Supported Collaborative Work (CSCW) it lays as one of the fundamental concepts of the discipline. The concept has been widely used but consequently widely criticized. Ackerman (2006) describes boundary objects as a *'[...] critical, but understudied, theoretical construct in CSCW'* (Ackerman, 2006:341). Boundary objects are also used in management research (Carlile 2002, 2004), in sociological studies of product development (Henderson, 1998) and in design research (Brandt, 2007).

III.2.1. Boundary objects in literature

Berg and Bowker (1997) describe how patients' records act as boundary objects that represent the patient to the staff of the hospital. Kovalainen (1998) observes the role of boundary objects in the coordination of work at a paper mill. Henderson (1999) describes how design engineers organize themselves around visualizations in the context of the shift of their tools from paper to digital. Yamaauchi (2000) uses boundary objects to analyze the information mechanisms used by open source programmers. Bossen (2002) observes how healthcare documents act as mediators between different communities of hospital staff. Carlile (2002) describes boundary objects as an approach to solve knowledge boundaries. Ackerman (2006) observe the role of artifacts in a service aimed at the practical achievement of safety and the role they play in organizational memories. Brandt (2007) uses boundary objects to illustrate how the level of detail in mock-ups affects the discussion between designers and professional users.

III.2.2. Introduction to the criticisms

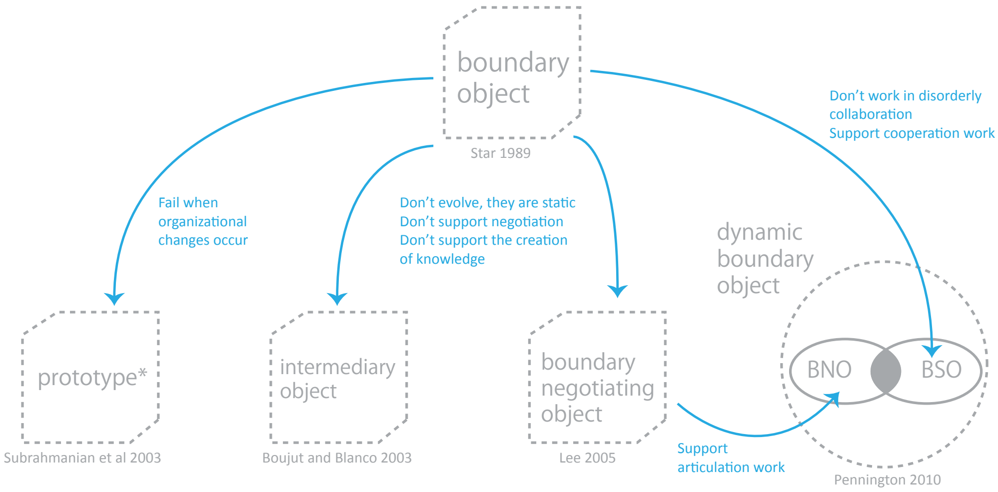


Figure 12.Criticisms and amendments to the concept of the boundary object.

Several research works that build on empirical studies have pointed out that boundary objects are insufficient to explain how artifacts support collaboration in practice. Sometimes the use of artifacts in practice does not match the definition of boundary objects or there are essential aspects that are unaccounted for.

The criticism addresses different aspects of boundary objects. These aspects are: the type of differences between the participants; the nature of the organizational or collaborative context in which the artifact is set; how the participants organize themselves around the artifact and the content of the artifact itself. The concept of the boundary object does account for the possibility that there can be *'good'* and *'bad'* boundary objects because there are different types of knowledge boundaries between individuals (Carlile 2002, 2004). To support collaboration some artifacts need contextual information to be understood by the receiving party (Lee, 2007). Boundary objects may fail when organizational changes happen because they are static (Subrahmanian *et al.*, 2003). In design work artifacts also support collaboration by conscribing participation (Henderson, 1999).

More to the point of this research is that boundary objects do not describe artifacts that support negotiation or confrontation between different parties (Boujut and Blanco, 2003) and that they are inappropriate for new collaborations in interdisciplinary teams (Lee, 2007).

III.2.3. Alternative concepts of material artifacts in collaboration

Criticism of the concept of boundary objects led authors to amend the concept and create alternative concepts. The research on this topic comes mainly from CSCW.

CSCW or Computer Supported Collaborative Work addresses *'[...] how collaborative activities and their coordination can be supported by means of computer systems.'* (Carstensen and Schmidt,1999)

Below I list the main concepts whose purpose is to theorize the role of material artifacts in collaborative practice. These theoretical concepts *'[...] overlap to form a patchwork quilt of frameworks that are moving us toward an increasingly sophisticated theoretical understanding of collaborative work.'* (Lee, 2007: 388). The concepts are:

1. Inscription devices (Latour, 1979)
2. Boundary objects (Star 1987,1989; Star and Greisemer, 1989)
3. Coordination mechanisms (Schimdt and Simone, 1996)
4. Conscription devices (Henderson 1999)
5. Prototypes (Subrahmamian, Monarch *et al.*, 2003)
6. Intermediary objects (Boujut and Blanco, 2003)
7. Ordering systems (Schimdt and Wagner, 2005)
8. Boundary negotiating object (sensu Lee, 2007)
9. Dynamic boundary objects (sensu Pennington, 2010)

As mentioned above, the works of Boujut and Blanco (2003) and of Lee (2005) are most relevant to this research. As the concept of *'prototype'* is useful in illustrating the criticisms to the concept of boundary objects I will introduce it first and then the concept of intermediary objects and boundary negotiating objects. Later I will further develop on the concept of boundary negotiating objects, as it is essential for understanding dynamic boundary objects.

III.2.4. Prototypes

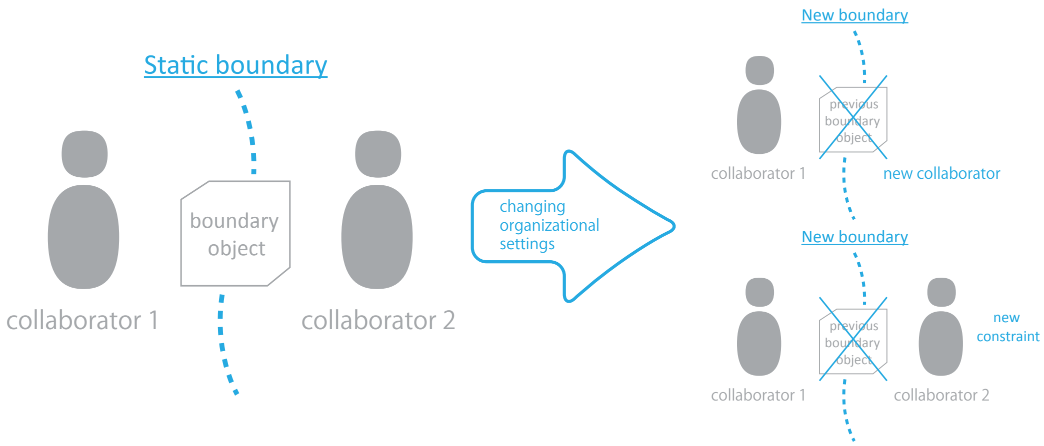


Figure 13.Boundary objects are static and will fail when organizational changes occur.

The concepts of prototypes and intermediary objects strongly amend the concept of boundary objects. For Subrahmanian et al. (2003) boundary objects may fail when organizational changes occur, as they cannot be updated. Subrahmanian creates the concept of prototypes to describe artifacts that represent the current state of the product or process being produced, which can be updated to continue to satisfy the information needs:

'Prototypes are not only static means of translation (Bowker and Star, 1999:297) but also dynamically change and rechange their representational status in the achievement and breakdown of shared understanding.' (Subrahmanian *et al.*, 2003)

Prototypes allow different individuals to learn about the concepts of others and support the creation of shared concepts between those different individuals:

' In our view, prototype reconcile at a cognitive level 'two or more differently naturalized classification systems' (297) by acting as intermediary between them enabling two communities to share at a cognitive level the same quasi classification system or concept (term) network.' (Subrahmanian *et al.*, 2003: 187)

III.2.5. Intermediary objects

Boujut and Blanco (2003) view co-operation as a process of negotiation and compromise to create specific shared knowledge. They conceive intermediary objects to describe objects that act as boundary objects and represent the undergoing collaborative process of negotiation and compromise to create specific shared knowledge:

'Intermediary objects act as boundary objects. But intermediary objects are also intermediate states of the product if we consider the objects as mediators translating and representing the future product.' (Boujut and Blanco, 2003:211)

III.2.6. Boundary negotiating objects

Figure 14.Boundary objects do not support negotiation.

Established collaboration refers to collaborations that are standardized, with individuals doing different specified tasks in a planned way. In this collaboration the needs, constraints and working methods of the different stakeholders involved are clearly specified and do not change.

Disorderly collaboration refers to collaboration that does not have a clear work protocol, where the needs and constraints of the different parties and the roles of the different stakeholders are not clearly specified.

For Lee (2005) boundary objects respect a specific collaboration protocol and are static. For example, the animal collector and the scientist use a form to share information about the captured specimen (Star and Griesemer, 1989:401). This form will not be useful anymore if the scientist has new information needs. In this sense the form is static in that it will fail in the face of change. For Lee, boundary objects are also meant to satisfy the information requirement of each user thus individuals do not need to discuss their use. Boundary objects arise from durable cooperation amongst communities so this becomes a problem for theorizing new and non-routine collaborations. Boundary negotiating artifacts describe artifacts that live within chaotic and non-standardized collaboration and are defined by the context of their use. They are artifacts that do not fit the definition of boundary objects. These artifacts can be used to create and change protocols and they support the negotiation between different individuals. Boundary negotiating artifacts are used to:

> *'[...] record, organize, explore and share ideas; introduce concepts and techniques; create alliances; create a venue for the exchange of information; augment brokering activities; and create a shared understanding about specific design problems.'* (Lee, 2007:403)

III.2.7. Dynamic boundary objects

Pennington (2010) investigates the relationship between boundary negotiating objects and boundary objects, which she renames *'boundary specifying objects'*. Pennington analyses disorderly collaboration and proposes that such collaboration can be divided in two stages that flow from one to the other. The first stage is articulation work, which is a process of negotiation between the different stakeholders. The second stage is cooperation work where the roles and tasks of all stakeholders have been specified and therefore distributed work can be carried out, as the stakeholders no longer need to interact or negotiate with each other. Articulation work leads to the creation of a shared understanding, which enables the stakeholders to specify their tasks and then do cooperative work. For Pennington, boundary negotiating objects support articulation work while boundary specifying objects support articulation work.

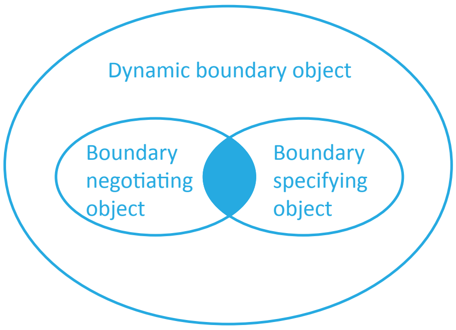


Figure 15.Dynamic Boundary Objects (sensu Pennington 2010).

III.2.8. Any object is not a boundary object

Star (2010) discusses her original concept of boundary objects in light of the criticisms that have been made about it. There are three important aspects of boundary objects: interpretative flexibility, organizational structure of the object and the dynamics between ill-structured common use and tailored local use. Interpretative flexibility has been the most used of these aspects to discuss the concept of boundary objects nearly becoming synonymous with interpretative flexibility.

Interpretative flexibility means that an object has different meanings and uses depending on one group's point of view (interpretation of the object). The same roadmap might be used by one group to find a campsite for recreation purposes, while another other group may be interested in the animal habitats the map shows.

Organizational structure of the object refers to the fact that boundary objects are organic infrastructures that arise from the information and work requirements of different communities doing things together. Boundary objects are *'[...] a sort of arrangement that allow different groups to work together without consensus'* (Star, 2010: 603).

