Adaptation by product hacking
A cybernetic design perspective on the co-construction of Do-It-Yourself assistive technology

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Lieven De Couvreur

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Adaptation by product Hacking
A Cybernetic Design Perspective on the Co-construction of Do-It-Yourself Assistive Technology

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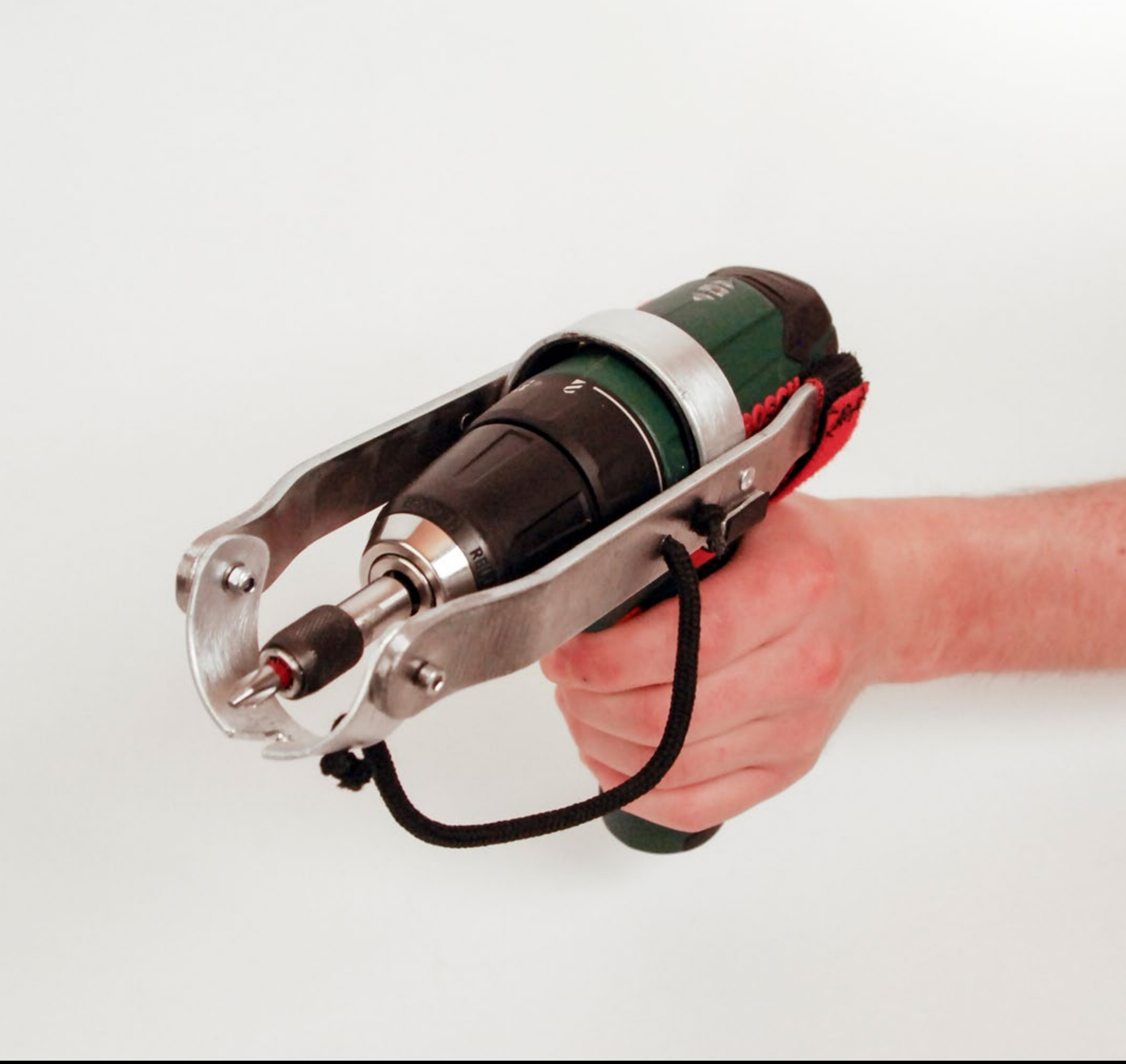
INTRODUCTION



1. FOCUS

ADAPTATION BY PARTICIPATORY
PRODUCT-HACKING

“Owing to this struggle for life, any variation, however slight and from whatever cause proceeding, if it be in any degree profitable to an individual of any species, in its infinitely complex relations to other organic beings and to external nature, will tend to the preservation of that individual, and will generally be inherited by its offspring.“

(Charles Darwin)

In this chapter we sketch the overall focus of the research project, as well as the research questions. We define the concept of participatory product hacking and position the phenomenon within the contemporary field of open-ended participatory design.

1.1 INTRODUCTION

In any exploration of product hacking, it is first necessary to clarify the term itself. '*Hacking*' has many definitions and connotations. Unfortunately, the predominant meaning of the word is used to refer to illegal activity performed by computer experts, such as accessing computer networks or databases, or intercepting telephone calls, legally or otherwise. However, these negative connotations have no true kinship with the original context in which hacking activities took place. In short: '*hackers build things, crackers break them*.'

A hacker is an adherent of the subculture that originally emerged in American academia in the 1960's around the '*Tech Model Railroad Club'* of Massachusetts Institute of Technology (MIT) (TMRC, 2015). This student organization used the term 'hacker' only in its original meaning, namely someone who applies ingenuity to create a clever result with non-conventional means. Each new connection or improvement in the train tracks was called a '*hack*' (see figure 1). Later on, the term was adopted by programmers when existing routines for controlling automated train machinery could be executed with fewer punch cards. Above all, the terminology refers implicitly to the manner in which the activity is done. Levy (2001) describes it as '*a project undertaken or a product built not solely to fulfill some constructive goal, but with some wild pleasure taken in mere involvement.*' Hacking activities entail some form of excellence, for example exploring the limits of what is possible, thereby doing something exciting and meaningful. The essence of a hack is that it is done quickly, efficiently and usually in an inelegant manner. Nevertheless, the unaccustomed result of the exploring activity evokes strong feelings of gratification.

The popularity of the word grew rapidly within a subculture of American computer programming. But the activity of hacking is not a new phenomenon: the practice is a basic expression of human ingenuity and is done by everyday people in a context of daily consumer products. The farmer reworking a piece of machinery to perform a different function than it was originally designed for, or the housewife cutting the bottom off a plastic bottle to make it into a scoop. Generally speaking, hacking is a human response when the resources at hand are scarce (Burnham, 2009). In India, this approach is called jugaad. This Hindi term roughly translates as '*overcoming harsh constraints by improvising an effective solution using limited resources*'. Everyday people, from local mechanics to political fixers, apply creativity to make existing things work or to create new things with meagre resources (see figure 2). Research has shown that other growing emerging markets (see figure 3), like China, Brazil and South Africa, have their own version of jugaad (Radjou, 2012).

Figure 1. Tech Model Railroad Club of MIT in 1958 (photograph by Charles Robinson)

Today in western society, jugaad or hacking principles are still applied vividly on consumer products and are often framed in design research as *non-intentional design* (Brandes & Erlholf, 2006; Brandes et al., 2009), *everyday design* (Wakkary & Maestri, 2008; Kim & Lee, 2014) or *do-it-yourself product design* (Hoftijzer, 2012). Do-it-yourself (DIY) refers to domestic activities in which a user is both producing and consuming (Edwards, 2006), whereas in hacking the emphasis is on repurposing objects or systems (see figure 4) in ways the original designer did not intend and does not necessarily agree with (Galloway, Brucker-Cohen, Gaye, Goodman & Hill, 2004).

In this research project, we define '*product hacking'* as any situated design process modifying or customizing everyday artifacts in a frugal manner with local resources, to improve their fit into people's environments while performing meaningful activities. This definition illustrates several distinct differences between product hacking and professional design.

- First of all, each product hack has a strong idiosyncratic character. Although some hacks start from the same professionally designed artifact, all the outcomes are one-of-a-kind artifacts due to the type of modification, resources and actual end-users. The abovementioned aspects ensure that even reproductions of product hacks in different contexts always contain small variations.
- A second aspect of product hacking is that everyday people become designers. By taking the resources at hand and using them to attain a constructive goal, anyone can practice design. The physicality of the process also makes it easy for stakeholders to join the process. No design expertise, such as knowledge of materials or modelling, is needed; rather, it requires experiential knowledge of artifacts used daily and of the environments in which they are used.
- Third, hacking design is characterized by local environmental adaptation. Although professional designers consider actual contexts from their research data and their own experiences, hackers tend to interact in more nuanced ways in real contexts, addressing

Figure 2. Jugaad solutions: A) a non-motorized meen body vandi jugaad-style improvised vehicle, spotted in Tamil Nadu, India; B) a bicycle bell re-purposed for a blind-man's walking cane, spotted near Mangaldas Market, India; C) wicker baskets repurposed to dry poppadum in the sun, spotted near Dharavi, Mumbai, India

real problems faced by real people. This local character of product hacking also implies a flexibility in thinking and action to use the available resources at hand.

- Fourth, all these hacking solutions are engineered in a frugal manner and focus only on essential aspects from the perspectives of their creators and their environments. Product hacking is not about seeking sophistication or perfection by over-engineering products, but about developing a 'good-enough' solution that gets the job done from the perspective of the end-user.
- Finally, hacking design embodies an identity-driven approach to product design. Hacking activities help people become the person they want to be in the environment they live in. Hackers expect to benefit from using a product or a service. In contrast, manufacturers expect to benefit from selling a product or a service.

1.2 RELEVANCE

It is likely that many users cannot find what they want on the market. Meta-analysis of market-segmentation studies suggests that users' needs for products are highly heterogeneous in many fields (Franke & Von Hippel, 2003; Franke et al., 2009). Professional designers working for mass producers tend to follow a strategy of developing products that are designed to meet the needs of a large market segment. By doing so, they aim to induce sufficient purchases and capture significant profits from a large number of customers. When users' needs are heterogeneous, this strategy of 'a few sizes fit all' will leave many users somewhat dissatisfied with the commercial products on offer and will probably leave some users extremely dissatisfied. If we look at the professional design process from an anthropometric point of view, we instantly link it with such terms as 'universal design' and 'design for all' – a

Figure 3. Spontaneous product hacking projects: A) William Kamkwamba is a Malawian inventor who built his windmill out of local materials. B) Maya Pedal is a Guatemalan NGO based in San Andreas Itzapa. They disassemble bikes from donors in the USA and Canada and use the components to build a range of bicimaquinas (pedal-powered machines). C) Arvind Gupta shares simple yet stunning plans for turning trash into seriously entertaining, well-designed toys that kids can build themselves while learning the basic principles of science and design

design philosophy targeting the use of products, services and systems by as many people as possible without the need for adaptation. These expressions all have one thing in common: the idea is to exclude as few people as possible from the whole design process (Molenbroek & Bruin, 2005). In reality, even if a product concept fulfils an essential need, no-one can design an actual product that will suit all 7 billion people living on our planet (see figure 5). Excellent work has been done (Woodson et al., 1992), but the emphasis was on providing cost-efficient aids and finding a certain compromise so that as many users as possible were satisfied with the product.

But what about those people who are outside the mainstream, and have needs and contexts of life that require unique tools? Moreover, are we not all sometimes outside the mainstream? Mass producers have invested in some attempts to broader the spectrum, through mass customization and personalization. This production strategy aims to offer products or services that meet the demands of each individual customer. In practice, the method deals with an active consumer configuring a product to meet his or her individual needs. Still, mass customization is an example of a top-down approach imposed by the designer who controls the design space behind the scenes. Hacking design fills this gap from a bottom-up perspective. In certain situations, people themselves can design better than anyone else. These everyday people create a strong diffusion in the long-tails of a product spectrum (Anderson, 2006) by making or adapting specific products and pushing these variations/innovations back into culture and society.