Boundary object is weakly structured in common use and tailored in local use (not interdisciplinary work) (Star, 2010). When communities cooperate without consensus they *'[…] talk back and forth between both forms of the object'* (Star, 2010:605); there is a dynamic between the common and the tailored use of the object.

To the question *'couldn't anything be a boundary object?'* Star answers that it depends upon *'Scale'* and *'Scope'*, as with any theory. The kind of object or scale a boundary object is at its most useful is the organizational level. The scope is the work arrangements and heterogeneity of communities working together.

When asked if a word could be a boundary object Star answers that there are better concepts that address the ambiguity of words and that the concept of the boundary object is more useful at an organizational level.

Some have asked if the national flag could be a boundary object (Star, 2010). To this Star answers:

> *'Under some circumstances, any of those examples might become a boundary object. All are certainly subject to interpretative flexibility. However I believe that the most useful level of scope for the concept is more specific. I think it would be more interesting to study people making and distributing American flags, and their work arrangements and heterogeneity than to simply say that many people have different interpretations of the American flag'.* (Star 2010)

III.3. Claim

This literature review investigated the concept of the boundary object because it is the main concept presented by design research to theorize the role of mock-ups in design collaboration. However the concept is heavily criticized in computer supported collaborative work since its introduction in 1989. The criticism has led to suggest that the concept is not appropriate to explain the role of mock-ups in design collaboration. Unfortunately these criticisms are not mentioned in design research.

Brandt says that the mock-ups of her case study act as boundary objects:

> *'[the mock-ups] can be seen as boundary objects where customers, users, and designers can interpret them in different ways according to their interest.'* (Brandt, 2007:187)

Although boundary objects have interpretative flexibility (Leigh Star, 2010) they can only be created when an agreement has been reached between the different stakeholders. This type of object is flexible enough to be used for the purposes of the different stakeholders and removes the need for them to interact and negotiate (Lee, 2007). The mock-ups described by Brandt cannot be understood as boundary objects because they are used to negotiate and find an agreement for *'[...] creating a design agreeable to everybody'* (Brandt, 2007:187).

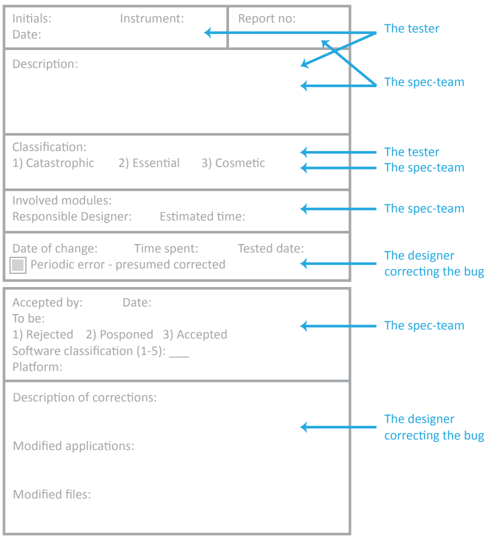


Figure 16.The bug report form (Schimdt and Simone, 1996).

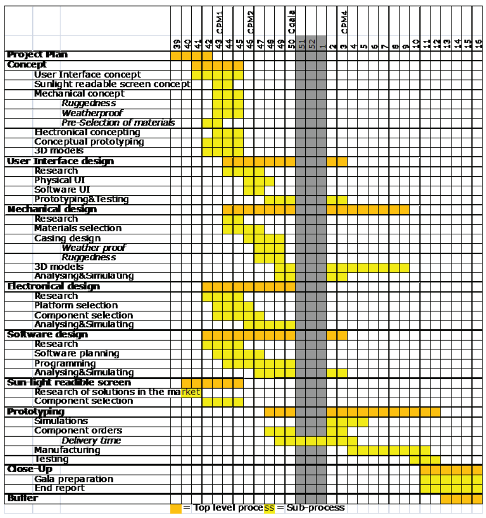


Figure 17.The Weatherway project schedule.

The bug report form described by Schimdt and Simone (Schimdt and Simone, 1996:164) is a clear example of a boundary object. The form is used to report bugs and has different parts that different teams have to fill in. In this sense, different teams can use the form for their own purpose thus removing the necessity to interact with each other, yet each separate team still contributes to the common goal of correcting the bug. The form is designed so that all the teams involved can access the information they need. If the information needs of one team changes or if the team itself changes the form will not be able to provide the necessary information anymore, a new form will be needed. In the sense the form is also static because it cannot support changing requirements.

The project schedule in the Weatherway project is a boundary object. The team members can look at the project plan schedule to understand their role without having to know about the work and time requirements of other team members. The project plan was made after the different team members discussed and agreed on their schedule. It shows each team the slot of time they have for their work and removes the need for each team to negotiate a schedule with other team members.

Mock-ups belong to a whole category of objects that support disorderly collaborations but that cannot be explained using the concept of the boundary object. Boundary objects (Star and Griesemer, 1989) describe objects that are static and unable to change their representational status making them vulnerable to organizational changes. They describe objects that do not involve negotiation of use or meaning. Boundary objects are also inappropriate for disorderly collaborations because they depend on a standardization of methods (Pennington, 2010).

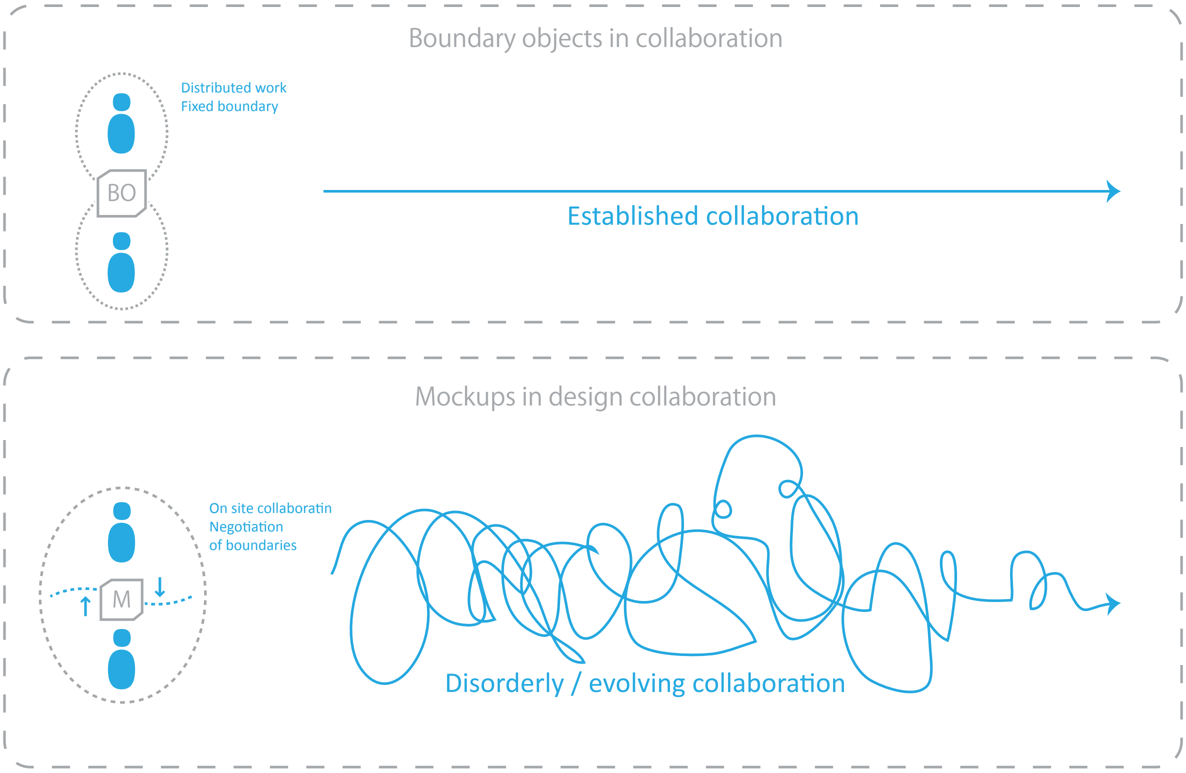


Figure 18.Mock-ups are not boundary objects.

The claim of this work is that the concept of the boundary object is not appropriate to explain the role of mock-ups in design collaboration despite that it is the main concept mentioned by design research. The concept of the boundary object is criticized because it cannot explain how artifacts support disorderly collaboration. On the other hand the concept of dynamic boundary objects and boundary negotiating objects seem more helpful in understanding the specific behavior of design mock-ups. The design process is a process of negotiation that does not rely upon a standardization of method. The mock-ups are made to elicit feedback, present points of view and lead to negotiation between the different stakeholders.

The next chapter will detail the boundary negotiating object and dynamic boundary object concepts.

IV. Boundary negotiating and dynamic boundary objects

IV.1. Boundary negotiating objects

Lee argues that the concept of the boundary object is insufficient to explain the role of artifacts in disorderly collaboration (see III.2.6) and suggests the alternative concept of boundary negotiating objects (sensu Lee, 2007). Boundary object is an important concept in CSCW but using it to describe artifacts that did not really fit the definition has deformed it (Lee, 2007). Boundary objects describe artifacts that sail across boundaries in established collaborations. Lee discusses that disorderly collaboration processes are not special cases and that the concept of the boundary object does not work to describe the artifacts living with them. The author supports her discussion with a one-year ethnographic study of the design of a museum exhibition. She suggests that the role of artifacts in disorderly processes is to establish and destabilize protocols and support negotiation between team members (Lee, 2007:308).

Boundary negotiating artifacts are artifacts and surrounding practices that '[…] iteratively coordinate perspectives' and '[…] bring disparate communities of practice into alignment, often temporarily, to solve specific design problems that are part of a larger design project.' (Lee, 2007:318).

Lee furthers the definition of boundary negotiating objects, stating that they are used to:

> *'[…] record, organize, explore and share ideas; introduce concepts and techniques; create alliances; create a venue for the exchange of information; augment brokering activities; create shared understanding about a specific design problem.'* (Lee, 2007)

There are five types of boundary negotiating object (Lee, 2007), each illustrating a specific context of use: self explanation, inclusion, combination, structuring and borrowing artifacts. Self-explanation artifacts are made by and for individuals or a few members of the same community. The other four are intended for crossing and negotiating across communities.

The case study that Lee uses to illustrate the types of boundary negotiating objects is an ethnographic study of the collaboration of an interdisciplinary team to design a travelling exhibition about wild and domestic dogs. The study focuses on the way team members use social practice and artifacts to collaborate.

Each group member brought his practice and set of values to the project. Sometimes these conflicted directly with those of other members. Even after the project ended, the role of the different members was never really clear. The conflicts and negotiation that occurred enabled the group to successfully coordinate itself.