The rise of third wave DIY (Toffler, 1980) has served as a mechanism to amplify it. This approach involves combining the read–write functionality of Web 2.0 with computer-aided design (CAD) and

Figure 4. Some non-intentional design manifestations: A) a screwdriver as a locking pin, B) a shopping trolley as a dog trolley, and C) a power adapter as means to keep a coffee mug warm (adopted from the thoughtless acts flickr group)

additive manufacturing. In addition, the new DIY is carried out at workshops where people use both handheld tools and computer-aided and manufacturing machines. Websites, blogs and forums have all been created to spread the practice of product hacking. Hobbyists post pictures, 'how-to's and tutorials online, making it as simple as possible for anyone who wants to replicate their clever ideas. Many of the third wave DIY examples are shown on the websites of Instructables and Make Magazine.

According to Toffler (1980), there were two earlier waves of DIY: subsistence DIY (first wave) and industrial DIY (second wave). In subsistence DIY, people grow what they eat and make what they need, as transport is expensive. For example, people build their own houses and products with local natural materials (wood, stone, metal, plants and animals) that are widely available (Waters, 2006; Lessig, 2014). The main exchange is knowledge and skills passed from one generation to the next through craftsmanship. In industrial DIY, people buy made-to-forecast kits of goods, such as pre-designed boats and furniture. These made-to-forecast kits are sold, together with standardized instructions, for self-assembly (Hoftijzer, 2009; Williams, 2014). Industrialization created a world in which goods and services were delivered to and for people. The knowledge and means were cut-off in a read-only culture at the expense of mass production.

By contrast, third wave DIY draws upon the read–write functionality of the Internet, and digitally driven manufacturing processes, to enable ordinary people to invent, design, make and/or sell goods that they think of themselves (Fox, 2013). Charles Leadbeater (2009) describes it as 'the world of with' where we can design our own tools again, a place where bits and atoms have found each other combining the openness and ingenuity of subsistence DIY with the quality standards of industrial DIY. The goals and philosophy are in some ways identical to those of the open-source movement, but are implemented for the development of physical products rather than software. The core idea of this open design movement is that design (including process, product and resources) should no longer be

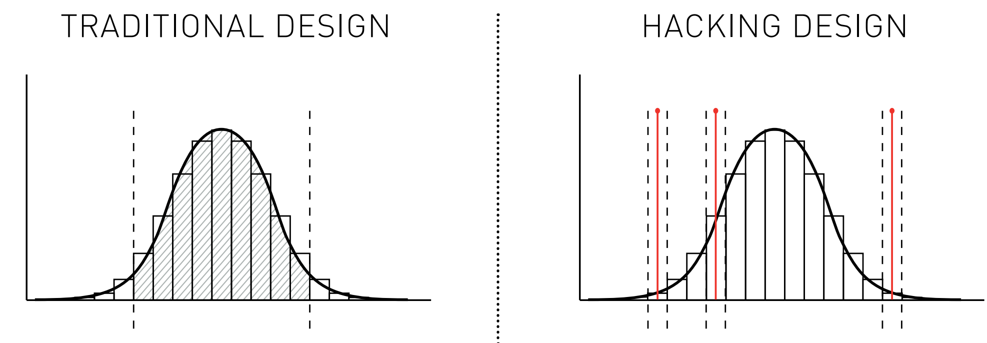


Figure 5. Shift from statistical ergonomic design towards individual product hacking

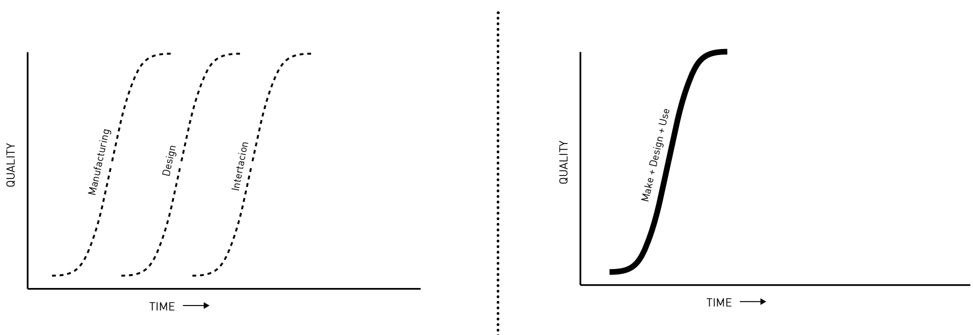


Figure 6. Learning curves in traditional design and hacking design (adapted from Dubberly, 2008)

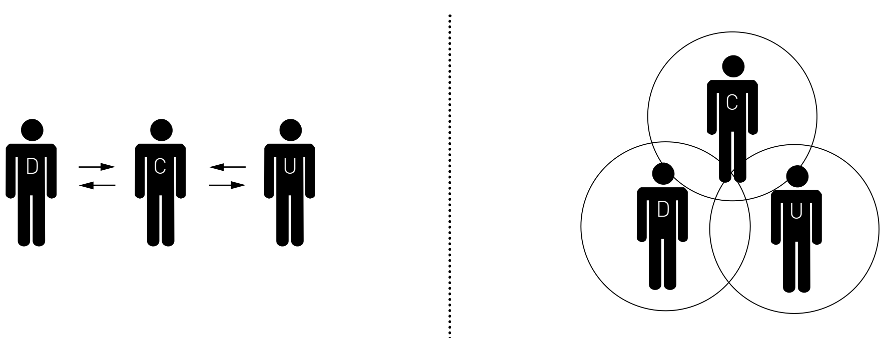


Figure 7. Separated roles in classic design vs merging roles in hacking design (adapted from Stappers et al., 2014)

exclusive, but should be open, particularly to end-users (Abel, Evers, Klaassen & Troxler, 2011). Open design still depends on creative people who are willing to design. However, adapting and changing everyday artifacts does not depend solely on creative people but rather involves everyone.

Workshop-based third wave DIY involves the use of handheld tools, as well as digitally driven manufacturing equipment at fixed locations and in mobile facilities, to make '*almost anything*' (Gershenfeld, 2008). It has its origins in North America and western Europe. Fablabs, hackerspaces and shops-in-boxes still have a relative limited implementation in other parts of the world. While fixed fablabs and hackerspaces are sited in urban areas, mobile fablabs and shops-in-boxes could be transported to rural areas. Another phenomenon in rural areas is cloud-based sourcing platforms (Wu et al., 2015), in which communities built around one manufacturing technique create a worldwide network to share production capacity. A good example is 3D-hubs, a web-based platform that connects 3D printing service consumers with providers in their local area. According to 3D-Hubs, most 3D printer owners use their devices for less than an average of 10 hours per week. The goal of 3D-Hubs is to allow 3D printer owners to establish social connections in their local 3D printing community to increase the utilization of their devices.

It has been claimed that the third wave DIY paradigm is revolutionary for its manifestation of prosumption behaviour (Fox, 2014). Prosumption (Ritzer & Jurgenson, 2010) involves both production and consumption, rather than focusing on either one or the other. Although findings indicate that third wave DIY may be increasingly possible through technical advances and operational improvements, the threshold to engage with these open design processes is still very high for non-technical agents (Ludwig et al., 2015; De Roeck et al., 2012). Some of the reasons pointed out as responsible for this practical barrier are the lack of functional literacy, computer skills, and access to industrial manufacturing infrastructure (Fox, 2014). A top-down way to solve the lack of computer skills is to optimize digital DIY toolkits with the aim of making them more intuitive and user friendly (Hermans, 2014). This meta-design approach changes the role of an industrial designer to that of a digital–physical tool-developer, transforming the interacting agent from adapter to creator. However, these toolkits consist of constrained design spaces in which the professional designer has almost full control over a range of designs.

Another approach is to redefine the role of professional designers in a local DIY workshop or fablab setting and explore their role in this new paradigm. This shift implies that the designers are no longer placed above users when determining what is right or wrong for the latter. Hummels (2011) describes this relationship as libertarian, which emphasizes the freedom and personal responsibility of every participating individual within an open-ended design process (Björgvinsson, 2008). As this research project is rooted within an industrial design education program, we explore this latter approach by randomly teaming up young professional designers with everyday people in the pursuit of adapting or modifying an everyday product. The young professional designers apply their practice like any other profession together with potential users, who add their own experience and specific competencies to the mix. Moreover, professional designers collaborate with these potential users, not as objective researchers performing one or several studies, nor merely as facilitators who run co-design sessions, but as subjective participants in an intensive process in which they themselves are part of the solution (Lee, 2008).

1.3 OBJECTIVE

Our objective is to explore this new role of professional designers and observe open-ended participatory hacking behaviour in situated co-design practices build around DIY assistive technology (for an elaborate description of the context see chapter 3). Open-ended practice assumes sharing, change, learning and ever-evolving knowledge and skills of all participating agents (Björgvinsson, 2008). Involving potential users in the hacking design activities of everyday products is an approach that is undergoing further development (Hyysalo et al., 2014, Seravalli, 2013). They frame participatory design as prototypical practices that can handle situated and fast changing needs and argue that designers can never fully understand practices and therefor need to hand over significant parts of designing to other agents. The activity of 'designing' is thus relevant not only to designers but to all agents who adapt their attitude to meet particular goals towards a preferred situation (Simon, 1996). Donald Schön (1984) insists that no matter what the profession, practitioners – namely designers and other professionals – work through 'reflections in action.' In this experience-driven design approach, the creative process directs the resultant user experience, and engaging users in turn directs this creative process (Desmet & Stappers, 2011). The role of the mock-up or prototype is therefore instrumental to engender favourable conditions for ongoing negotiation of meaning. It creates a shared language between all the stakeholders by converting their expertise and needs into tangible product experiences.

The definition of "*prototype*" in the context of hacking design used here is:

> *Any shared physical manifestation externalizing an otherwise internal or unavailable adaptation of a future situation that contains a local goal, technology and potential agents.*

Prototyping, on the other hand, is an activity wherein agents interact with prototypes to explore or evaluate a future situation in a certain context (Blomkvist, 2014).

> *Prototyping is the ongoing local interaction with changing prototypes to engage, explore or evaluate specific hacking contexts.*

In classic innovation processes (Cooper, 2008; Buijs, 2003, Roozenburg & Eekels, 1995), prototype activities are properly aligned to interact sequentially with different external groups of stakeholders and their domain-specific knowledge (see figure 6). These models help designers and companies to plan and manage their project and to keep an overview while designing. In open-ended participatory design (Björgvinsson, 2008), activities have a non-linear and more dense character, involving simultaneously stakeholders with domain-specific knowledge on manufacturing, design and interaction.

In this open-ended approach, 'a finished design is the result of the emergent properties of the interacting system' (McCormack, Dorin & Innocent, 2004), rather than the work of one central designer or design team. Consequently, open design also emerges from the new science paradigm of complexity and self-organizing structures (Hummels, 2011), which endorses self-directed and competency-centred learning (Doll, 1989). This type of collaborative learning through making is a holistic process of adaptation. It is not just the result of cognition but involves the integrated functioning of the total group (thoughts, feelings perceptions and behaviours) and cooperativily learn to capitalize on one another's resources and skills. Today it is still quite unclear how these adaptive processes within participatory product hacking are practically established. That is, we do not know the micro-level mechanisms by which adaptation is actually done in collaborative hacking activities. Other than in professional design processes, product usage and production is situated, which makes it impossible to plan actions or follow standard procedures (Suchman, 1987).

The main research question of this dissertation focusses on how adaptive hacking behaviour organizes itself between designer, participating agents and their environment:

How do specific prototyping interactions influence general adaptation in participatory hacking behaviour?

The key aspect in this research project is 'adaptation' within in open-ended hacking behaviour. According to the Oxford English Dictionary the main definition of 'adaptation' makes a distinction between two meanings, namely: 'The action or process of (1) *adapting* or (2) *being adapted* to fit a changed environment.' Krippendorff (1986) also distinguishes these two kinds of adaptations. Both are used in this research project to postulate two different hypotheses. (1) The nature of *'adapting'* has an opposing connotation. Krippendorff describes it as Singerian adaptation, after Singer, who described how organisms, particularly humans, change the nature of their environment so as to eliminate threats to or prevent the destruction of their own internal organization. (2) The nature of '*adaptive'* or '*being adapted*' has a more transubstantiate character. This phenomenon is named Darwinian adaptation, after Darwin, who observed how organisms change their internal structure when their environment makes existing forms no longer viable.