The fives types of boundary negotiating objects are:

- Self-explanation artifacts describe artifacts that are privately created to solve a specific problem, record or remember information. They might then be used as inclusion artifacts to present personal ideas to other members. They are called 'self-explanation' because they are involved in the activity of '[…] learning, recording, organizing, remembering and reflecting' (Lee, 2007:319). An example of a self-explanation artifact is the personal journal in which Martin collects notes and pictures of things that he likes and potential ideas for future exhibitions (Lee, 2007:319).
- Inclusion artifacts describe artifacts that are used to present and discuss ideas. They act as a symbol of an idea. They can be created from self-explanation Artifacts to present a personal idea to other members. They can be used to create alliances or exert pressure on other members. They are called 'inclusion artifacts' because they are involved in including practices such as '[…] presenting, accepting, rejecting, and reserving judgment' (Lee, 2007:323). An example of an inclusion artifact is Martin's sketch of the object theater (Lee, 2007:321). With this idea Martin wants to show in the exhibit that dogs are part of human culture. The educators are reluctant to accept this idea because it involves more work. When the curators manifest their wish to see more culture in the exhibition Martin presents them his sketch. This eventually results in an alliance between Martin and the curators and Martin's idea is included in the exhibition despite the educators.
- Compilation artifacts describe artifacts that are used to organize information for the specific purpose of bringing disparate communities of practice into temporary alignment just long enough to create a shared understanding of a specific problem or task. An example of compilation artifacts is the table that Angela makes specifically for the graphic designers (Lee, 2007:323). Angela's table transforms a table originally made by Emma, organizing it with additional content and specifically created terms. Angela's table becomes a bridge between Emma and the graphic designers but not a boundary object because she then needed to explain how to use and read the tables to the graphic designers.
- Structuring artifacts describes artifacts in which members organize and order information according to their vision. The members expect these artifacts to be used in a specific way. They are often at the center of conflict between communities that have different perspectives. They are used to establish ordering principles. Sometimes they are used to negotiate and push boundaries. An example of structuring artifact is the document entitled 'the curator's narrative' (Lee, 2007:325). The document included descriptions and suggestions on each topic of the exhibition and how they could be presented and which material could be used for that. While the curators thought it would be used as a framework to structure the exhibition, they were surprised to discover that the educators were using it only as a source of content for the exhibition and modifying and removing text to make his own narrative. The two narratives were involved in a conflict on who was to decide for the narrative of the exhibition as they ordered information in a way that favored the vision of one group rather than the other.
- Borrowing artifacts describe artifacts that reuse artifacts from other communities for a different and unexpected purpose. They are focused on the action of taking possession of artifacts rather than creating artifacts. They can be used as another type of boundary negotiating object such as self-explanation artifact. They imply a close relation between communities. An example of borrowing artifacts is the collage created by Brent (Lee, 2007:331) using the sketches and the narrative from other project communities. The purpose was that he could understand the big picture and decide on the human resources he would allocate to the construction of the exhibition.

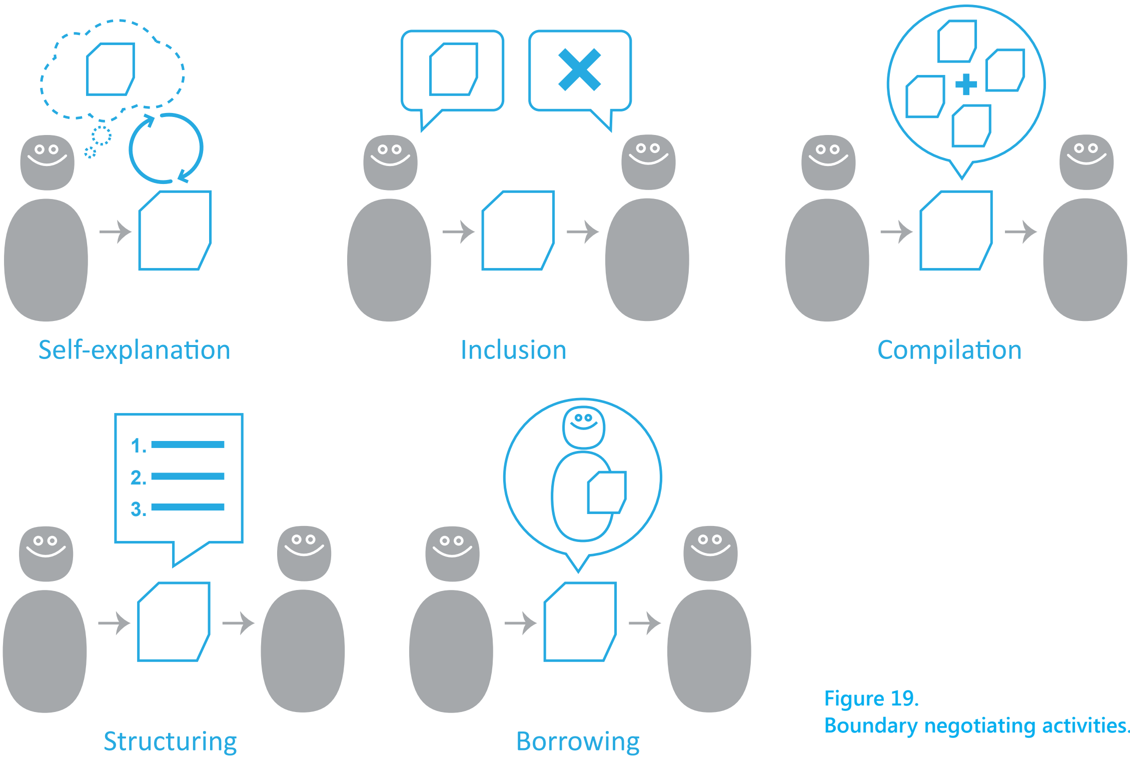


Figure 19.
Boundary negotiating activities.

IV.2. Dynamic boundary objects

Pennington investigates the relationship between boundary negotiating objects and boundary objects. She reframes the concept and develops a dynamic model of boundary objects or dynamic boundary objects evolving from one state to another at the same time as the progression of collaboration. To support her findings she uses a design-based research methodology to study material artifacts made by a cross-disciplinary science and technology team.

Note on terminology

'Work method' refers to the process by which a task is completed. A work method has specific steps and requirements. The mechanical engineer needs precise volume specifications to create the 3D model of the outer shell of the device. The industrial designer can create a mock-up of the shell of the device using approximate dimensions.

'Method alignment' refers to the process of adapting the work method of different stakeholders so that they are compatible with each other.

'Standard method' refers to a work method that is shared between different design stakeholders to complete a specific set of tasks.

Note on methodology

Pennington builds on literature about material artifacts in collaboration as boundary objects (Star and Griesemer, 1989) and successive literature criticizing the insufficiency of this concept for new collaborations. In the steps of Lee (2007) she argues that lack of a standardized method is the reason for this insufficiency and then discusses the relationship between boundary objects and method standardization.

Pennington uses the concept of artifacts as learning scaffolds to explain how artifacts support the creation of a shared understanding that then leads to the alignment of methods and their standardization. She describes collaboration work as a recursive process going from articulation work to cooperation work (Schmidt and Simone, 1996) and temporally locates boundary negotiating objects and boundary specifying objects on the timeline of an evolving collaboration.

IV.2.1. Artifacts as learning scaffolds

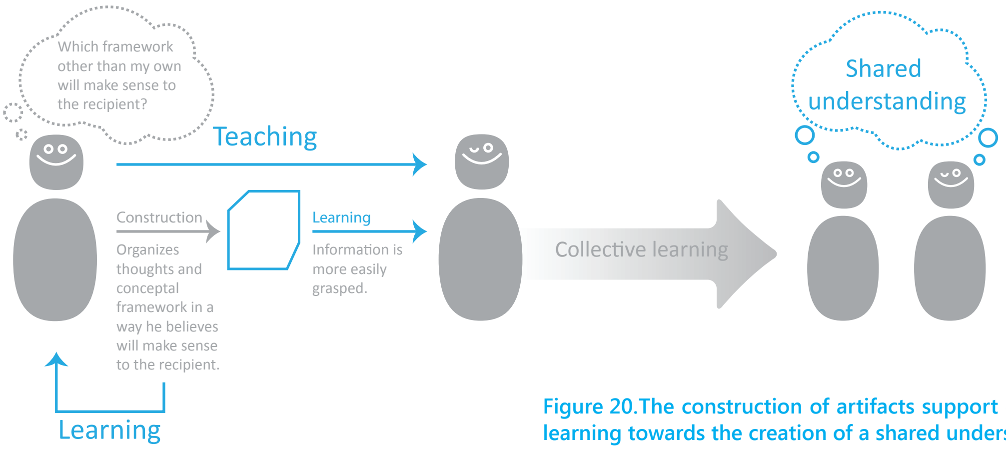


Figure 20.The construction of artifacts support collective learning towards the creation of a shared understanding.

In inter-disciplinary collaboration, different individuals represent different perspectives. If those individuals want to collaboratively solve a problem then they must learn about each other's perspectives. In a situation where a more expert individual tries to teach a specific concept to a novice, artifacts can be used as supports to facilitate the learning of the novice. Artifacts act as a temporary learning support, and once the concept is understood, the artifact is not necessary anymore. At the same time, the expert makes the artifact so that the novice can understand the concept. The expert has to think about what will make sense to the novice and therefore he also learns from this activity because he has to adapt his mental model. The construction of artifacts for learning purpose acts as a support for collective learning (Pennington, 2010).

IV.2.2. Role of boundary objects with respect to method standardization

In inter-disciplinary collaboration, different individuals have different work methods. Star and Griesemer (1989) say that work method standardization is essential to collaboration. Boundary objects are produced from the standard work method that has been negotiated between the different individuals or communities working together. Boundary objects use the standardized method as a structure that is intelligible by the different parties using the artifact.

However in disorderly collaboration a lot of collaborative work is needed before a collective work method can be standardized. The different parties need to negotiate to reach a shared understanding of each other's work methods so that they can compromise on one that is acceptable for all. This process of negotiation is a process of progressive alignment of the different work methods used by the different individuals involved in the process. The artifacts that support the negotiation process are called boundary negotiating objects. Pennington states that:

> *'[...]the role of boundary negotiating objects during incipient collaboration is to help generate conceptual linkage from which aligned and standardized method can emerge'* (Pennington, 2010:190)

Once the different parties have reached a shared understanding and an aligned method has been standardized, boundary specifying objects can be created that use the method as a structure known to the different individuals. The standardized structure of the objects guaranties that the method will seamlessly fit into the collaboration process. Different individuals can then use the same boundary object for their own purpose without having to worry about how another party uses the object.

IV.2.3. Dynamic model of boundary objects

There are three levels of a system design: task, approach and enactment. The task level is where the design objectives are stated (Pennington, 2010:192). The approach level is how the work is going to be structured to accomplish the task. The enactment level is where the task is actually completed.

There are two types of collaboration: disorderly (see III.2.6) collaboration and established collaboration. In established collaboration the task, the approach and the enactment level are clearly defined. However, in disorderly collaboration, a lot of collaborative work is needed before these three aspects can be clearly specified.

Disorderly collaboration can be divided into two stages (see figure 22): articulation work and cooperative work (Pennington, 2010:193). In collaborative work different individual activities can have complex interdependencies that need to be understood and articulated. Articulation work is the process of articulating the relationship between the different individual activities. Cooperative work is when different individuals depend on each other to complete a task and they interact with each other by each completing one part of that task (Schmidt & Simone, 2010:157).

The purpose of articulation work is to articulate the relationship between the separate individual activities. Before this is possible the relationships and interdependencies between the different individual activities need to be discovered and then negotiated (see figure 22). The articulation process is a boundary negotiation process that is mediated by a special category of artifacts. This category of artifacts corresponds to boundary negotiating objects. On the other hand, boundary specifying objects support cooperative work by enabling individuals to work independently (Pennington, 2010:194). Pennington further states that:

> *'Boundary negotiating, method alignment, method standardization and boundary specifying have temporal contexts that are related to the system articulation or cooperative work that is occurring.'* (Pennington, 2010:193)

The type of dynamic boundary object that supports the process of collaboration is related to the specific stage of collaboration in which they are used (Pennington, 2010:194). New collaborations go from articulation work to cooperation work. Articulation work is a process of boundary negotiation while cooperation work is supported by boundary specification.

In articulation work participants will use objects to facilitate the communication of their individual viewpoints. This describes boundary negotiating objects. Once boundaries have been specified objects will be used that enable the participants to work independently on different activities. This describes boundary specifying objects.

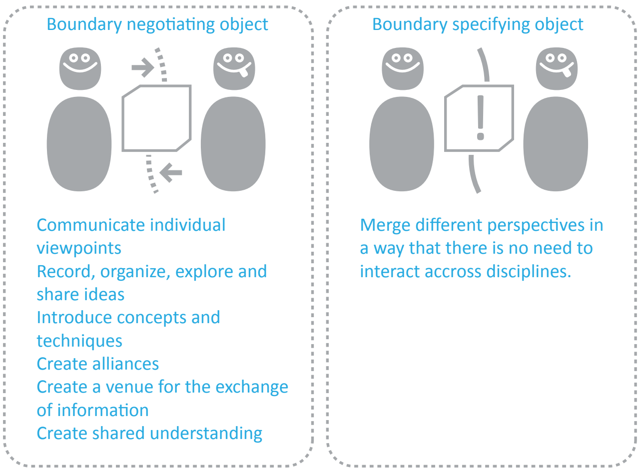


Figure 21.Role of boundary negotiating and boundary specifying objects. The relationship between the object and the collaboration stages is clarified in figure 22.