In order to answer the main question, the following sub-questions will be answered simultaneously:

> *(1) How do adapting prototyping interactions influence general adaptation in participatory hacking behaviour?*

> *(2) How do adaptive prototyping interactions influence general adaptation in participatory hacking behaviour?*

The main question will be answered through a pragmatic approach based on phenomena and events in real-life hacking practices. As an objective to unify our research, we apply practice-based design research that focusses on collaborative hacking behaviour.

1.4 SCOPE

From a co-design perspective, product hacking is a new medium that both designers and non-designers can use. The field of participatory design has grown rapidly with shifting roles for designers and stakeholders (Stappers & Sanders, 2014a). Generally speaking, the co-creation spectrum evolves from familiar approaches in which users and other stakeholders work with designers in the design process (Sanders, Brandt & Binder, 2010) as a way to change from 'use-before-use' (Redström, 2008) to a more meta-design approach (Fischer, 2011; Fischer & Giaccardi, 2006), deferring design and participation till after the design activity, that is, design at use time or 'design-after-design' (Redström, 2008).

A similar approach is the idea of a continuing 'design-in-use' (Henderson & King, 1991). The tools and practices of making originated from three distinct approaches that have become increasingly intertwined today: probes, generative tools and participatory prototyping (Stappers & Sanders, 2014b). As a rule, probes and generative tools focus on making sense of the future. The probes approach invites people to reflect on and express their experiences, feelings and attitudes in forms and formats that provide inspiration for designers (Gaver et al., 1999, Mattelmäki, 2005, 2008). Generative tools describe a participatory design language that can be used by non-designers (i.e. future users) in the front end of design so that they can imagine and express their own ideas about how they want to live, work and play in the future (Stappers & Sanders, 2003). Here, making activities are used as vehicles for collective exploring and expressing.

Participatory prototyping presupposes that you know what it is that you are designing, for example a product, a device or an environment. Prototypes are used by designers and non-designers to create representations of future objects and/or scenarios in order to give shape to the future, that is, to help them see what it could be and how it might feel. The focus of this dissertation lies clearly in the field of participatory prototyping. Aside from the physicality in use and design, open design also involves production-related aspects such as material resources, skills and crafts. Generally speaking, hacking design is seen as confronting the abstract with the concrete. The aim of this research is to understand adaptation in hacking design activities and to frame hacking design as a conversation medium that enables learning, coordination and collaboration (Dubberly & Pangaro, 2009) between professional designers and non-designers. In classic design, the relationship with a designer is often based on instructionalism (tell me how it should be) instead of constructivism (collaboratively explore meaning in context). This classic view of design identifies three roles: the user, who buys and will use the product; the designer, who conceives the product; and the client, who manufactures and distributes the product.

Open design shifts away from this linear and unintegrated approach (see figure 7). In open design, roles and responsibilities interact, merge or even switch back and forth between engaging agents. Besides experiential learning, the willingness to share this learning is an important requirement to increase knowledge (Nonaka & Takeuchi, 1995). These conversations are a progression of exchanges that are led by prototyping interactions among participants. To solve a problem, the required information and problem-solving capabilities must be brought together. Design problems are characterized by a symmetry of ignorance (Rittel, 1984), meaning that no individual stakeholder, or group of stakeholders, has all the relevant knowledge, yet the knowledge of all stakeholders is equally important in the process of framing and resolving the problem (Arias et al., 2000). Each participant is a 'learning system,' that is, a system that changes internally as a consequence of experience. This fits Schön's reflective practice and Dewey's pragmatism, both of which are based on the ability of professionals to know, reflect and learn in and through action; to learn by doing and, through reflection, gain an understanding that arises from experience (Schön, 1983; Dewey, 1997).

In these design activities, cognition is situated (Suchman 1987 ; Clancy, 2008) and should be regarded not as thinking (a mental process), but as an activity of inquiry through interactions between all involved agents and their environment (Geydrend, 1998). In design research this argument is elaborated both by Lim et al. (2014) and by Hartman et al. (2006), who recognize the iterative prototyping as a pivotal activity for generating insight into the design process. The root of conversation theory and reflective practice can be traced back to cybernetics, which permeated a diverse group of fields such as philosophy, artificial intelligence, pedagogy and sociology (Pask, 1976; Steier & Ostrenk, 2000). Cybernetics is a way of thinking that bridges action, perception and cognition, and encompasses the active involvement of the observer. The language of cybernetics will therefore be used to explore adaptation by prototyping interactions through a behaviour-focused perspective.

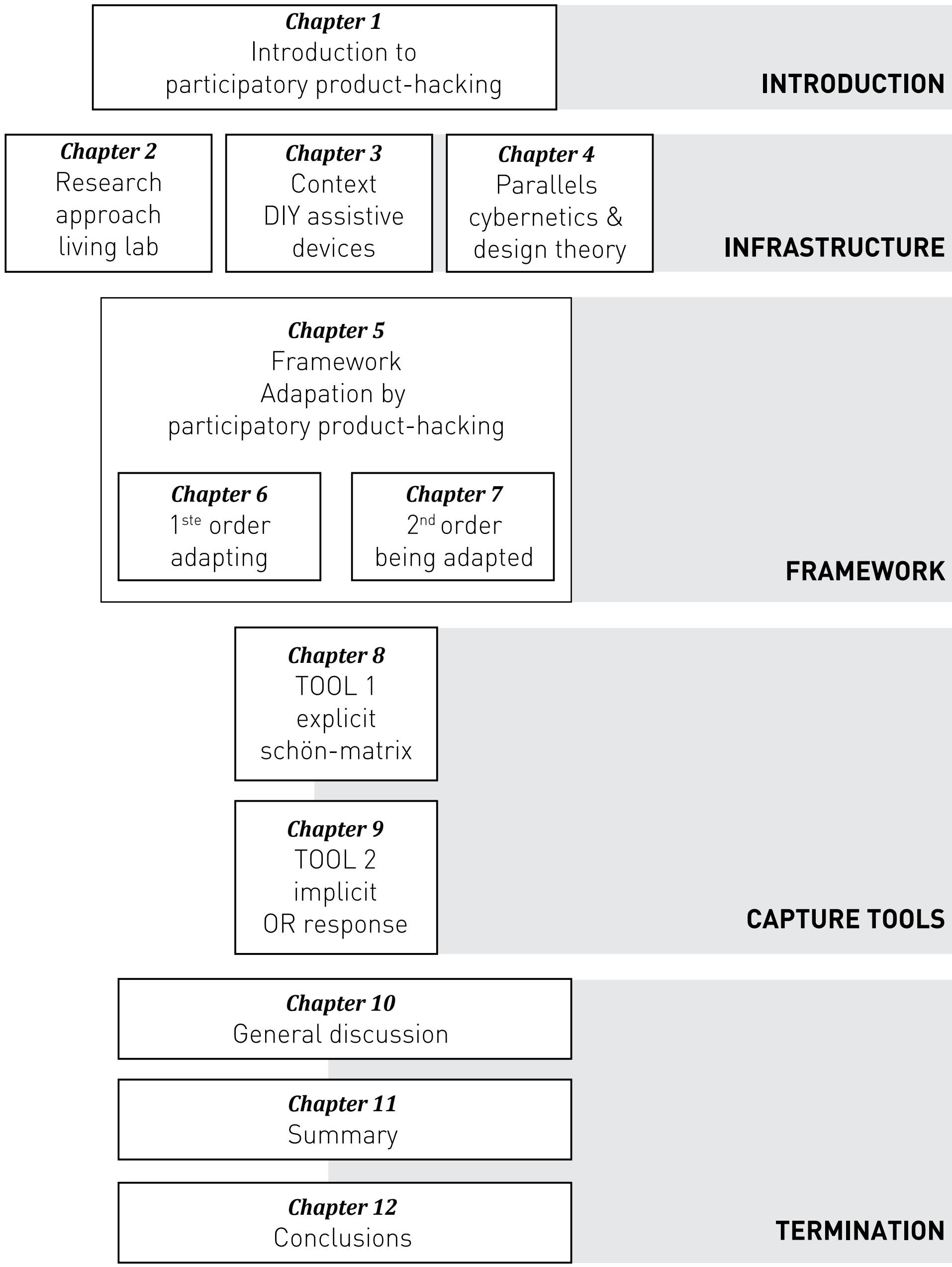


Figure 8. Reader's guide

1.5 READER'S GUIDE

This thesis contains eleven chapters that are divided in five parts. The second part, which consists of chapters 2, 3 and 4, describes the infrastructure process. It deals with the research approach, a description of the research context and discusses some fundamental concepts of experiential learning (adaptive learning) that are referred to in later chapters. The third part, consisting of chapters 5 to 7, applies the infrastructure to describe and explain the nature and dynamics of adaptation strategies. Chapter 5 gives a holistic perspective on key dynamics which are later discussed more in-depth in chapters 6 and 7. The fourth part, which consists of chapters 8 and 9, focuses on the applied tools to capture adaptive learning within hacking activities. Finally, the fifth part entails an overall discussion of the findings and sketches new opportunities for future research (see figure 8).

Chapters 3, 5 and 8 were published previously in papers that have been reproduced verbatim in this thesis. In addition, chapter 7 was written on the basis of on a previously published conference paper. Using papers as chapters offers the advantage that the chapters can be read separately, according to the reader's interest. To extend this advantage, the remaining chapters (except the general discussion chapter) have been written with a similarly independent structure. This approach has one drawback however namely that some chapters repeat the explanation of certain concepts, especially in the introduction sections. This is largely compensated by the fact that the explanations are often illustrated by means of other case studies

I. INTRODUCTION	
Chapter 1	***Focus***
	In this chapter we sketch the overall focus of the research project, as well as the research questions. We define the concept of participatory product hacking and position the phenomenon within the contemporary field of open-ended participatory design.
II. INFRASTRUCTURE	
Chapter 2	***Research Approach***
	In this chapter we explain the approach and rationale within our case-based research approach coupled to the practical set-up of the living lab project which facilitated the case studies.
Chapter 3	***Research Context***
	In this chapter we explore the historical changes within rehabilitation engineering. We discuss a new generation of makers and occupational therapists which create one of a kind product adaptations in people's homes, sheltered workshops and rehabilitation centres.
Chapter 4	***Theoretical Underpinnings***
	The literature review provided a strong basis for our research and in addition to the set-up of the living lab, the framing of the theory was part of the infrastructure process. Although the literature review has been the object of a continuous effort, it was generally marked by insights that were made through the connection of two fields, namely cybernetics and design theory. The purpose of this chapter is to explore two subjects, cybernetics and design theory, in order to establish and demonstrate a relationship between these two fields with regard to self-directed learning. The main shared propositions between both fields are forming the fundamentals of the framework.
III. FRAMEWORK	
Chapter 5	***Framework on Adaptation by Product Hacking***
	In this chapter a cybernetics design approach was chosen to develop a general framework that explains how specific prototyping interactions influence general adaptation in participatory hacking behaviour. Step by step we build up the theory supported by real-life illustrations from case studies on Do-it-Yourself Assistive Technology (DIY-AT).