Boundary negotiating objects describe artifacts and surrounding activities that support disorderly or new collaborations. These artifacts mediate the negotiation of concepts between different individuals and can be used to create and change work methods. Boundary negotiating objects afford collective learning towards the creation of a shared understanding. Artifacts in this kind of collaboration belong to different categories of boundary negotiating objects depending on the activity in which they are used. Lee (2007) identifies five such activities in his list of: Self-explanation, inclusion, compilation, structuring and borrowing.

Boundary specifying objects describe artifacts that support established collaboration between different communities. These artifacts can be used by different individuals with different goals and have a standard structure that is understood by all users. The artifacts convey sufficient information so that one individual can use one for his own activity and does not need to negotiate its use with other users. Boundary specifying objects have three important properties: interpretative flexibility, organizational structure of the object and a change of structure between individual and common use (Star, 2010).

During the boundary negotiation process artifacts serve as scaffolds for learning and negotiation. Though not all evolve into other artifacts and some are discarded, they all contribute to the construction of a shared understanding between participants.

The artifacts that will be used between boundary negotiation and boundary specification might have dual citizenship. Depending on the perspective of the individual using the artifact they may be either boundary negotiation artifacts or boundary specification artifacts. This describes mixed-use boundary objects.

Artifacts dynamically afford the creation of integrated conceptual framework and lead to progressive refinement of the conceptualization of a problem from task to enactment. In new collaborations boundary negotiating objects enable the construction of a standard method. Standardized methods enable the construction of a boundary specifying object. In between the two, the artifacts can correspond to both boundary negotiating objects and boundary specifying objects. In the face of changing requirements new conceptualizations are renegotiated. Radical innovation happens when the process is brought back to the definition of the task level (Pennington, 2010:194).

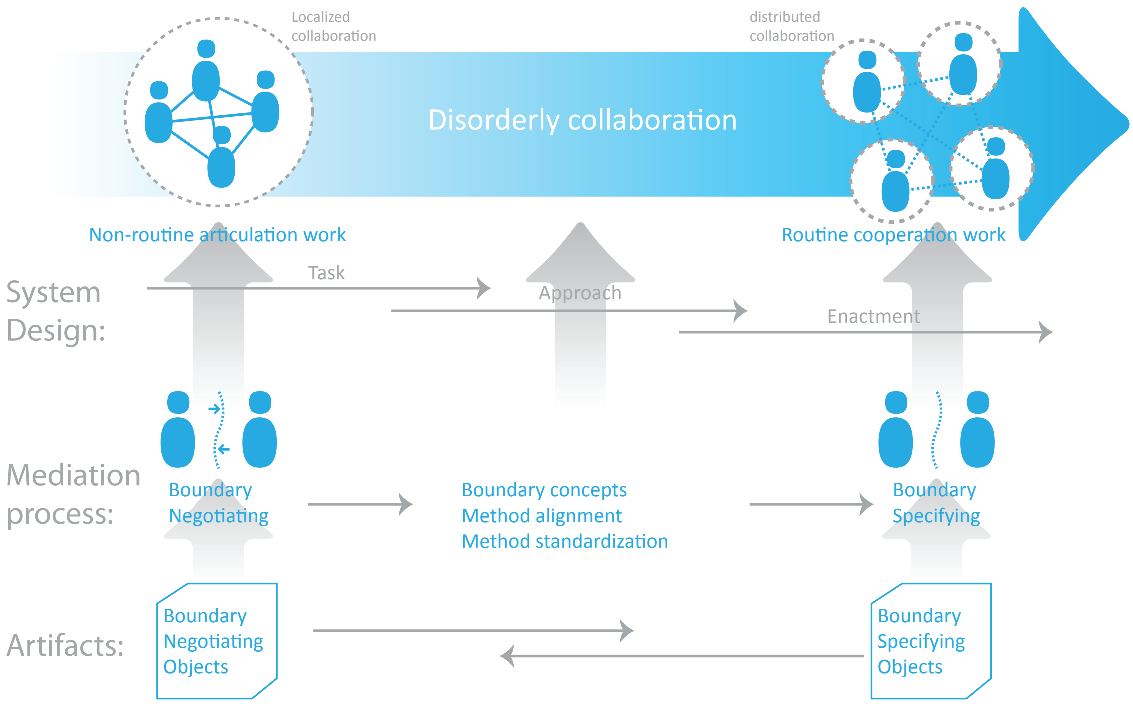


Figure 22.Dynamic model of boundary objects (adapted from Pennington, 2010:194). Disorderly collaboration is at first a process of negotiation that supports the creation of a more orderly cooperation.

IV.2.4. Summary of review and data analysis method

Disorderly collaboration is a process where the needs and constraints of the different stakeholders must first be specified. It involves negotiation, sharing of ideas and conflict between the different stakeholders. In this process the different stakeholders articulate their needs and constraints together until they r¬each a shared understanding that enables them to specify their position, decide on their task and a work method that enables them to cooperate while carrying out distributed work (Pennington, 2010).

In the next chapter I will present the Weatherway project. Successively I will analyse the data from the project to demonstrate that the project is a process of disorderly collaboration as suggested by Pennigton and that the role of mock-ups in this collaboration can therefore be explained with the concept of boundary negotiating object.

V. The Weatherway project

Figure 23.The Weatherway handheld terminal.

V.1. Introduction

The site for the fieldwork was a project to design a handheld usable smart device called the Weatherway. The Weatherway project took place between September 2009 and April 2010 as part of the Product Development Project (PDP) program of Aalto Design Factory. The project was sponsored by Vaisala, a Finnish weather instruments company. An interdisciplinary team of ten students was charged with the responsibility to design this device.

The brief given by Vaisala to the Weatherway team members is to design a handheld terminal to monitor and troubleshoot a mobile weather station. The goal of the project is to deliver a working prototype of the handheld device to Vaisala. The handheld device is to replace an existing one. The device is to be used by firemen or the army on a temporary airfield or heliport to support air operations. The device should support everyday weather use a well as extreme temperatures, and be suited to both night and day use in bright sunlight. The user should be able to use and interact with the device using protection equipment consisting of clumsy apparel and gas masks.

V.2. Actors, teams and collaboration

The ten team members of the Weatherway project divided themselves into seven different teams with different specialized functions.

- The materials team researched materials and manufacturing technology
- The ergonomics team led research and user tests to develop the shape of the device
- The holder team developed the holder to fix the device to the Tacmet system
- The interface design team developed the interface and the controls of the device
- The mechanics team was in charge of meeting the strict standards demanded by Vaisala, to manufacture the shell of the device and the button membrane
- The software development team created the code for the interface
- The electronics team realized the electronic circuits of the device and researched for low consumption and light readability screen technology as well as a suitable platform for the implementation of the interface

Other important actors that shaped the design of the Weatherway terminal are:

- The sponsor that provided access to key experts and direction throughout the project
- The Vaisala Boulder (USA) sales team that informed the design on the needs of the main customer for this device
- The user and test users

The student team consisted of Master students in Industrial Design, Design Engineering and various Engineering educational backgrounds such as electronics, automation, mechanical and material engineering. The students came from KTH and what is now Aalto School of Art and Design and Aalto School of Technology.

The Weatherway team members worked part-time on this project while taking care of other academic duties. One core group worked in Helsinki and another small group worked remotely from Stockholm. The core group held meetings every week in the premises of the Aalto Design Factory, the second group joined the core group once a month and more often at some periods of the project. The collaboration sometimes took the form of group work were various members where meeting and working on a common task, and other times the form of individual work where individuals or small specialized groups took care of their own task. The meetings where used to share the results of the research and progress of the different members of the team; to meet the academic supervisors; to prepare for presentations and galas; to meet with various partners of the sponsor company; to discuss ideas, priorities and schedules; and to solve organizational problems.

During the meetings and on some other occasions the project team gathered as a large multidisciplinary group to collaboratively generate ideas and elaborate the needs and constraints of the project together. Sanders (2008) describes co-design as collaborative creation of designers and other stakeholders in the design, proposing that future co-design will involve all the stakeholders in the design process (see I.I). In this sense instances of collaboration in the Weatherway design process can be described as co-design and reflect the future evolution of it.

When the team members were not performing group activities they were taking care of other academic duties or working individually or in small specialized groups on one part of the project that required their specialized knowledge. These activities included: research of screen and material technologies; finding a company to manufacture the buttons of the device; manufacturing the outer shell of the device; coding the software; creating the electronics circuit board; conducting user and usability tests; creating the graphical interface and making mock-ups.

Recommended practice for designing usable smart devices is to follow a user centered design process and multidisciplinary collaboration (see I.1). The Weatherway project team often worked as a large multidisciplinary and involved the user in its design process (see V.4 and figure 25).

V.3. Prototypes and mock-ups

When designing usable smart devices the biggest challenge is combining the knowledge of the different stakeholders involved with the needs of the users and the technological constraints of smart devices. Such a challenge can be supported by early and iterative use of prototypes (Säde, 1999). During the entire length of the project the team made iterative use of prototypes to support the alignment of method and the integration of knowledge from the various stakeholders and articulate it with the needs and constraints of the project. The form of prototype involved sketches, mock-ups, 3D models, graphical representations, scenarios, technical drawings, dimensioned drawings, interactive models, working prototypes and manufacturing prototypes. Other types of artifacts supported the collaborative work, such as project plans, project schedules and meeting briefs.

One of the main drivers of the project was the usability of the device. The team identified that one fundamental requirement for the realization of a usable device was the balance of needs and constraints between the ergonomics and the interaction with the user interface. The user should be able to use the device in rough weather conditions wearing heavy-duty equipment. These conditions seriously hindered the ability of the user to interact with the user interface and hold the device.

Mock-ups allow empirical evaluation of ergonomics because of their three-dimensionality. Mock-ups were extensively used in the project to articulate the ergonomics of the device with the human interface interaction and the technological constraints of the device. The mock-ups were made of foam. They were shaped by the industrial designer or the ergonomics team to support learning and idea generation and then used to test the ergonomics with the user or to gather feedback from the rest of the team members. The mock-ups supported negotiations between the different stakeholders and were adjusted by the designer or the ergonomics team to include the comments and decisions made by the group.

Throughout the project various challenges unfolded such as the difficulty to meet the user, the complex interrelations between the different technological constraints of designing hardware and software and the technical limitations of the student to manufacture the device. The biggest challenge of this project was to articulate these different problems into a credible design solution. The extensive use of prototypes and in particular the iterative use of mock-ups provided a valuable support for the integration of specialized knowledge (See the scenario in 5.6). The team met their task of delivering a working prototype in April 2010. The prototype was presented at a gala and was met with great enthusiasm both by the academic supervisors and the sponsor company. The project was a success as it was awarded the prize of 'best project of the year' amongst fifteen other similar projects.

Figure 24.Prototypes and mock-ups in the Weatherway project.

V.4. Development of the project

This part lists important steps in the development of the Weatherway device.

The 'graph' lists the important steps in chronological order. On the left side is the timeline. At the center is a list of the key moments of the project. This list also shows when the ergonomic mock-ups were developed. On the right side parallel processes that interacted with the development of the ergonomic mock-ups are shown.

1. Start of the project. The team meet for the first time. The team is introduced to the project.
2. Visit to Vaisala headquarters. The team meets the sponsor as well as various specialists that introduce the Tacmet system for which the device has to be developed.
3. Workshop in Aalto Design Factory. The team has to develop a solution to the project brief in 6 hours. Through this exercise the team is able to establish design drivers for the project. Start of the concept phase for the interface.
4. Conference with the sales team of Vaisala in Boulder (USA). The sales team informs of the specific needs of the client. Feedback on the rough interface concepts.
5. The team meets the user in Nininsalo, a Finnish army base. The user explains how he uses the Tacmet system. The team presents a paper mock-up of the interface and rough mock-ups of the shell of the device to discuss with the user.
6. Meeting with the sponsor in Vaisala Headquarters. The team and the sponsor refine the specifications for the project.
7. The ergonomics team makes the first mock-up of the shell of the device. The mock-up is then tested with test users.
8. Following the feedback from the previous user tests the ergonomics team creates new mock-ups for user testing. A design is selected.
9. The selected design is refined and a new mock-up is made.
10. The Christmas gala is a mid-project presentation to the other students and professors of the PDP project. The Weatherway team presents the status of the project.
11. Several ergonomic mock-ups are created by the interface design team.
12. A new ergonomic mock-up is created by the ergonomics team.
13. The ergonomic and interface concept is presented to Vaisala.
14. The team discusses the concept and the engineering of the device with Vaisala experts.
15. The final interface concept is presented to the Boulder sales team. Skype web conference.
16. The interface design team creates a final ergonomic button. The mock-up enables evaluation of button design.
17. Workshop with the Vaisala sponsor in Aalto Design Factory. Discussing design details, button layout and preparing for manufacturing.
18. The team meets Vaisala experts to discuss engineering challenges.
19. A 3D print is made by the Mechanical engineering team. This leads to adjustment of the dimensions of the device.
20. A mock-up is made by the interface design team to adjust the ergonomics to the new dimensions and for the user to evaluate the device.
21. Final 3D print of the shell. The components fit. The design of the shell is ready for manufacturing.
22. All the components have been manufactured. All the parts fit together. The prototype is ready.
23. Final presentation of the project and working prototype during the PDP Gala in Aalto Design Factory. Fifteen PDP projects are presented that day. The Weatherway project is awarded with the PDP project of the year award.
24. The project and the working prototype are presented at Vaisala headquarters. Closing of the project.

9

Start of the project and
organization of the teams

10

A day in VAISALA HQ
Introduction to the project

PD6
Product Development in 6 hours workshop

Meeting with the sales team
skype conference to Boulder (USA)

11

Meeting with the user
Nininsalo Finnish army base

A day in VAISALA HQ
Presentation to the sponsor

M1

M2

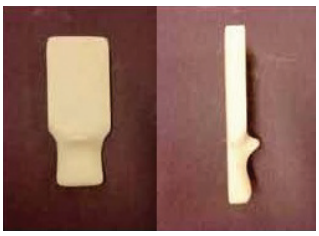
M3

12

Christmass Gala
Presentation in Aalto Design Factory

1/2011

M4



M5

Interface development

Background research

2

Design review
Phone meeting with VAISALA

Consulting VAISALA
handheld experts

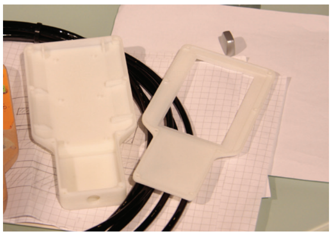
Presentation of the final interface design
Conference with the sales team

M6

Design workshop with VAISALA
Last variables are fixed

3

Expert revision
VAISALA HQ



M7

M8

M9

4

All the parts fit together
the prototypes is ready

PDP Gala 2010
Presentation

5

Presentation to VAISALA staff
CLosing of the project

Manufacturing

Buttons development

Figure 25.Development of the Weatherway project 9/2009 - 5/2011.

V.5. Description of the ergonomic mock-ups

- M1 Is a rough foam mock-up made by the ergonomics team. The mock-ups features a horizontal screen and a long handle with small pins instead of buttons and a small bump at the back of the handle called a finger stopper. The function of this bump is to have a better grip when holding the device with one hand. This mock-up is part of a series made to gather feedback on the ergonomics from test users. The mock-up was tested with students from KTH and the result led to the next mock-up.
- M2 is an improved version of the previous user test mock-up also done by the ergonomics team. The mock-up features an improved handle shape and size based on the user test results. The ergonomics of this mock-up are also tested with students from KTH. The test was done with the user trying to hold the mock-up and press the control pins with and without protective gloves. Three versions of this design where tested.
- M3 is a fine foam model made by the ergonomics team to present the shell concept to the other team members. This mock-up takes into consideration the results from previous user tests with improved handle design and dimensions. This mock-up is the proposal of the ergonomics team for the shape of the device. This proposal was refused by other members of the team, who preferred a vertical screen and a short handle design.
- M4 is a rough foam mock-up made by the interface design team to propose an alternative to the design of the ergonomics team. The interface design team aimed at creating a mock-up that was more suited to their interface design concept. The mock-up features a vertical screen and a short handle.
- M5 is a rough foam model made by the ergonomics team to propose their own vision of a design with a vertical screen and a short handle. The mock-up considers the design proposed in M5 but adds the finger stopper that was developed during the ergonomics research.
- M6: is the final proposal for the shape of the device. It is a foam model featuring a vertical screen, a short handle and a finger stopper. The design of the shape is more refined than the previous model. As mock-upall the team members agree the design of this mock-up it is also used to elaborate on button design. The design of this mock-up is then transformed into a CAD model.
- M7 is a 3D print of the shell made in ABS by the mechanics team using the CAD model from M6. The purpose is to evaluate the dimensions and the fitting of the components with other teams such as the electronics team. The 3D print features two parts, one for the top shell and one for the bottom shell. The model is very detailed and already features screw holes and supports for electronic components. Misfits between components and discrepancies between the 3D print and the final design when comparing with M6 lead to adjustments of the design and a return to foam modeling.
- M8 is a fine foam mock-up made by the interface design team. The purpose is to arrange the ergonomics of the device to the adjustments dictated by the evaluation of M8. The mock-up features a larger screen frame and a thicker and longer body to allow more space for components. The mock-up was also used to test the final button design with a test user. The final button design is made of paper and foam sheets. The design was selected as the final design for both shell and layout. The CAD model was made a bit thinner to improve the ergonomics.
- M9 is a 3D print of the CAD model made out of M8 by the mechanics team. The purpose was to check the fitting of the parts, the fitting with the electronic components and the fitting with the button membrane 3D print. Everything fitted together, and the design of the shell was ready for manufacture.

Figure 26.The ergonomic mock-ups.

V.6. Development of the ergonomic mock-ups (scenario description)

1. Background research, interviews with the user in Nininsalo and demonstration of the Tacmet system.

2a. After the background research the ergonomics team writes down the ergonomic specifications for the future Weatherway terminal. The device should be easy to hold and the buttons should be able to be pressed when using the device with bare hands and when wearing protection gloves. The user should be able to perform other activities in normal circumstances therefore he should be able to use the device with one hand. When wearing heavy gloves the user should be able to use the device with two hands.

2b. Based on the ergonomic specifications the ergonomics team creates several mock-ups (M1). While making M1 the ergonomics team is iterating its vision of the ergonomics.

2c. M1 is then presented to the test user who compares the different proposals of handles by holding them with the gloves and trying to press the buttons. The user then evaluates the different mock-ups.

3. Following the results of the evaluation of M1, the ergonomics team refines the design proposal in M2. The mock-ups are then newly presented to the test user who compares and evaluates them.

4. Following the evaluation of M2 by the user, the ergonomics team creates a more refined mock-up (M3) to propose its vision of the design to the rest of the team.

5. The ergonomics team presents the M3 to the rest of the team. The design proposal is refused by other team members who do not agree with the proposal of a device with a long handle and a horizontal screen. The interface design team who has been designing an interface with a vertical layout feels threatened, while the mechanics team thinks that the current design looks too fragile and will greatly complicate the engineering work for the design of the shell. After discussion the project team decides that it would be better to design a device with a vertical screen and a shorter handle.

6. In order to promote their vision of a device with a short handle and a vertical screen, the interface design team creates M4.

7a. The interface design team propose his alternative vision (M4) to the ergonomics team.

7b. The new design proposal (M4) is judged positively but still lacking some important ergonomic features of the ergonomics team. The new design is difficult to hold with one hand and would benefit from a finger stopper on the rear of the handle, which would make it easier to hold.

8. In order to articulate this vision with the proposal of the interface design team, the ergonomics team refines the design of M4 by improving the design of the handle and adding a finger stopper (M5). The ergonomics team then shows M5 to the interface design team for feedback. M5 is met positively and both teams agrees that it suits both their visions.

9. The interface design team presents M5 to the mechanical design team to discuss the engineering constraints of the design. The mechanical engineering team requests that the device should have larger dimensions.

10. The interface design team refines the mock-up taking into consideration the request of the mechanical engineering team. A new mock-up with larger dimensions is created (M6).

11. The resulting mock-up features a vertical screen, a small handle with a finger stopper and improved dimensions. M6 merges the evaluation of the test user, the design proposals of the ergonomics and interface design team and the engineering requirements of the mechanical engineering team.

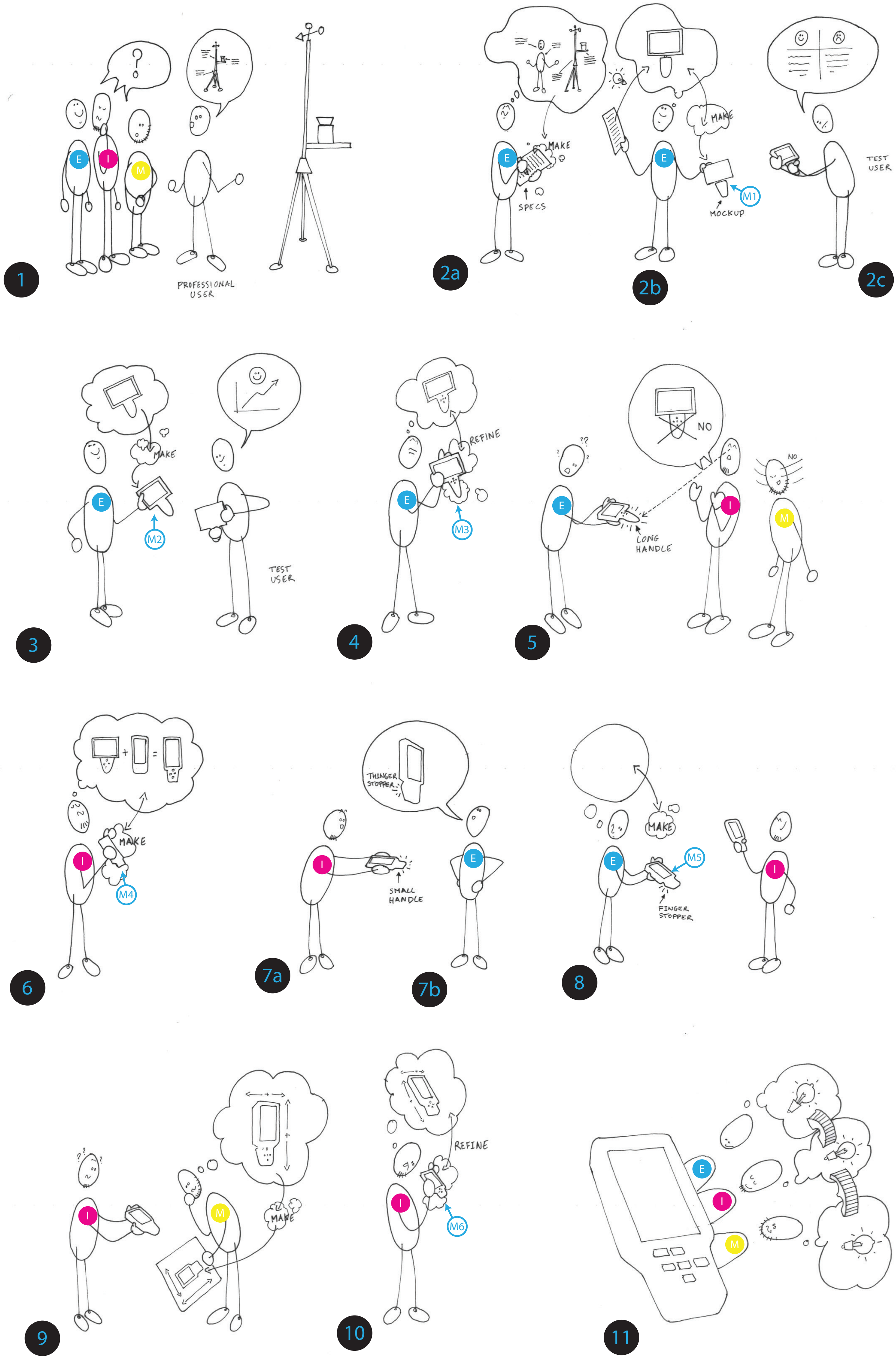
12. The mechanical engineering team uses measures of M6 to create a CAD model featuring a top and bottom shell and detailed mechanics.