Chapter 6	***Adapting : 1st Order In-Depth Analyses***
	In this chapter we describe how adapting (or external adaptation) and being adapted (internal adaptation) prototyping interactions influence general adaptation in participatory hacking behaviour. This is done through an in-depth time-series analysis of a hacking design process on DIY-AT. The main goal is to illustrate the self-regulating prototyping dynamics within one single case study.
Chapter 7	***Being Adapted : 2nd Order Cross-Case Analyses***
	In this chapter we explore how adaptive (or internal adaptation) prototyping interactions influence general adaptation in participatory hacking behaviour. This is done through cross-case analyses on all DIY-AT case studies to show the variety of double-loop adaptations and their practical manifestations within product hacking activities. At first, we untangle the manifestations of essential variables and afterwards we discuss the self-regulation dynamics they can provoke.
IV. CAPTURE TOOLS	
Chapter 8	***Tool 1 - Explicit Capturing***
	In this chapter we describe within a single case how the reflective Schön matrix serves as an explicit self-regulation tool that helps hacking practitioners to document their momentary co-experiences explicitly together with their prototyping interactions. As discussed in chapter 2, the design tool and its variables are explicitly used from 2011 until 2015 within the living lab projects. The design trajectories and events it has elicited through case-based research are used to build up the theory and illustrated key aspects in chapters 4 to 8.
Chapter 9	***Tool 2 - Implicit Capturing***
	In this chapter we explore the implicit use of physiological technology to tag the orienting response of design agents while performing hacking activities. Our goal is to tag adaptive behaviour by synchronizing electrodermal activity with a video stream of prototyping activities. Unlike all the other case studies, the studies comprised in this chapter were conducted within a semi-controlled laboratory setting. The development of the tool was mainly triggered as a digital optimisation of the conscious analogue tool descripted in chapter 8
V. FINALISATION	
	Discussion, Summary & Conclusion

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Part II

INFRASTRUCTURE

2. RESEARCH APPROACH

DESIGN FOR (EVERY)ONE
AS MICRO LIVING LAB

“In the varied topography of professional practice, there is a high, hard ground overlooking a swamp. On the high ground, manageable problems lend themselves to solution through the use of research-based theory and technique. In the swampy lowlands, problems are messy and confusing and incapable of technical solution.

The irony of this situation is that the problems of the high ground tend to be relatively unimportant to individuals or society at large, however great their technical interest may be, while in the swamp lie the problems of greatest human concern.”

(Donald Schön)

In this chapter we explain the approach and rationale within our case study based research methodology coupled to the practical set-up of the living lab project which facilitated the case studies.

2.1 METHODOLOGICAL FRAMING

My approach to this project is highly influenced by my background in industrial design engineering. Industrial design is applied, contextualized, and multi-disciplinary, in contrast to fundamental research, which is mono-disciplinary, generalizable and can thus be applied in multiple contexts.

Horváth (2007) views design research as a link between basic, fundamental research and industrial design engineering through which knowledge is transferred from one end to the other. He identifies three types of design research that are characterized by a growing degree of design involvement: Research in design context, design inclusive research and practice-based research.

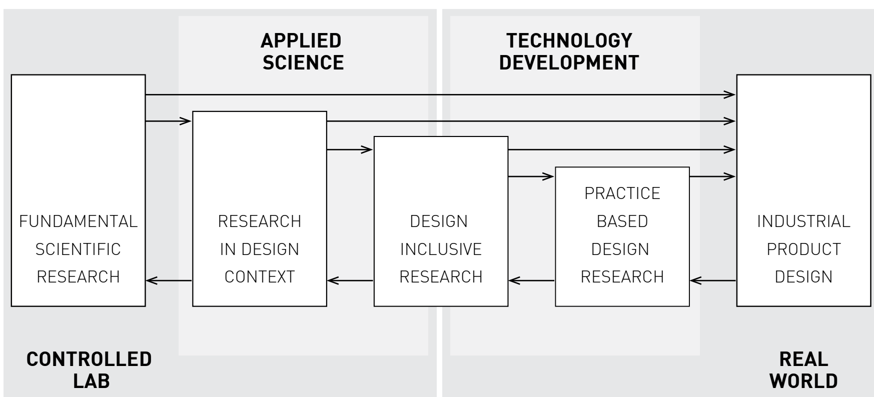

Figure 1. different approaches on design research (Horváth, 2007)

Research in design context is most similar to fundamental scientific research; it uses research methods of the basic disciplines to study design-related phenomena. It is a research method wherein an artifact, the design, is used as the stimulus material for an experiment. The research methodology and objectives are borrowed from fundamental research. *Practice-based research*, on the other hand, is mainly driven by design practice. This research method has its origins in the arts and crafts. It takes design as a verb or an activity, to plan and create re-action with the aim of reaching a giving objective. Contrary to *research in design context* the objective and testable knowledge is generated through cycles of building and evaluating structurally varied, experiential prototypes. The *practice-based research* process describes thoroughly design behavior within design processes and the insights thus generated to extract knowledge about how artefacts and design processes can be created in a more efficient

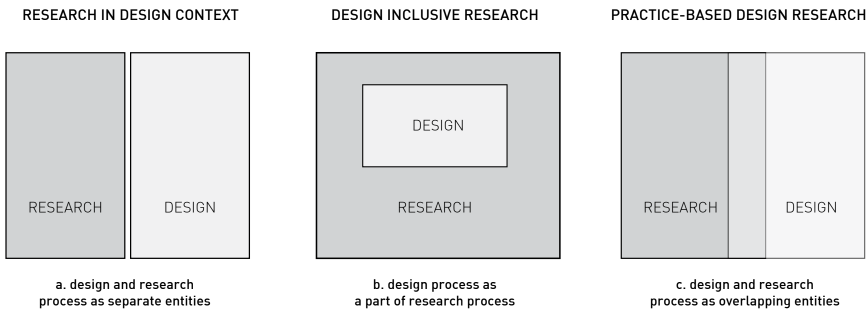

Figure 2. Relations between design and research (adapted from Stappers & Sleeswijk Visser, 2014)

and qualitative way. *Design inclusive research* lies between the former two types of design research. Horvath combines the methodologies found in both design practice and in fundamental research (see figure 1). He encapsulates a design process within a research process and sees design as the step between theory and proof. Unlike *practice-based design research*, the design process is documented, but it has little interaction with the objectives of the research project.

Given the nature of participatory hacking activities this dissertation takes a *practice-based design research* (PBDR) approach, which means that observations and explorations within real-life design practices are used to answer the main research question.

2.2 PRACTICE-BASED DESIGN RESEARCH

Practice-based design research is concerned with the nature of design practice and leads to new knowledge that has operational significance for that practice. The main focus of the research is to advance knowledge about the practice, or to advance knowledge within practice.

The practice-based research question within this dissertation is framed as a 'how-question' and thereby contains a research and design goal :

- The research goal is to develop knowledge and understanding on how specific prototyping-interactions influence general participatory hacking behaviour.
- This knowledge will contribute to the design goal; the development of tools to capture and manage changing participatory hacking behaviour.

One of the main aspects of *practice-based design research* is its high level of contextualization and level of knowledge synthesis or integration (see figure 2). In this doctoral thesis, the results of practice-based design research are fully described in text form and are illustrated with the inclusion of several creative outcomes from real-life case studies. Within these real-life case studies the practitioners were positioned as observers. The conversation, reflection, and action that occur in response to the generation of prototypes have the potential to form the basis for an understanding. They steer the design researcher to relevant perspectives and practices within a specific design domain .

To ensure the potential to create generalizable knowledge, and to meet certain criteria of scientific inquiry the research approach sticks to the following criteria for practice-based research (Cross, 2006) :

- *purposive* - based on identification of an issue or problem worthy and capable of investigation,
- *inquisitive* - seeking to acquire new knowledge,
- *informed* - conducted from an awareness of previous related research,
- *methodical* - planned and carried out in a disciplined manner, and
- *communicable* - generating and reporting results, which are experiential and accessible by both the members of de design practice as the design research community.

Last but not least, the basic assumption of *practice-based design research* is that there is a need for designerly knowledge production and the acknowledgment that this can be done by observing spontaneous design processes within their context. The aim within practice-based design research is to conceive a design theory that illustrate the diversity of events which occur within the real-life practices. Design theories are not like scientific theories. For this distinction we like to state Forlizzi (2007) who nuanced that “scientific theories often predict action irrespective of context and situation”. On the contrary, “design theories describe conditions for change, often looking holistically at groups of phenomena together”. This represents important problem framing in design, which is different from problem framing done by scientific disciplines.

2.3 METHODOLOGY

Participatory action research

We argue that observing design behavior in highly dynamic contexts of participatory design is not possible with only a set of reductionist techniques : the impact and implications of prototyping-interactions created within co-design teams cannot be designed nor understood completely prior to the intervention. In addition, all design actions are so-called one-shot-operations, which cannot be repeated, and are too complex to be tested with multiple condition experiments. Creating understanding out of random design events requires lots of explorative experiments performed in the messy field or real world (Schön, 1995).

Within this typical research process participatory product hacking is put into the focus of observational and explorative investigations. In essence such research includes practice as an integral part of its method and falls within the general area of action research (Saakes, 2013).

Action research is very similar to practice based design research, but its methodology of research is far more established (Archer, 1995). I will apply participatory action research to study designers within a living lab project. Action research (Lewin, 1946) originates from organizational psychology, and is an iterative process involving researchers and practitioners acting together in a particular cycle of activities (Avison, 1999). Action research cycles consist of planning, acting, observing, and reflecting. These actions provide a qualitative way to study and learn from changes in organizations and communities. In the participatory action research method (Whyte, 1989) the participation of practitioners is emphasized, in the definition by Argyris (1999, p.434: “Participatory action research is a form of action research that involves the proposition that causal inferences about the behavior of human beings are more likely to be valid and enactable when the human beings in question participate in building and testing them”. Participatory action research thus acknowledges the users as experts on their own work process and domain.

Case study as research method

The main method used within this dissertation is the case study. The aim of case study research is the study of a contemporary phenomenon within a real-life context (Yin, 2013).

Case studies are a form of qualitative descriptive research, conducted through intensive analyses and descriptions of a single (or a bounded) system in space and time. Topics which can be examined include individuals or groups, artifacts or events, processes or activities. Through case studies we hope to gain in-depth understanding of situations and meaning for those who are involved.

In general we considered a case study design approach for this dissertation according to the following reasons (Baxter & Jack, 2008) : (a) the main focus of the study is to answer a “how” question; (b) we can and do not want to manipulate the behaviour of those involved in the study; (c) we want to cover contextual conditions because we believe they are relevant to the phenomenon under study; or (d) the boundaries are not clear between the phenomenon and context.

According to Yin (2014, p.18) the case study inquiry process copes with a technically distinctive situation in which there will be many more variables of interest than data points:

- and as one result it relies on multiple sources of evidence, with data needing to converge in a triangulating fashion.
- and as another result it benefits from prior development of theoretical propositions to

The principles of action research and action learning according the action learning action research inc

(adapted from ALARA; 2013)

1. *Action Learning and Action Research practitioners aim at and/or ground their work in the world of practice.*
2. *Action Learning and Action Research is explicitly and actively participative. That is, research and projects are conducted with, for and by people rather than on people.*
3. *Action Learning and Action Research practitioners openly acknowledge and welcome a wide range of ways of knowing (including intuitive, experiential, presentational as well as conceptual) so that action and understanding are each embodied in the other.*
4. *Action Learning and Action Research practitioners address questions that are of significance to the flourishing of human community and the more-than-human world as related to the foreseeable future.*
5. *Action Learning and Action Research practitioners actively consider the ethics of research practice for this and multiple generations.*
6. *Action Learning and Action Research practitioners seek to develop enduring capacities amongst those involved within projects.*
7. *Action Learning and Action Research practitioners appreciate and acknowledge first (personal), second (interpersonal) and third person (systemic) perspectives.*
8. *Action Learning and Action Research practitioners engage reflectively and critically with methods and methodologies in the design and implementation of research.*
9. *Action Learning and Action Research practitioners acknowledge that there are culturally distinctive approaches to Action Research and Action Learning. They seek to make explicit the assumptions in the cultural tradition from which they work, and to understand differing traditions.*
10. *Action Learning and Action Research engages the context of research with systemic thinking and practices.*

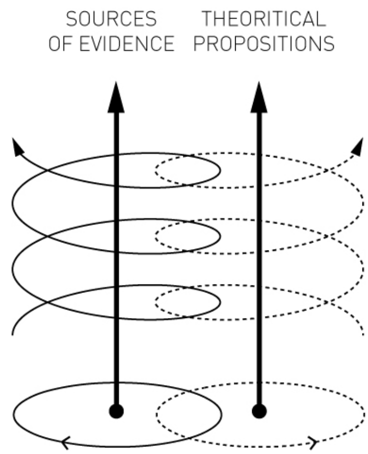

Figure 3. Overview of dual approach within case study based research

guide data collection and analysis

The essence of the conducted case studies within this dissertation is to illuminate crucial decisions triggered by meaningful prototyping-interactions, for example: why they were taken, how they were implemented and with what result. Like any other research method, case study based research is a way of investigating an empirical topic by following a set of prespecified procedures. The main actions of this qualitative research process can be divided into three stages (see figure 4): (1) define/design, (2) prepare/collect and (3) analyse/conclude. Each of these stages will be discussed briefly to illustrate the approach and rationale within this dissertation.

CASE STUDY DEFINE AND DESIGN

Published case studies (see Hancock & Algozzine, 2015) demonstrate the wide diversity in study design. Each case study is designed to suit the case and research question. Three main activities that are structuring the design process are : (1) theory development, (2) defining the type of case study and (3) the data collection protocol.

Theory development

The differences between case studies and related methods such as ethnography and grounded theory is the crucial step of theory development prior to the conduct of any data collection. The purpose of case studies is to develop or to test theory. The goal is to have a sufficient blueprint for your study, and this requires theoretical propositions. A typical approach is not to explore the phenomenon through one lens, but rather through a variety of lenses which allow for multiple facets to be revealed and un-

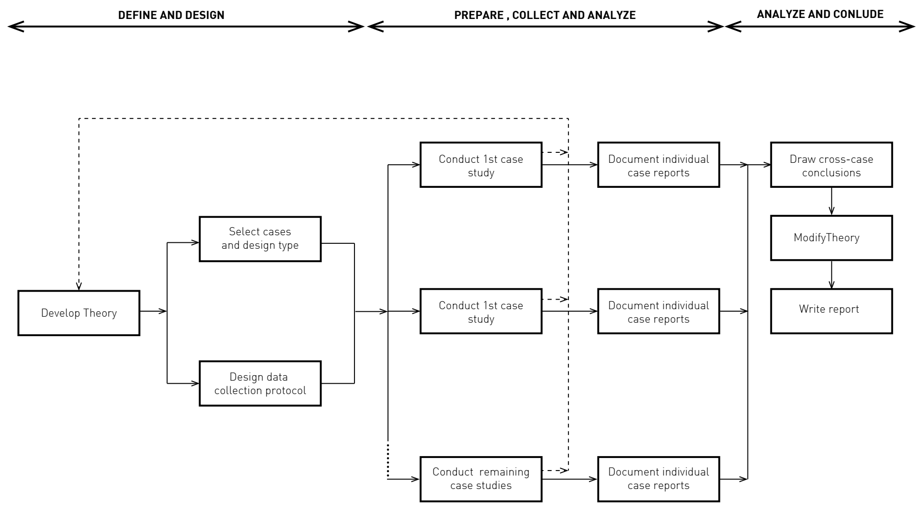

Figure 4. case study method (adapted from Yin, 2009)

derstood (see table 1). In general the theory development ranged from micro (specific prototyping interactions) to macro-mechanisms (general adaptation behaviour). It is and important practice during the analysis phase of any case study to return to the main theoretical propositions (see chapter 1) to avoid drifting away due to the many variables of interest .

Type of case studies

Within this dissertation we approached the propositions through three types of case studies, namely descriptive, exploratory and explanatory (Yin, 2013). Descriptive studies are used to take a deep dive to better understand a single cases. The purpose is not to build any theory but to describe or illustrate the phenomenon within a real life situation: for example in chapter 6 on the spontaneous dynamics of self-directed learning and chapter 8 to demonstrate the practical use of a self-regulation tool. These case studies were not undertaken primarily to avoid a bias. As a rule they were selected for their particularity, ordinariness and their consistent progress reports (see paragraph on case study reports). A second type of case studies have a more instrumental character. An explanatory case study type was used to accomplish something other than understanding a particular situation. It provides insight into a general behavior and was mainly used to test or refine the theory within the research context of participatory product hacking. In short this case study type was mainly used to support and illustrate the theory development process. The last applied design type include exploratory case studies that enable the researcher to explore the variety of similarities within and between cases. The goal is to find the differences and nuances across cases. A general overview of the applied types can be found in table 1.

The data collection protocol

A next step within the case study protocol is to consider if it is prudent to consider a single holistic case study or a better understanding of the phenomenon will be gained through conducting a multiple case study. Single case studies have giving us the ability to look at sub –units that are situated within specific and detailed prototyping-interactions (see chapter 6 , chapter 8 and chapter 9a). A rationale for the selection of single case studies was the representative or typical case. The case study may represent a typical "project" among many other projects.

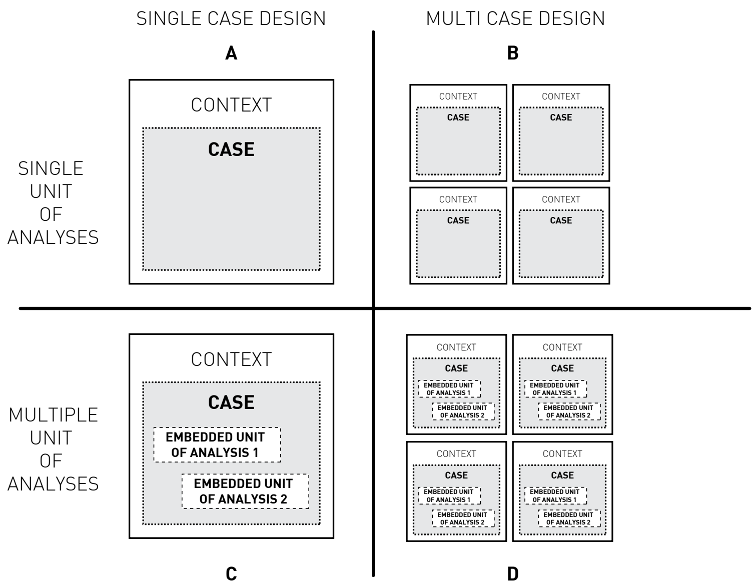

Figure 5. basic types of design for case studies (adapted from Yin, 2009)

On the other side of the spectrum we also applied a multi case design, studies with more than a single case, to gain more insight on general adaptive design behavior and its related phenomena (see chapter 3, 4, 5 and 7). The multi case designs were always performed with all the available case studies at that point in time. Our approach of multiple cases can be compared as multiple experiments which follow *"a replication design*". This is far different from the often misused analogy with "*survey sampling design*" or " *repeated measurements*" which mainly focus on attaining quantitative proof. In this dissertation replication is used to reflect on sources of variability both between all case studies and (potentially) within case studies. A replication study within field settings involves repeating a study using the same methods but with different subjects and within different contexts. Case studies are not the best method for assessing the quantitative prevalence of a phenomenon as it yield a large number of potentially relevant variables. Each single case design embedded more than one unit of analyses to

chapter	# cases	time frame	unit of analyses	theory building	type	single or multi
chapter 3	26	from 2009 to 2010	situation	rehabilitation engineering	exploratory	multi cases
chapter 4	98	from 2009 to 2015	activities	theories of action	descriptive	multi cases
chapter 5	62	from 2009 to 2013	process	cybernetics	explanatory	multi cases
chapter 6	10	from 2013	process	single loop learning	descriptive	single case
chapter 7	98	from 2009 to 2015	events	double loop learning	exploratory	multi cases
chapter 8	14	from 2011	process	co-experience	descriptive	single case
chapter 9a	1	from 2012	events	situation awareness	descriptive	single cases
chapter 9b	10	from 2015	events	co-experience	exploratory	multi cases

Table 1. Overview of chapters and their case study designs

gain more in depth insights (see figure 5, type C). On the contrary all multiple case-studies consist of multiple holistic cases which allow naturalistic cross-case methods (see figure 5, type B) .

CASE STUDY PREPARE AND COLLECT

An important part of the case study method figure is the dashed line feedback loop (see figure 4). The loop represents the situation where important discovery or problem occurs during the conduct of one of the individual case studies. Such discoveries or problems require action learning and therefore a reconsideration of the current approach. Practically such "*redesigns*" of the case study types involved mainly changes in the data collection protocol within subsequent case study protocols (i.e., theoretical development, data collection and design type) (see table 1).

Within the research process a lot of effort went especially to capturing a rich and relevant data collection of spontaneous design activities. The iterative process to attain this is illustrated (see table 2) by the development of the several variables. Through the research project we development discontinue and continue logging techniques, namely the low-end "*Schön matrix*" (for an extensive overview see chapter 8) and high-end "*OR glasses*" (for an extensive overview chapter 9). Both techniques grow out of the process of attuning the case study designs and capturing breakthroughs and relevant insights on prototyping-interactions.

- The "*schön-matrix*" is a reflective tool that helps the engaging designers to make a semi-structured self-report on each prototype-interaction. The tool captures the goal of the prototyping action and classifies the consequences into expected and unexpected events. The technique was used in the real-life field settings and used to gain empirical data for different analysis within chapters : 3, 4, 5, 6, 7, 8.

- The development of the *"OR glasses"*, which use electro dermal activity to sense the physiological arousal, can be framed as a next generation version of the "schön-matrix" originated out observed experiences and specific disadvantage of self-report studies. This technique was only used within the case studies of chapter 9.

Type of data collection

Within this dissertation we used mainly three sources of evidence. Throughout all source of evidence the involved co-design team is a sort of vicarious observer, the reconstruction is created from the involved understanding of situations and meaning for those who are involved.

1. All the case studies were documented through weblogs. A weblog is an informational site published from a first person perspective on the world wide web. Technically a weblog consists of discrete entries ("posts") typically displayed in reverse chronological order by the participants.
2. A second source of evidence were experiences from open-ended interviews performed as guided group conversations during feedback moments. Each feedback moment the teams were asked to share their own process and stress their most meaningful highlights.
3. A third source of evidence are third-person memoranda of direct observations within the workplace and coming from video fragments and physical artifacts posted on the blogs.

The main rationale for using multiple sources of evidences within case study-based research is triangulation. During the research process we created hybrid strategies in which triangulation of data and triangulation of different observers were applied. For the latter, the co-experiences from the stewardship team (the main researcher, a design engineer and an occupational therapist) within the living lab projects were engaged as feedback.

Type of data analyse

During design practices within the living lab we try to make sense of specific prototyping –interactions that influence general design behaviour through the complex reality of all involved design agents. There for we use naturalistic analyses which are necessarily open-ended and emergent, tied to and deriving from specific pieces of what has been experienced and captured within the field.

The general strategies to structure the data analyses were relying on the theoretical propositions within each chapter and the types of the case-study design. Within this dissertation we used mainly four sources of data analytic techniques:

time	datasets progress report
2009	**(T)** time, **(R)** progess report
2010	**(T)** time, **(R)** progess report, **(D)** design cycles, **(A)** adaptation stragtegy
2011	**(T)** time, **(R)** progess report, **(D)** design cycles, **(A)** adaptation stragtegy, **(U)** expected/unexpected, **(Pm)** Prototype Mood
2012	**(T)** time, **(R)** progess report, **(D)** design cycles, **(A)** adaptation stragtegy, **(U)** expected/unexpected, **(Pm)** Prototype Mood
2013	**(T)** time, **(R)** progess report, **(Pa)** prototype action, **(Pi)** prototype inheritance, **(Pg)** prototype goal, **(U)** expected/unexpected, **(Pp)** prototype production
2014	**(T)** time, **(R)** progess report, **(Pa)** prototype action, **(Pi)** prototype inheritance, **(Pg)** prototype goal, **(U)** expected/unexpected
2015	**(T)** time, **(R)** progess report, **(Pa)** prototype action, **(Pi)** prototype inheritance, **(Pg)** prototype goal, **(U)** expected/unexpected
time	**datasets videologging**
2012	**(T)** time, **(S)** skin conductivity user, **(B)** event-mark buttons, **(V_f)** first person video
2015	**(T)** time, **(R_1)** self-report user 1, **(R_2)** self-report user 2, **(S_1)** skin conductivity user 1, **(S_2)** skin conductivity use r 2, **(V_t)** Thrid person video

Table 2. evolution of datasets.