13. The CAD model is printed in ABS using a 3D printer (M7).

14. The mechanical engineering team shows M7 to the interface design team and to the electronics team. The interface design team criticizes the M7 as being different from the design of M6 and

requests an improved CAD model to be made. The electronics team realizes that the electronic components do not fit into it and requests that the design be made larger.

15. The mechanical engineering team and the interface design team discuss the modification of the dimensions. The interface design team decides to participate in the modeling of the future CAD model to make sure that the design of the CAD corresponds to the design of the mock-up.
16. The interface design team creates M8 to test the ergonomics with the new dimensions and evaluate the final design of the buttons.
17. The interface design team presents M8 to a test user for evaluation. The user tries to hold the device and to press the buttons with and without gloves. The feedback from the user is positive.
18. The interface design team presents M8 to the mechanical engineering team and discusses adjustments. There is no time to create a new mock-up so the last modifications will be made directly during the modeling of the CAD model.
19. The interface design team and the mechanical engineering team create the CAD model of M8 together.
20. The CAD model is printed in ABS using a 3D printer (M9).
21. M9 is the final mock-up of the design of the shell. M9 merges the point of view of the user (feedback on user test with M1, M2 and M8), the interface design team (vertical screen and short handle design, ergonomics of M8), the ergonomics team (handle and finger stopper design), the mechanical engineering team (dimension needs) and the electronics team (component fitting).



K electronics team E ergonomics team I interface design team M mechanics team

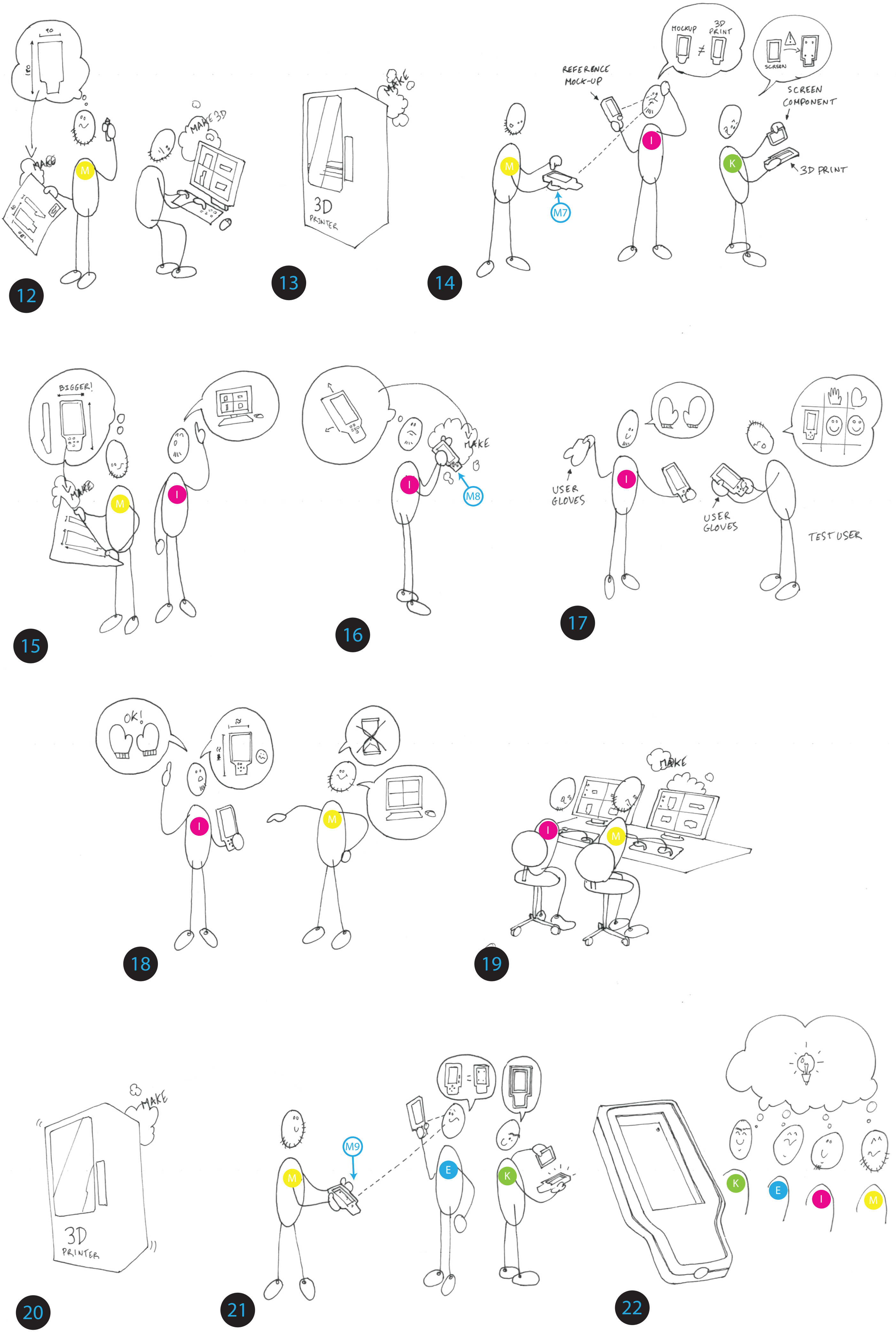


Figure 27.Development of the ergonomic mock-ups.

VI. Analysis

VI.1. The Weatherway as disorderly collaboration.

The concept of the boundary object is criticized because it cannot explain how artifacts support disorderly collaborations (see III.2). This part explains the nature of collaboration in the Weatherway design process and shows why it should be understood as a process of disorderly collaboration.

Pennington describes two types of collaboration: established and disorderly collaboration. In established collaboration the task, the structure and the method of group-work are clearly defined. However in disorderly collaboration a lot of collaborative work is needed before these three aspects can be clearly specified (see IV.2.2).

The collaboration between hunter and zoologist in Star and Griesemer (1989:401) is an example of established collaboration. The hunter that captures the animal has to do it in a specific way so that it can still be used by the zoologist, the animal has to be in good condition, the hunter has to record location and time of capture on a specific form. The zoologist will receive the animal and the compiled form and will then classify and store the animal sample. This collaboration follows a specific process; the form is essential for the work of the zoologist who needs to know the precise location and time of capture to classify the specimen. The task of the hunter is to collect the animal and fill the form and the task of the zoologist is to classify the animal aided by the form. Both hunter and zoologist have established tasks and an established collaboration method involving the form. The collaboration between the hunter and the zoologist can be understood as a process of established collaboration. In this collaboration the form acts as a boundary object bridging the needs of the hunter and the zoologist.

The design process as presented by the British Design Council (see I.3) describes a process of disorderly collaboration. The design process is described as a succession of activities and methods that are arranged together depending on the needs and constraints of a specific project. The British Design Council argue that there is no best practice design process that can be used for all projects. However the UK Design Council (see I.3) defines a core of four steps that is common to all projects. The four steps of the double diamond design process – Discover, Define, Develop and Deliver – are actually a process of specifying the task, the approach and the enactment level of the specific design project.

The Weatherway design process is a process of disorderly collaboration. The main steps of the project were planned from the beginning as seen in figure 17. However, a predefined process akin to the form of the museum collaboration was not present. Specific activities had to be organized as unforeseen challenges unfolded. For example, the teams created their own mock-ups without following a specified or predefined input structure. The teams that would communicate through each mock-up were also not predefined.

In the design of the Weatherway terminal the decision to add a LED to display the power status of the device caused different teams to collaborate together on a challenge that could not be foreseen. The interface design team decided late in the project that they wanted to have a LED indicator on the front of the device to display the power status of the device when the screen is off. This posed concern for the mechanical engineering team who were concerned that this would cause a hole in the button membrane that would hinder its water resistance. It was also problematic for the electronics team because it complicated the design of the electronic circuit. Solving the LED issue is a task that emerged during the process, forcing the electronics team to re-structure their work to include the LED on the circuit. This describes a process of disorderly collaboration where the specific project steps are defined to face the challenges that are met along the way.

Disorderly collaboration is made of articulation work and cooperative work (Pennington 2010). Articulation work is the process of articulating complex interdependencies that exist between the different design activities. Cooperative work is when different individuals depend on each other to complete a task and they interact with each other by each completing one part of that task (see figure 22).

The challenge of designing usable smart products is combining the knowledge from different fields and articulating it with the user needs (see I.1). Throughout the year of the Weatherway project the collaboration between the different stakeholders reflected an evolution of group-work from articulation work to cooperative work. At the beginning of the project the different members were often doing articulation work as they were meeting and working together in groups where they discussed the ideas, the organization of the project and the task of each team member. In these situations usually team members from different background specializations discussed their ideas, their individual priorities, how their skills could be used and tried to find compromises. This kind of work usually saw the use of different types of prototypes such as sketches, computer models, graphic representation and mock-ups.

Ergonomics mock-ups M3, M4 and M5 show how the different visions of the design of the shell are articulated. M3 was presented by the ergonomics team to the rest of the project team and featured a horizontal screen and a long handle. The ergonomics team discovered that they had a different vision of the shell design from the interface design team and the mechanics teams who were thinking of a design featuring a short handle and a vertical screen. Once this difference was discovered M4 and M5 were made to articulate the different visions. M4 proposed a design with a vertical screen and a short handle. M5 took into consideration the proposal of M4 but tried to make it more ergonomic by adding the finger stopper at the back of the handle. The project team saw a change in collaboration methods as the ergonomics team and the interface design team both started making mock-ups of the shell to negotiate their point of view. The structure of the work also evolved as the interface team became actively involved in the design of the shell.

Towards the end of the project the collaboration work grew more cooperative as activities grew more separated. In this situation the work was done by individuals or by small specialized groups who focused on the tasks requiring their specialized knowledge. Such activities were creating the circuit board, coding the software of the device and making the 3D model of the outer shell of the device. This kind of work was usually supported by artifacts such as project timetables, specification of demands documents, meeting brief notes and dimensioned drawings.

During the manufacturing part of the Weatherway project a technical drawing was used by the mechanics and the electronics team to support their own specialized activity. The mechanical team was designing the inner architecture of the shell such as the positions of screws and supports. The mechanical team used a drawing featuring the dimensions of the shell and the overall dimensions of the circuit board so that the architecture would not use space reserved to the circuit board. The electronics team was designing the inner circuit board and deciding on the position of the electronic components. The electronics team used the same drawings to design the position of the holes to attach the circuit to the shell. Both teams used the same drawing as a method to share information. The drawing supports the collaboration in the way of the Repositories or Coincident Boundaries types of boundary objects described by Star and Greisemer (see III.1.2).

Articulation work is a process of boundary negotiation while cooperation work is supported by boundary specification. Two different types of artifacts support boundary negotiation and boundary specification activities. Boundary negotiating objects and boundary specification objects are both subcategories of boundary objects. In the Weatherway project the mock-ups are an example of boundary negotiating objects.

The Weatherway project is a process of disorderly collaboration because according to the British Design Council (2007) there is no best practice design processes and because the Weatherway project was structured along the way as challenges unfolded. The collaboration in the Weatherway design process evolves from articulation work towards cooperation work. The ergonomic mock-ups of the Weatherway project were involved in the process of articulation and therefore should correspond to boundary negotiating objects and not to boundary specifying objects. The following pages will outline the argument of the mock-ups as boundary negotiating objects in more detail.