- A first naturalistic research method applied with in this dissertation is the use of *key incidents* (Emerson, 2004). These particular events within specific prototyping-activities are used to describe critical phenomena within a real life situation and stimulate new original lines of inquiry and conceptualization (see chapter 3 and 8).
- *Pattern matching* is the core procedure of theory-testing with cases. Testing consists of matching an in-the-field "observed pattern" with an "expected pattern" derived from the theory development. The technique enabled me to explore differences within and between cases. The goal is to find the differences and nuances across cases (see chapter 4).
- *Causal model* stipulates a complex chain of events. The events are staged in created case-effect cause effect patterns. As an analytical technique, the use of of logic models consists of matching empirically observed events to theoretically predicted events (see chapter 5).
- *Time-series analyses* is a technique that enabled us to trace changes over time and observe in-depth dynamics. Within this dissertation we compiled events chronologically (see chapter 6 , 8 and 9).

CASE STUDY CONLUDE AND REPORT

One of the advantage and disadvantage of naturalistic observation is that everyone looks at things differently. Therefor we applied this technique deliberately with a participatory action research framework. It is participatory because many project stakeholders are involved both in deciding the sorts of change to be recorded and in analyzing the data.

Illustrative description selection

The selection of these illustrative cases was done differently for single and multi-case designs(Dart & Davies, 2003).

- *Most significant change* (multi-case studies). Essentially, the process involves the collection of significant change stories emanating from the field level, and the systematic selection of the most significant of these stories by panels of designated stakeholders or staff members (Dart & Davies, 2003).
- *Consistency progress report* (single-case studies). The selection of single case studies that are covered through chronologically structure within the dissertation (chapter 6 en 8) were selected on the basis of their consistent progress report and their representative characteristics of a typical ”project” among many other projects.

The report of outcomes the process is generally narrative in nature, consisting of a series of illustrative descriptions of key aspects of the case (Hancock & Algozzine, 2015). Through these illustrative descriptions we try to describe the phenomenon itself as well as the context within which the phenomenon is occurring (Baxter, 2008). Each chapter consists of a specific theory section linked to the propositions to fully understand the findings and contrast the results with what can be found in literature.

chapter	data collection	data analyse	variable	case selection	report format
chapter 3	progress report, interviews & direct observation	key incidents	(R)	most significant change	unsequenced
chapter 4	progress report, interviews & direct observation	pattern matching	(R)	most significant change	theory building
chapter 5	progress report, interviews & direct observation	causal model	(R)	most significant change	theory building
chapter 6	progress report, interviews & direct observation	time-series analyses	(T)(Pa)(Pi)(Pg)	consistent progress report	lineair-analytic
chapter 7	progress report, interviews & direct observation	key incidents	(U)	most significant change	unsequenced
chapter 8	progress report, interviews & direct observation	time-series analyses	(T)(R)(U)	consistent progress report	chronological
chapter 9a	self-report, physiological data & first person video	time-series analyses	(R)(S)(B)(Vf)	no selection	lineair-analytic
chapter 9b	self-report, physiological data & third person video	time-series analyses	$(R_1)(R_2)(S_1)(S_2)$(Vt)	no selection	lineair-analytic

Table 3. Overview of analyses and report

Report formats

All of the chapters have an adapted report structure which connects in a compressive manner with the discussed propositions and the case study design type. In short the different structures are :

- *Unsequenced structure*: no specific structure is used in these often descriptive case studies reports (see chapter 3, 4 and 7).
- *Theory building structure*: the sequences of sections follow a theory building logic (see chapter 4 and 5).
- *Lineair-analytic structure*: standard journal article structure (see chapter 6 and 9).
- *Chronological structure*: reporting a case study by covering events over time (see chapter 6 and 8).

Within table 3 you can find an overview of applied analyze and report techniques for each chapter.

2.4 OPERATIONALISATION

The living lab

The main benefit of practice-based design research is that it allows researchers to explore new domains in a holistic way, and to refocus the research as understanding of these domains increases. To study participatory product hacking behaviour on the level of rehabilitation engineering we created an interdisciplinary micro living lab on open-design assistive technology, namely *design for (every)one* (De Couvreur, 2009). The living lab projects were the main resource for the data gathering.

In general a living lab project empowers participants to create content and value within a real life context. The concept is based on a systematic user co-creation approach integrating design research and innovation processes. Ballon and colleagues (2005) define it as : "An experimentation environment in which technology is given shape in real life contexts and in which (end) users are considered 'co-producers." This approach is in line with Almirall and Wareham (2011), who state that living labs are fundamentally infrastructures that surface tacit, experiential and domain-based knowledge such that it can be further codified and communicated". The type of living lab applied within this research project is user-driven. The living lab is established by user communities within the network of the occupational therapy education program and focus on solving users' everyday-life problem (Leminen, Westerlund & Nyström, 2012). Such open platforms involve a diversity of users, not only as observed subjects but also as a source of creation (Schuurman, Demarez & Ballon, 2013). Unlike other experimentation platforms living labs balance between low immature to high mature technologies, and compromise between testing and design activities.

The main objectives are to explore new ideas and concepts, experiment new artefacts or process-

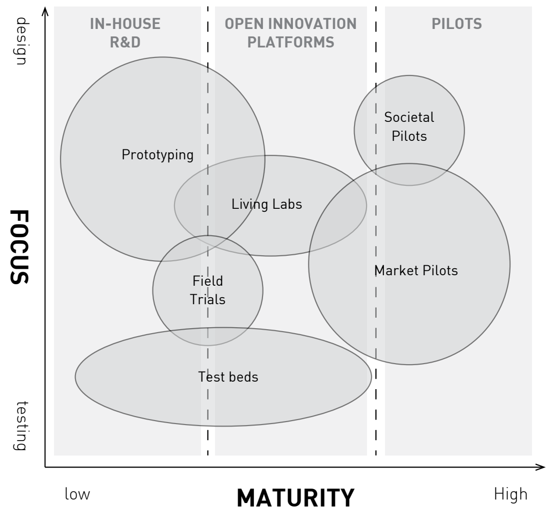

Figure 4. Framework of Test and Experimentation Platforms (adapted from Ballon et al, 2005)

es and evaluate breakthrough scenarios that could be turned into successful innovations. Living labs typically stand at the crossroads of different society trends and paradigm shifts (Pallot et al., 2010). Within *design for (every)one* living lab we explore the interactions between open design (van Abel et al., 2014) within a self-care perspective (Dubberly et al., 2010) to facilitate open-ended participatory design processes (Björgvinsson, 2008) on Do-It-Yourself (DIY) assistive technology. (for extensive overview see chapter 3).

In this section we concentrate on the settings, tools, and infrastructure which were needed for the facilitation of the *design for (every)one* living lab projects. To make a comprehensive overview of all the practical issues, we categorize them based on two cycles that are central to living lab projects (Enoll, 2012).

- *The collaboration and management cycle* gives us an overview of the management process of finding partners, defining the project, running it, and finally take the next steps.
- *The product development cycle* contains all the elements within the iterative development of DIY assistive artifacts together with end-users and other stakeholders (see chapter 3).

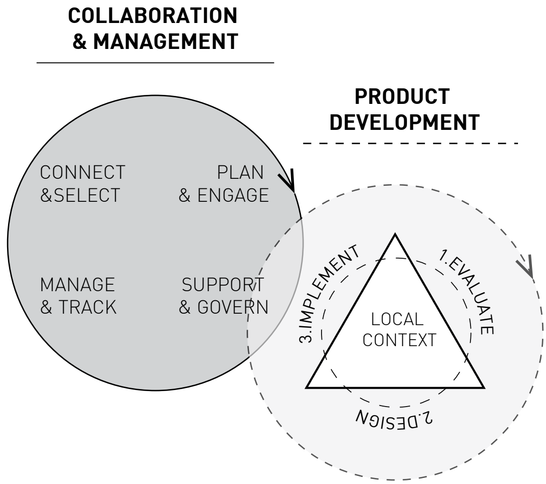

Figure 5. The two cycles that are central to living lab projects adapted from Open Living Lab Knowledge Centre (Enoll, 2016)

The collaboration and management cycle

CONNECT & SELECT

The first step in the set-up of a living lab is to connect partners and to define partners and define initial contributions for each of them. In this phase the initial contacts are made between the cross border partners , the basic ideas and plans are evaluated, made more concrete, and a more formal approach to the collaboration is established.

For the living lab on product hacking we created a synergy between 2 local educational programs, namely the master industrial design engineering from the University of Ghent and the bachelor program on occupational therapy from University college of Howest. Both education programs embedded co-creation and interdisciplinary teamwork as a crucial competence in their curriculum.

We defined the goal - To connect design and occupational therapy students with people who could do with a little help in their lives, from being it people living with a disability since birth or that acquired a disability over the course of a lifetime. The deliverable of the course is to create an open-design assistive device build around a meaningful activity of the challenging client. The aim was to develop the device through a process of participatory hacking to develop a quick, low-cost solution.

We defined the contribution - Each year both education program participate a full semester with their students and teaching staff including both experienced practitioners and knowledgeable academics.

Figure 6. Screenshot from the website, logo and project branding

All of the participating lecturers had a strong connection with the work field connected to of their corresponding discipline. The occupational therapist contributed with their daily experiences in community-based practices and their client-centered perspective on well-balanced occupations. This perspective consisted out of three factors: the individual himself, his activity capital and the surrounding habitat which contains both social and physical capital aspects. In their manner industrial design engineers contributed with practical expertise on product hacking and creative problem solving. Both were applied in iterative design cycles.

We defined the project identity - Aiming to fill the gap between universal design (or design for all) and rehabilitation engineering (or design for one).We choose to pick a name which linked the two frameworks, namely *design for (every)one*. Later on a logo, website and presentation template were created (see figure 6).We defined the rewards : During the entire project no monetary rewards were applied. All of the rewards had a non-monetary nature. A *design for (every)one* project combines many important factors in offering a valuable learning experience for students : working in a collaborative team, living a real world experience, developing strong relationships with a “client”, developing a real solution (and not just a product concept) through an iterative design process, learning how to listen and understand the needs of others, connecting with your immediate environment.

PLAN & ENGAGE

At the second stage of the living lab collaboration, the collective consortium needs to define the organizations’ roles more clearly, as well as negotiate partners’ responsibilities. Practically we synchronized two educational courses, stemming from their respective education programs. Both resulted in one interdisciplinary co-design course which became a powerful engine to the practice based design research, ensuring the dynamics within the living lab.

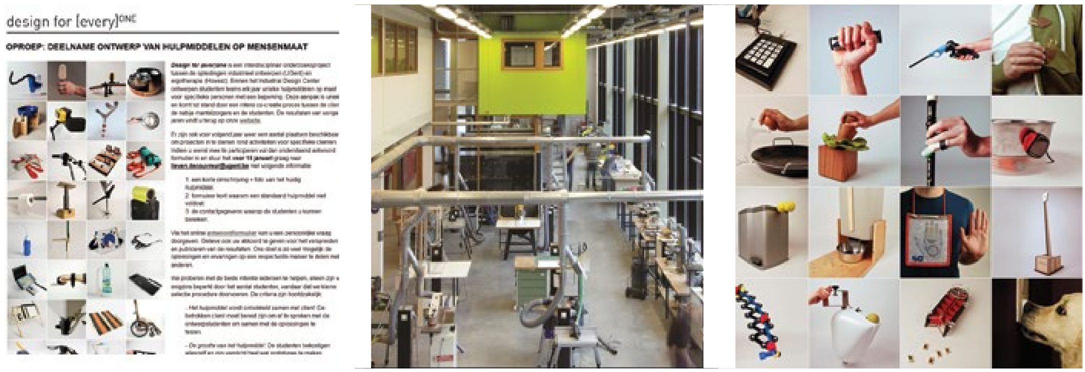

Figure 7. Screenshot from call, the industrial design center and a random team out of the living lab

We created a “*stewardship team*” for the students, including the roles of facilitator, knowledge leader, event coordinator and administrator.

The role of facilitator and event coordinator was performed team wise by all of the engaged lecturers As facilitators they supported the students from the sideline within the co-design processes. Their main contribution was providing feedback on the limitations of technical prototypes and the capabilities of clients. The role of the event coordinator is inducing the growth of the community and the planning of several regular events.

The project contained five milestone events which were commonly planned within the period of one semester : one kick-off moment, tree intermediate deadlines and one closing event, beside the classes. On all of these moments all the teams were mandatorily present at the industrial design center, the central hub of the *design for (every)one* living lab project (see figure 7).

In the first stage the community of clients was established using the network of the occupational therapy education program. On the one hand occupational therapy students could bring in a client whom they had encountered during a previous internship in a sheltered workshop, daycare or rehabilitation center. On the other hand the occupational therapy lecturers also used their network. Later on the people who attended the closing event received a newsletter in which they could apply to join the living lab project. This call was launched once a year. During the entire project we have chosen not to use social media as the capacity of operational case studies was limited between 10 to 15 places depending on the number of participating students.

The role of knowledge leader, and administrator was mainly performed by the design researchers. Their tasks consisted of generating the inventory, assembling the teams, building and organizing a community repository.

Figure 8. Some random teams out of "design for (every)one" living labprojects

The administrator performed the first identification and selection of potential clients. The main criteria to participate within the living lab were formulated within the call :

1. The assistive device has to be developed for and together with one client. This implies that the client must be willing to meet with the design students to test the solutions together. In some situations the caregivers applied for the living lab project instead of the actual client, which we refused to accept. With this criteria we wanted to emphasize the importance of intrinsic motivation.
2. A limited assistive device size is acquired. The participatory hacking process requires a lot of prototyping resources. as they pay all the expenses for themselves , the living lab didn't accept large scale assistive devices in order to reduce the costs for the students
3. The geographical location of the participating client and caregivers should be limited. The students will meet the client several times within his local environment. To reduce the cost on transportation we didn't accept proposals that were located at more than 100 km from Kortrijk.

The final selection of the project was performed with the entire "*stewardship team*" to anticipate the possibilities and limitations of the students and the clients. The team refused multiple "*design for all projects*" that were submitted by organizations as the main goal of the project was to design and study product hacking behaviour which was tailored to one specific client.

Besides the selection of the potential client the administrator also assembled the co-design teams. This was done in a purely random and balanced way. The average composition of a team consisted of two master students industrial engineering and one bachelor student occupational therapy. If the stewardship team considered a proposal to be more complex, some teams were reinforced with an additional random student.

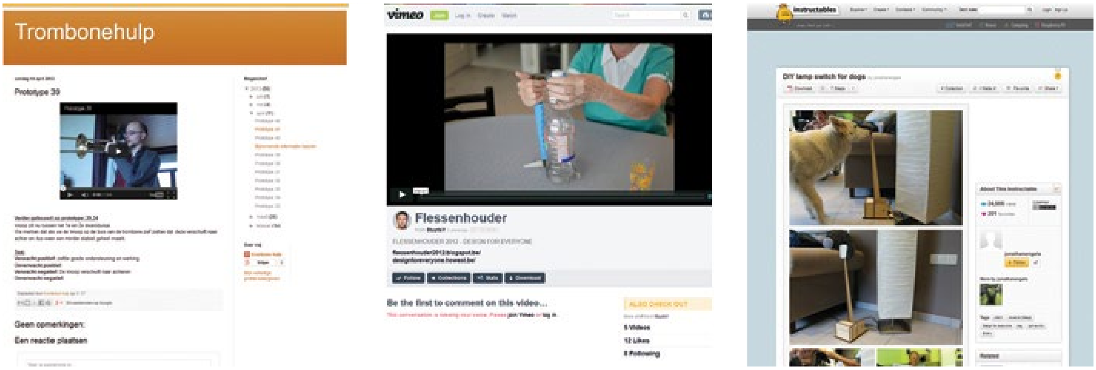

Figure 9. Screenshots of the used social media: Blogger for the self-reporting diary, Vimeo for sharing the after-movie and Instructables for sharing the building plans of each assistive device

Maintaining trust is crucial to keep the network together and alive, therefore it was necessary that the knowledge leader clearly defined the ownerships and issues related to intellectual property rights. All of the clients that participated within the living lab agreed with the fact that both the design processes as the final open-designs are shared with the *design for (every)one* community.

This approach requires clients to develop their skills, and enables them not only to help themselves but also to contribute to something bigger, that is, a community of people that can benefit from their ideas. The resulting experience contributes to a sense of purpose and meaning that generates a sustainable experience, supporting the user's wellbeing in all stages of the process. The voluntary participants sign an inform consent contract with the knowledge leader in which they agree with the publication of online video's and pictures in which they appear. The actual design of the assistive devices resulted in "*open-design products*" which were all licensed under a creative commons attribution. Based on the fablab philosophy, devices are produced that can be tailored to local or personal needs in ways that are not practical or economical using mass production techniques. The intellectual property of the source design remains with the patient while the alteration and realization of the final product anchors in the resources and realities of a local manufacturer. People who's proposals had been approved but who refused to sign the contract, were turned down and advised to work with a professional product development agency.

SUPPORT & GOVERN

The support and govern phase focusses mainly on methodology development. It includes the support and govern phase as well as tasks related to supporting the operational work within the living lab network. As the intention of this dissertation was to observe spontaneous participatory hacking behavior we did not consciously nor systematically apply design methodologies. All of the participating

Figure 10. Master students working at the Industrial Design Center

students used their domain-specific competences in an integrated and reflective manner. The purpose of a living lab is to stimulate interaction that is driven by spontaneous behavior within a real-life context, and to learn from it. This learning will have an impact on both the participant, the students and the stewardship team, and this without the need for direct contact or communication with the design researcher. In this sense it is a double-blind method.

At the start of the project all of the participating students joined the kick-off event. During this gathering moment the facilitators gave a twofold presentation on the purpose and background of the Living Lab. This was deliberately done in a dual manner from the perspective of each discipline in order to create a common language. The students were told to collaborate to create an open-design device that helps the client to become the person they desire to be within the environment they live in. The main methodological recommendations which were communicated in that presentation concerned the conditions in which the adaptive prototyping should take place.

The notion of adaptive prototyping used in this thesis builds on the work of Ehn and Kyng (1991), who generally used mockups as tools for engaging with stakeholders rather than prototypes to be evaluated. Later on, this prototyping focus was further elaborated with the work of Buchenau and Fulton Suri's (2000) notion of experience prototyping and prototyping for social action (Kurvinen, 2007). The students were briefed to execute all prototyping actions in line with the following conditions required for studying social-technical interaction within participatory hacking behavior: (1) make and use physical artifacts to express ideas or concepts (2) create a social setting with more than one person, (3) focus on spontaneous design behavior, (4) maintain openness for observing unexpected interactions, (5) observe the behavior within a sufficient time span and (6) generally focus on the sequential unfolding of events (for an elaboration see Kurvinen, Koskinen, & Battarbee, 2008). The industrial design center at Kortrijk, assumed the role of a rich makerspace (see figure 10). The infrastructure offers the design students a unique variety of both low-tech as high-tech prototyping techniques.

Figure 11. Flyers for the open-design fairs

At the end of the kick-off presentation each co-design team received his design brief with the contact details of their client. In this brief the client summarizes his problem to participate within a meaningful activity and motivates why a standard assistive devices doesn't satisfy his needs. The team members learns to know each other and try to contact their client to arrange a first co-design session.

The intermediate feedback sessions were the only instruments we used to govern the project. These sessions were organized between each co-design team and the stewardship group. The process takes approximately 12 weeks (see figure 12), during which the group alternates between several design activities within various locations. Each session was planned every four weeks and is coupled with a theoretical phase within the product development process. This way the co-design team mirrors its status towards objective references and compares his progress with that of other teams. (1) The first feedback session focuses on grasping the needs of the client and exploring new solutions, (2) the second feedback session focuses on a proof of concept for an integrated ideal/final solution and (3) the third feedback session focuses on low-volume production aspects and the optimization of the open-design assistive device. Through a round- table discussion the co-design team presents its status on the basis of prototyping-interactions.

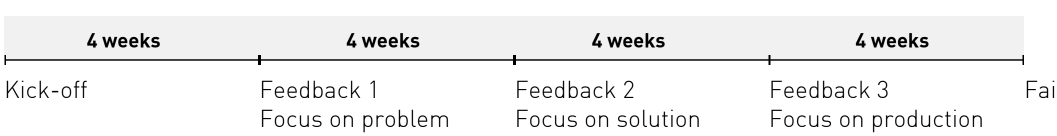

Figure 12. timescale of one living lab project

Figure 13. A1 posters on the livinglab projects used for the design fair and repository

The closing-event is organized in the last week of the project. The event is branded as an open-design fair accessible for companies, NGO's, academics and family members (see figure 11). All of the co-design projects are captured in mini documentaries introducing the people and the story of the process. The film is a mini project in itself and should be edited to a timeframe of less than three minutes. In the first part of the event the audience watches all the mini-documentaries . When this is finished everybody can grasp the prototypes and discuss the solution with the co-design team. Each of the teams have constructed a small booth on which they present their solution and process as in physically as possible. At the end of the open-design fair the co-design teams hand over their assistive devices to the participating clients.

MANAGE & TRACK

One of the crucial aspects of conducting interaction research within living labs is the establishment of reliable and structured ways of capturing and documenting the data generated by the living lab, so that it can be subjected to analysis, reflection and valorization (Dalsgaard & Halskov, 2012).

Design process - Documentation of the investigative design process may serve the double role of supporting reflection, thereby serving as a source of insight, and providing evidence that supports the insight gained. From day one, students are only allowed to communicate using tangible prototypes and reporting their findings on a self-reporting shared blog. The final structure of a post is semi-structured and contains (see figure 9): (1) the anticipated inquiry goal of the prototype. (2) the antecedent prototype or benchmark on which they developed or refined the prototype.(3) a picture or video of the prototype-interaction. (4) the reflective observations and conclusions.

Figure 14. Activities on the open design fair: expert panel, presentation of after-movies and public voting process

Designed products - A community repository has been uploaded on the central website of the *design for (every)one* website (see figure 13). Each year a press release is produced with studio pictures of all the objects. From all the open-design devices a building plan was created through a step by step picture manual (see figure 9). Later on we switched to instructables.com, a web-based documentation system for user-created DIY projects.

The quality of co-design projects cannot be measured in conventional ways. Traditional reductionistic methods are not likely to capture the creativity and self-initiative by which a co-design team creates value. The value of the knowledge produced by a co-design project is context-dependent. Therefore we applied an evaluation system based on four independent procedures (see figure 14). (1) During the closing-event the co-design teams are evaluated by all the visitors through a public voting process. Each visitor receives 3 sticky dots which he can use to vote for his favorite projects. (2) Meanwhile an expert panel, which consisted of academics, entrepreneurs and practitioners coming from both fields, evaluates all the co-design projects from their professional perspective. (3) The reactions of the participating clients were also taken into account. (4) The last integrated evaluation was carried out by the stewardship team, which also takes the whole design process and complexity into account. Altogether, approximately 500 students were directly involved in 110 co-design projects over the academic years 2009-2016.

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3. CONTEXT

DO-IT-YOURSELF ASSISTIVE TECHNOLOGY

This chapter was previously published as:
De Couvreur, L., & Goossens, R. (2011). Design for (every)one: co-creation as a bridge between universal design and rehabilitation engineering. CoDesign, 7(2), 107-121.

“Somewhere today there are millions of young children being born whose technology of self-expression has not yet been invented. We have a moral obligation to invent technology so that every person on the globe has the potential to realize their true difference”.