VI.2. Weatherway ergonomic mock-ups are boundary negotiating objects

VI.2.1. Identification of boundary negotiating activities

This part explores the premise that ergonomic mock-ups in the Weatherway projects can be characterized as boundary negotiating objects. Lee (2007) suggests different types of boundary negotiating artifacts for different boundary negotiating activities (see IV.1). The objective of this part is to determine how a single mock-up supports boundary negotiating activities. If the mock-ups in the Weatherway project correspond to boundary negotiating objects then they must correspond to the following criteria:

- They are used for the activity of self-explanation either individually or in a small group from the same community.
- They are used for activities of inclusion, compilation, structuring and borrowing in interdisciplinary interaction settings.

VI.2.2. Semantic analysis of the ergonomic mock-ups development timeline

To analyze the boundary negotiation activities in which the ergonomic mock-ups were involved a scenario was used (see figure 27). The scenario was then analyzed with a semantic analysis (see figure 28). The semantic analysis was conducted in two steps:

- The activities that appeared in the scenario were named using product design terms and common terms.
- The resulting terms were compared with the terms used to describe the activities of boundary negotiation by Lee (2007) in the way of Pennington (2010:185).

The table (see figure 28) is used to associate the keywords used by Lee with the keywords used to describe the boundary negotiation activities in the scenario (see figure 28). The associations are made by searching for synonyms. The lower row lists the keywords from the scenario and the first row lists the keywords used by Lee. The keywords are ordered in columns according to the boundary negotiation activity to which they correspond.

In situation 4, the idea is refined into the mock-up M3. This process of refinement is an individual work where the ergonomics team iterates its own idea. The activity of iterating ideas can be associated with the self-explanation activity of reflecting and analyzing ideas.

In situation 5 the ergonomics team proposes its vision of the design to the rest of the team. This activity can be associated with an inclusion activity because it involves proposing and presenting an idea that is personal to the ergonomics team to other team members. Additionally this activity can be associated with a compilation activity because it gathers the point of view of the user (user feedback to tests with M1 and M2) and the vision of the ergonomics team. Furthermore the activity of proposing M3 to the rest of the team can be associated with a structuring activity, because it pushes the boundaries or ask the other team members to compromise on their needs.

Individual use	Interdisciplinary use			
Self explanation	Inclusion	Compilation	Structuring	Borrowing
Learning Recording Organizing Remembering Reflecting Analyzing ideas	Artifact creator: Involving Creating Proposing Receiver: Accepting Rejecting Reserving judgment	Remembering Gathering Organizing Discussing Anticipating needs Presenting and explaining	Pushing and negotiating boundaries Establishing ordering principles Coordinate	Re-use other objects for a different purpose
Iterate ideas Test Evaluate Refine Improve Challenge Push the limit Combine	Propose Communicate/ show an idea Ask for feedback Criticize Judge Accept Refuse Denying support Compare	Propose modifications Acknowledge difficulties Giving feedback	Promote an alternative point of view Demonstrate an idea Feeling threatened	

Figure 28. Table of comparison of boundary negotiating activities named by Lee (Row 1) with activities in the Weatherway ergonomic mock-ups development timeline (Row 2).

VI.2.3. Weatherway ergonomic mock-ups in boundary negotiating activities

In the scenario the same mock-up can be involved in four of the boundary negotiating activities outlined by Lee. The mock-up M3 for instance was involved in the activity of self-explanation, inclusion, compilation and structuring (see figure 25). It appears that with such mock-ups it is difficult to specify precisely the type of boundary negotiating activity because they are not text documents. Most of the objects studied by Lee and Pennington are text base making it possible to search for written instances of inclusion, compilation or structuring.

The recognition of elements is essential to the analysis of artifacts. The inclusion, compilation and structuring artifacts described by Pennington and Lee are text-based documents such as Angela's table and the curator's narrative (see IV.1). Semantic analysis of these documents as conducted by Pennington (2010:185) makes it possible to distinguish, for example, addition of specialized terms (inclusion artifacts), the reuse of picture and text from other documents (compilation artifacts) and ordering principles like textual lists of tasks (structuring artifacts)mock-up. Fortunately the ergonomic mock-ups used in the Weatherway project are focused on shape and the reuse of shapes can be visually identified.

Self-explanation mock-ups are used privately to solve and iterate ideas by oneself, to solve problems, to record or remember information. In self-explanation the designer ideates, models and evaluates the representation of his idea. This loop can be repeated indefinitely until the designer is satisfied with the representation of his idea or until the time runs out. Self-explanation is seen in the M8.

In situation 16, the interface design team creates the ergonomic mock-up M8 to test ergonomics solutions for the new dimensions decided in situation 15. The interface design team iterates the arrangement of the ergonomics until a satisfactory result is obtained. This describes a process of self-explanation. In this situation M8 is a self-explanation mock-up.

Inclusion mock-ups are used to present the idea of the designer and discuss it with other design stakeholders. M5 in situation 9 is an example of an inclusion mock-up.

In situation 9 the interface design team presents the mock-up M5 to the mechanical engineering team. M5 is an inclusion mock-up because it is used to present and discuss an idea as well as creating an alliance with the mechanical engineering team.

Compilation mock-ups combine information from different sources for the specific purpose of creating shared understanding of a problem with another design stakeholder. M5 in situation 8 is an example of a compilation mock-up.

In situation 7 the interface design team proposes his vision of the device layout to the ergonomics team. The new layout of the device is a vertical screen and a short handle, which is radically different from the model proposed in 5 by the ergonomics team. However the ergonomics team considers that the finger stopper, a main ergonomics features on the reverse of the handle, is missing. Consequently the ergonomics team proposes in situation 8 a new mock-up that reuses the layout of the previous one but now includes a finger stopper. The mock-up in situation 8 corresponds to a compilation artifact because it gathers information from different sources (the design of M4 plus the finger stopper) to create a shared understanding between the ergonomics team and the interface design team.

Structuring mock-ups are used to promote design priorities by forcing the structuring of knowledge in accordance to a specific perspective. This type of mock-up is often at the center of conflicts because it forces design stakeholders to align their needs and constraints in a specified way. M3 in situation 5 is an example of a structuring mock-up.

In situation 5 the ergonomics team presented a mock-up of the device ergonomics to the interface design team and mechanics team. The ergonomics team had conducted user test and gathered statistical data that supported the mock-up and was presenting it to the rest of the team to get their approval. The way the mock-up was presented gave the impression to the interface design teams and to the mechanics team that the outcome of the ergonomics research would give the definitive layout of the device. The two teams strongly felt that it was also their job to contribute to shape the outer shell of the device. The mock-up was perceived as putting the importance of the ergonomics as primary and that the needs of the interface and of the mechanics of the shell as secondary. From this perspective this mock-up can be seen as a structuring artifact.

This analysis has identified that there are four boundary negotiation activities that support design collaboration in the Weatherway project: self-explanation, inclusion, compilation and structuring. Unlike the boundary negotiating objects presented by Lee and Pennington the boundary negotiation mock-ups of this research can individually support all four of the boundary negotiation activities. The ergonomic mock-up M3 for instance is involved in all four activities at different times.

In situation 4 the mock-up supports a self-explanation activity. The mock-up acts as a support that helps the ergonomics team to refine the shell concept following the results from the ergonomic research. In situation 5 the mock-up supports an inclusion activity. The ergonomic team uses the mock-up to propose the ergonomic concept to the rest of the team, and the mock-up is formatted specifically for the presentation as it has been refined and polished in situation 4. In situation 5 the mock-up is also involved in a compilation activity. The mock-up combines the feedback from the user tests with the vision of the ergonomics team into a presentation for the rest of the project team.

I propose that a mock-up can support four boundary negotiation activities depending on the situation. One mock-up can support ideation (self-explanation mock-up); be used to promote one's idea to the rest of the team or to create alliance with other stakeholders (inclusion mock-up); to involve other stakeholders (compilation mock-up); and can also push stakeholders into a new role or generate conflict (structuring mock-up). It is not necessary to have one mock-up for one specific boundary negotiation activity, one mock-up suffices for all.

Pennington proposes that disorderly collaboration is a dynamic process evolving from articulation work to cooperation work (see IV.2.3) In this process the negotiation between the project stakeholders leads to the creation of a shared understanding which later facilitates boundary specification and the creation of a shared understanding. In the Weatherway ergonomic mock-ups, the evolution of the negotiation is visible through the physical modifications brought to each successive mock-up. From the ergonomic mock-up M1 to M9 the shape evolves to testify a compromise with an increasing number of team members.

I argue that this compromise, physically inscribed on the ergonomic mock-ups, reflects the creation and the evolution of a shared understanding between all the team members. With this shared understanding the mock-ups will then be used to create boundary specifying objects such as technical drawings that can be used by the different team members for their own specialized work.

From this analysis it can be seen that the mock-ups testify the creation of a shared understanding, and in this sense conform to the concept of a dynamic process of disorderly collaboration by Pennington. The analysis also demonstrates that mock-ups in disorderly collaboration can still be analyzed within the framework of Lee's boundary negotiating objects. However, the mock-ups slide easily between being one type of boundary negotiating object or another. This leads to the proposed amendment of the boundary negotiating object into the concept of boundary negotiation mock-ups in design research (see VII.4). This amendment is that in disorderly collaboration a single boundary negotiation mock-up has no linear flow of boundary negotiation activities, and can support more than two activities dependant on the situation and stakeholders present.

VII. Conclusion

VII.1. Claim

Several authors in the Design field reflect on how prototypes support collaboration and suggest the theoretical concept of the boundary object to explain how they support the integration of knowledge from various stakeholders. (Leonard-Barton, 1991; Henderson, 1999; Brandt, 2007). The boundary object concept is a fundamental concept of sociology and computer supported collaborative work (Lee 2007, Subrahmanian, 2003) to explain the role of artifacts in collaboration.

I claim that the concept of the boundary object as used by design literature is not appropriate to explain how mock-ups support collaboration in design. I present literature from other fields to explain how the concept has been misinterpreted and how it is not suitable for design collaboration (see III and III.3). Finally I propose that the role of mock-ups in design collaboration is better explained by the boundary negotiating object concept.

VII.2. The concept of the boundary object is not suitable for design collaboration

The concept of the boundary object leads to confusion because it is used by design research to mean interpretative flexibility. In literature a boundary object describes an artifact that has interpretative flexibility and is supported by standardized work method. The reliance on method standardization has been overlooked by design research in the role of prototypes in collaboration. Mock-ups support integration of knowledge because they evoke different things to different design stakeholders and allow them to find the limits on which they can agree. While interpretative flexibility can explain this first aspect, it is insufficient to explain how mock-ups support negotiation.

The concept of the boundary object is adapted for scientific work or distributed collaboration of actors with predetermined tasks such as software bug reports. Boundary objects exist in a collaboration in which the needs and constraints of the different parties have already been discovered and negotiated, and which are now established boundaries that do not change. In such collaborations individuals with different interests, needs and constraints separately work on their own specialized task while contributing to the objective of the entire group. Boundary objects support this type of collaboration by bridging the boundaries of the different stakeholders in a way that they do not need to interact with each other and negotiate anymore.

The concept of the boundary object is not sufficient for design collaboration because design only partially relies on standardized work methods. Design is a process of negotiation and continuous restructuration. The needs and constraints of designing a usable smart product are progressively discovered and negotiated through interaction between the different design stakeholders. The design process itself is vaguely structured and its specific steps are progressively defined throughout collaboration. The mock-ups support this kind of collaboration by serving as a platform to reveal and negotiate the needs and constraints of the different stakeholders.

VII.3. Design as a process of disorderly collaboration

The two previously mentioned collaborations are called ‘established’ for the first and ‘disorderly’ for the second. Established collaboration is supported by boundary specifying objects while disorderly collaboration is supported by boundary negotiating objects. Pennington suggests that disorderly collaboration is dynamic and can be divided in two stages, which succeed each other: articulation and cooperation work. Articulation work is supported by boundary negotiating objects while cooperation work is supported by boundary specifying objects.

In the steps of Pennington I conclude that the design process should be understood as process of disorderly collaboration. Design collaboration begins with articulation of the needs and constraints of the different stakeholders and progressively evolves into a cooperation where the different design stakeholders work individually or in small specialized groups on their own task.

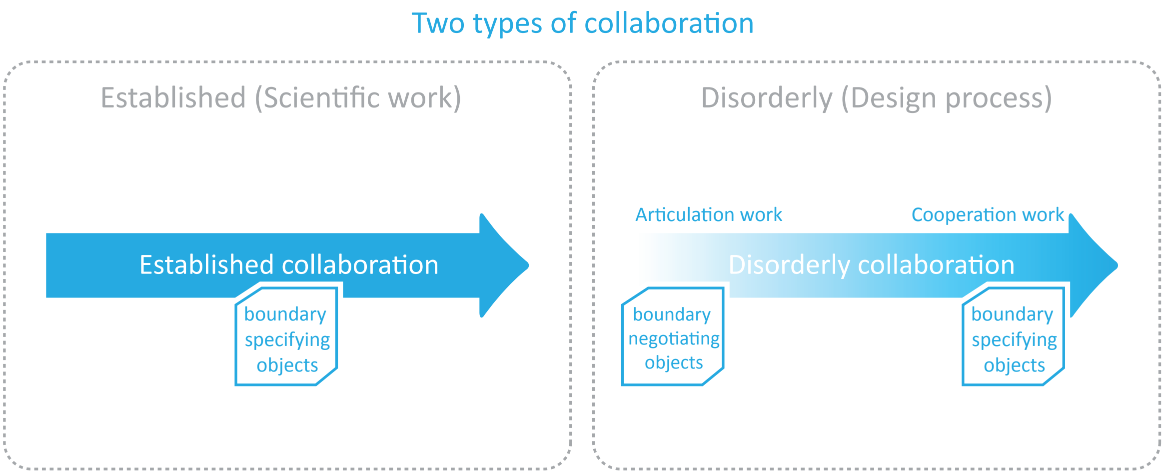


Figure 29.The design process should be understood as a process of disorderly collaboration.

VII.4. Mock-ups are boundary negotiating objects

I conclude that design mock-ups should be understood not as boundary objects, but as boundary negotiating objects. Lee (2007) created the concept of boundary negotiating objects to explain how documents and sketches supported different types of boundary negotiation activities during the design of an exhibition. Lee suggests 5 types of such activities: self-explanation, inclusion, compilation, structuring and borrowing. Analysis of the Weatherway project scenario demonstrates that the mock-ups were involved in four of these activities. While Lee's boundary negotiating objects corresponded each to one or two activities, the Weatherway mock-ups were in fact involved in several activities at different times of use. From this perspective, mock-ups are boundary negotiating objects that support the boundary negotiating activities of self-explanation, inclusion, compilation and structuring knowledge. I conclude that it is not necessary to have one mock-up for one specific boundary negotiation activities; in fact one mock-up could support all.

Therefore I propose that mock-ups involved in boundary negotiating activities should be called self-explanation, inclusion, compilation and structuring mock-ups depending on the activity. Boundary negotiating mock-ups are:

- Self-explanation mock-ups used privately to solve and iterate ideas by oneself, to solve problems and to record or remember information. In self-explanation the designer ideates, models and evaluates the representation of his idea.
- Inclusion mock-ups are used to present the idea of the designer and discuss it with other design stakeholders.
- Compilation mock-ups aim to create shared understanding about a specific problem or task with a specific design stakeholder. The mock-up organizes knowledge from different stakeholders for that particular purpose.
- Structuring mock-ups are used to promote design priorities by forcing the structuring of knowledge according to one perspective. This type of mock-up is often at the center of conflicts because it forces design stakeholders to align their needs and constraints in a specified way.

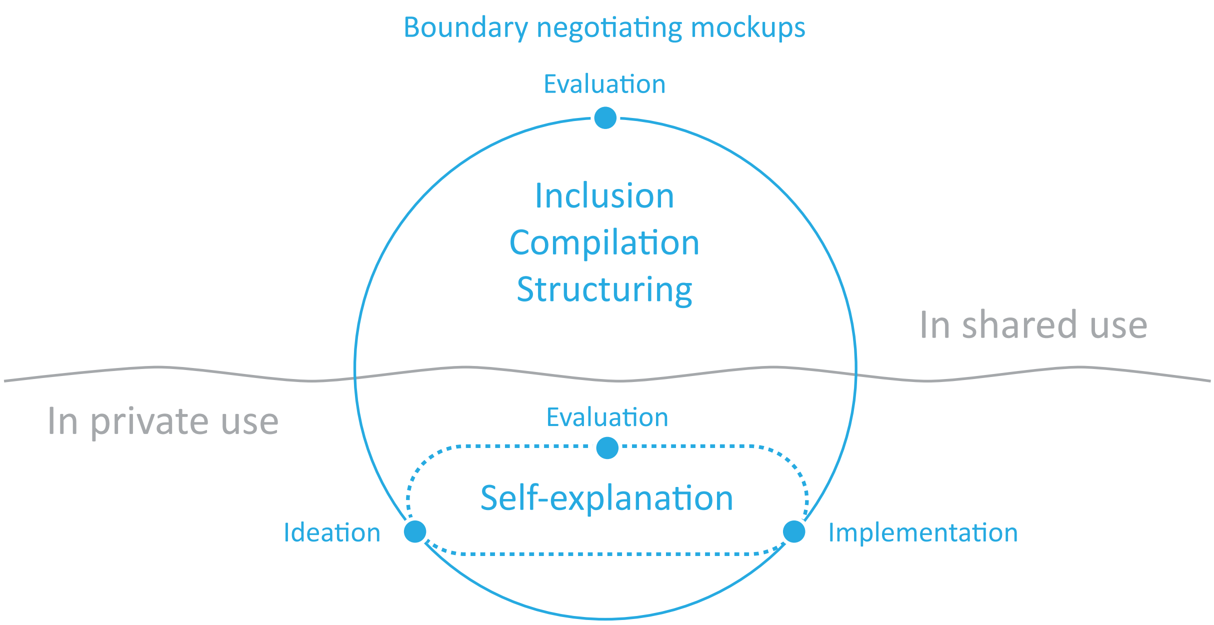


Figure 30.Boundary negotiating activities in the iterative cycle of mock-ups creation and use.

VII.5. Boundary negotiating mock-ups lead to boundary specifying objects

I conclude that the use of boundary negotiating mock-ups in design collaboration leads to the creation of boundary specifying objects thus conforming to the concept of a dynamic process of disorderly collaboration as described by Pennington. Pennington suggests that the use of boundary negotiating objects supports the creation of shared understanding which is the pre-condition for boundary specification and the creation of boundary specifying objects.

In the Weatherway project the progressive inscription of knowledge is obvious through the physical modifications brought to the mock-up. As the project goes on the mock-ups are adjusted by negotiation and the decisions taken by the different stakeholders. The last mock-ups are the product of the entire process of negotiation and are representative of a shared understanding between all the team members. With this shared understanding the mock-ups will then be used to create boundary specifying objects such as technical drawings that can be used by the different team member for their own specialized work.

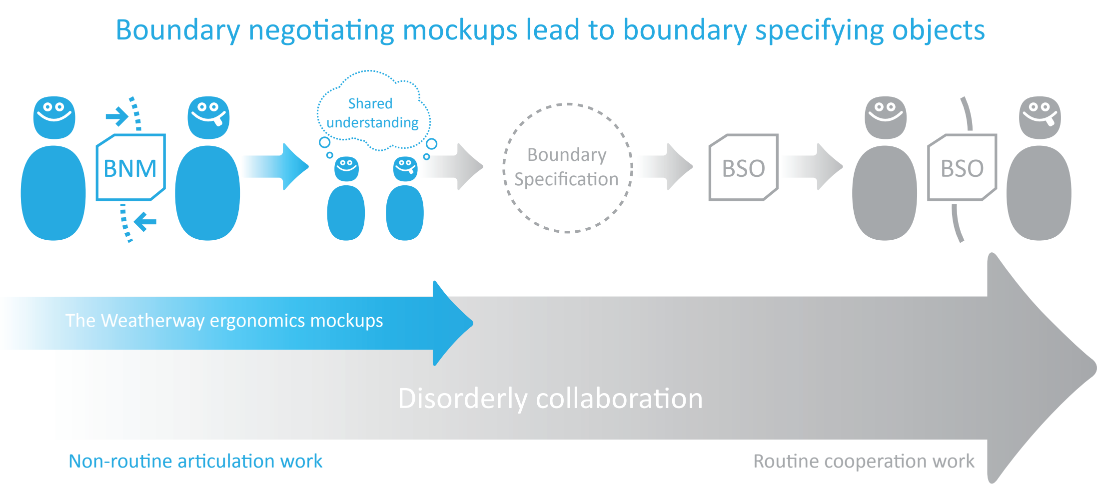


Figure 31.The Weatherway ergonomic mock-ups witness the creation of a shared understanding towards the creation of boundary specifying objects.

This work demonstrated that the concept of the boundary object by Star and Griesemer (1989) is not appropriate to explain how mock-ups support collaboration in design. The design process should be understood as a process of disorderly collaboration (Pennington, 2010) where mock-ups act as boundary negotiating objects (Lee, 2007). To describe the specificities of the concept when applied to design mock-ups the 'boundary negotiation mock-ups concept' was coined.

Boundary negotiating mock-ups allow for analyzing the tremendous impact of mock-ups in design collaboration in four different categories: 'self-explanation', 'inclusion', 'compilation' and 'structuring' mock-ups. These four categories explain how mock-ups serve as tools for ideation, for getting support and proposing ideas, for involving design stakeholders and ultimately for pushing the roles of people and generating conflict. The concept of boundary negotiating mock-up does not only allow us to understand the impact on collaboration between stakeholders but also the role of mock-ups dependant on the project scale. Boundary negotiating mock-ups move freely (without prior definition) between the categories, depending on which activity is most suited to the current negotiation need. Therefore, boundary negotiating mock-ups directly support disorderly collaboration through their adaptability, leading the way to a shared understanding and consequently the successful refinement of the design.

Creation of a shared understanding with the Weatherway ergonomics mockups

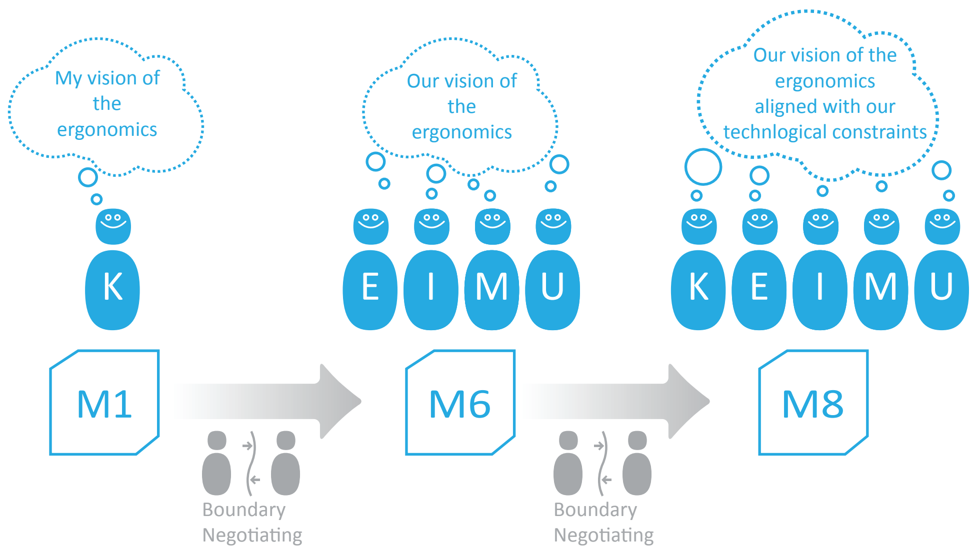


Figure 32.The Weatherway ergonomic mock-ups are witnesses of an evolving shared understanding between the ergonomics (E), interface design (I), mechanics (M), electronics team (K) and the user (U).

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