(Kevin Kelly)

In this chapter we explore the historical changes within rehabilitation engineering. We discuss a new generation of makers and occupational therapists which create one of a kind product adaptations with DIY technology in people's homes, sheltered workshops and rehabilitation centres.

3.1 ABSTRACT

Design for (every)one is a micro living lab which attempts to identify, share and use "hidden solutions" in community-based rehabilitation contexts and translate them into disruptive assistive devices built with local resources or appropriate technology. Within healthcare contexts, local solutions are frequently more effective as they reflect the physical, emotional and cognitive needs of specific patients and engage all stakeholders in a specific local context. By using open horizontal innovation networks, where Do-It-Yourself assistive devices can be easily shared and physically hacked by other allied health professionals, general patterns could be detected and translated into standard universal design objects. This generative design thinking approach is more than feasible with digital trends like crowd sourcing, user-generated content and peer production. Cheap and powerful prototyping tools have become easier to use by non-engineers; it turns them into users as well as self-manufacturers of their personal assistive artifacts. We discuss the different aspects of this open innovation process within a "design for disability? context and suggest the first steps of an iterative co-design methodology that brings together expertise's from professional designers, occupational therapists, patients and other stakeholders. The overall aim is to gain more insights on the co-construction of Do-It-Yourself assistive technology.

3.2 CURRENT STATE – REJECTION AND ABANDONMENT

Healthcare has long tradition in the use of technical aids to replace or support body functions of disabled human beings. Within the field of "design for disability," two main approaches emerged in the 20th century. In the late 1960s universal design was inextricably bound up with architectural accessibility. It became clear that many of the environmental adaptations needed to accommodate people with disabilities actually benefited everyone. Slowly, universal design evolved from removing physical barriers to people with disabilities towards integration of all people within all environments. Universal design became a general design approach in which designers ensure that their products and services meet the needs of the widest possible audience, irrespective of age or ability (Story et al., 1998). As a design method universal design resulted in a set of general guidelines and accessibility standards on different scopes that can be applied in traditional design processes.

A second approach emerged to receive the return of thousands of disabled veterans during world War II. This modern rehabilitation movement, guided by surgeons, recommended multidisciplinary scientific and engineering endeavors in rehabilitation (Brandt et al., 1997). Efforts to improve prosthetics and orthotics resulted in a specialty that adopted scientific principles and engineering methodologies. As a design method this second approach became known as rehabilitation engineering which resulted in the development of assistive technology.

Although coming from quite different histories and directions, the impact of universal design and assistive technology are the same: increasing independence, improving the quality of life and reducing the physical and attitudinal barriers between people living with and without disabilities (Hoening et al., 2003). Paradoxically, several studies on the field report also high rates of rejection and abandonment. Some of the reasons pointed out as responsible for these phenomena are lack of overall fitness, high costs, suboptimal performance, high barriers to procuring the device, inadequate flexibility to adapt the technology to changes in ability, specific needs and lifestyles and product stigmaticity (Phillips & Zhao1993; Riemer-Reiss & Wacker, 1999; Scherer, 1996; Pape et al., 2002; Vaes, 2014). Today there are 600 million people living with disabilities who lack proper assistive devices or whose assistive devices does not yet fit well. The overall aim of *design for (every)one* is to increase the usage rate of appropriate assistive devices and gain more insights on co-designing qualitative occupational experiences for disabled users.

3.2 KEY PROBLEM - THE LACK OF CONTEXTUAL PUSH

Universal design aspires to address the needs of the widest possible audience in the mainstream, whereas assistive technology attempts to meet the specific needs of individuals. From an industrial design point of view, both have more than one opposed characteristic (see figure 1). Universal design is based on the principle of “economies of scale,” which involves mass production techniques and traditional design processes. This “market pull” strategy (Vanderheiden & Tobias, 2000) homogenizes the abilities of users. It puts the emphasis on providing cost-efficient aids by finding a certain stage of consensus; thus it includes as many users as possible.

On the contrary, the force of innovation within rehabilitation engineering is characterized by a technology push strategy. New inventions are pushed through medical R&D without proper consideration of whether or not it satisfies a user need (Gregor et al., 2005). In most cases, assistive technology products are produced in small batches due to tailored and high-end aspects that makes them almost unaffordable without the help of government agencies or charitable bodies. Due to the rarity of niche markets, the diversity and variations of specific assistive devices are very limited, they lack esthetical beauty and brand the user with a product stigma. Most of the time, rehabilitation technologists are forced to use standard assistive products that approximate the user’s requirements as well as possible. Furthermore, the low rate of assistive device use has also been associated with lack of information regarding the devices (Gitlin & Schemm, 1996). The clients are rarely seen as the customer, because, they neither paid for their equipment nor had a major say in the choice of the equipment purchased.

Through the industrialization and mass-production culture, universal design gained a lot of attention. The approach became so strong that it still influences rehabilitation engineering to this very day on the level of accessibility, availability and affordability. The bottom line, however, is that both approaches have difficulties to incorporate the experiential knowledge of disabled users into their design process. The lack of contextual push urges for new types of research, such as cultural probes and generative tools which sketch out the user-experience spectrum (Stappers et al., 2009). Every single contextual disability is connected with individual conflicts of values, goals, skills and specific interests. Thus: if one wants to design meaningful DIY assistive devices, one should take into account the whole product ecology (Forlizzi, 2008) of an individual context.

Rehabilitation engineering has a history of trial and error through iterative processes between rehabilitation technologists and patients. Still this process only takes places in rehabilitation institutions. In real life people do not live in institutions; they live in their community with family, friends and colleagues. *Design for (every)one* aims to closes this context gap by introducing user-driven innovation on the level of rehabilitation engineering. This paper will sketch out the overall framework and add some application examples.

3.3 MICRO LIVINGLAB - DESIGN FOR (EVERY)ONE

The World health organization (2010) redefined the meaning of disability as not being intrinsically part of the person, but rather as a function of the person's interaction with the environment. This social redefinition has lead to a new strategy namely community-based rehabilitation (ILO et al., 2004), which deals with contextual disability. The strength of CBR programs is that they can be made available in areas with limited infrastructure, as program leadership is based on self-organization of a community. CBR programs build around assistive devices involve people with disabilities themselves, their families and appropriate professionals. *Design for (ever)one* sketches out an alternative holistic framework (see figure 1) where assistive technology manufactures build horizontal user innovation networks next to their mainstream design processes supported by the methodology of community-based rehabilitation programs.

Disabled individuals and allied health professionals who participate in these open networks , design and build DIY assistive devices for their own use, and afterwards freely reveal their design information to others. Based on open design principles, others are invited to replicate and improve devices and share their improvements in turn. Eric von Hippel (2007, p.1) describes this type of open network as a place where "innovation development, production, distribution and consumption networks can be built up horizontally – with actors consisting of only innovation users (more precisely: user/self-manufacturers)". A horizontal user innovation network enables each (disabled) individual to develop the DIY assistive devices according to his or her specific needs with the use of local resource and

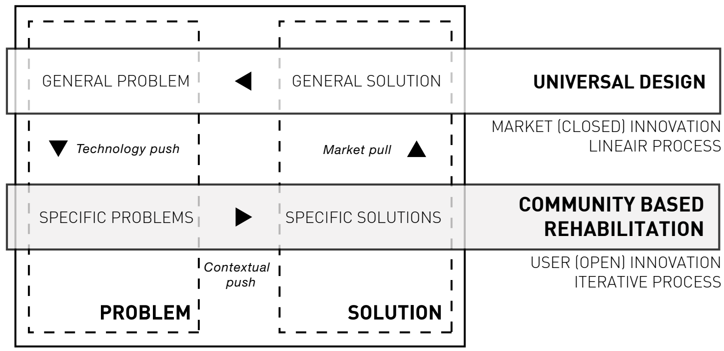

Figure 1. Possible macro interactions: *Design for (every)one*, to answer the research questions within this research project we started a micro living lab on the level of community-based rehabilitation

appropriate technology. Through these community-based programs a person is no longer restricted to available marketplace choices nor reliance on specific manufacturers. A strong diffusion of needed DIY assistive devices can be build and validated. This 'variety' creates a whole host of potential different solutions which can be pushed back into society in the form of universal design.

By adapting professional lead user methodology (Von Hippel, 1986) into the field of design for disability, the authors state that:

- Individual disabled people participating within a CBR program benefit directly from the process and the solutions that respond to – or address their specific skills and activities. This implies an increasing usage of assistive artifacts that are build around the ingredients of daily meaningful occupations (Desmet, 2011).
- Universal design and assistive technology manufacturers can use this "in vivo" generative design research in an indirect way. Due to demographic ageing, nascent disabilities lie in the path of everyone's future. From this viewpoint disabled people and their stakeholders can not only serve as a need-forecasting group but also show us actively new and upcoming possibilities. The traces they leave help us to detect general patterns and could determine which artifacts should be – or should not be designed and manufactured as universal design products.

Each *Design for (every)one* living lab project is a self-organizing open network wherein disabled people and their caregivers become conscious actors, rather than being objects of pity and in need of care. Giving the right expressive tools, occupational therapists and their patients can become manufacturers themselves. The most relevant phenomenon which describes this behavior in real life society is the growing Do-It-Yourself (DIY) or physical hacking culture. In a way, hacking is a natural response when the resources at hand fall short. For companies it is an ideal way of looking around to see which needs are vivid and how their technology gets exploited towards new possibilities.

When visiting a rehabilitation center one cannot imagine how many objects have been repurposed or precisely tailored to the user's needs and desires. Within the field physical rehabilitation and assistive technology, there has even been a call for empowering individuals with DIY Assistive Technology (Hurst & Tobias, 2011; Hurst & Kane, 2013; Hook et al., 2014). Patients or therapists do not use the universal products but take them as starting points to build their own personalized applications. In a certain way one could say that hacking is embedded in the rehabilitation technologist's nature. Most DIY assistive artifacts are not radical innovations that use high-end new technology. Contemporary user-innovations have a more disruptive character, which answers needs that were previously not served with the technology at hand. A vivid horizontal network as intructables.com (2010) shows the potential with the Humana Health by Design Contest. Each of these home-made artifacts can be considered as user prototypes (Glasemann & Kanstrup, 2011) which articulate emotions and human values regarding qualitative occupational experiences.

The authors recognize the three conditions, described by Eric von Hippel (2007), under which user innovation networks can function entirely independently of manufacturers:

1. *at least some users have sufficient incentive to innovate* Disabled people are often outstanding problem solvers because they simply have to be creative. Life for disabled people is a continuous series of challenges to be overcome (Miller & Parker 2004). There is no such thing as an 'average' (disabled) person. People who fall outside of the mainstream have individual needs and contexts of life that require special tools. The largest healthcare provider in many nations are not the national healthcare systems but the local families (Arno et al., 1999). In most cases disabled people have certain caregivers in their environment for the daily support with whom they have a strong emotional tie. These relatives or friends are also longing for new assistive devices which give them new possibilities to interact with their disabled kids, parents or friends. Often they play the important role of initiator and are very driven to express and build their ideas. The image of the caregiver working in his garage and developing a unique solution so that a disabled friend can perform a job more efficiently, has a personalized appeal in this complex age of technology; but it is an everyday occurrence. Some nice examples of a strong commitment of caregivers and their disabled family resulting into products are the handicap international DIY competition (2010), the story of team Hoyt (2010) and the eyewriter project of the Graffiti Research Lab (2009).
2. *at least some users have an incentive to voluntarily reveal information sufficiently to enable*

others to reproduce their innovations. According to Lawrence Lessig (2008), the inventor of Creative Commons, we are making a move back to a read-write culture wherein creativity is fed by sharing, remixing and collaborating through the internet. With the rise of social media, relatively inexpensive and accessible tools enable anyone to publish or access information on the internet. The popularity of initiatives like Facebook, Twitter or Youtube can only endorse this statement. New digital technologies like blogs, podcasts and videos give user-innovators a pallet of opportunities to express their ideas and bring a personal message to a user community. Another strong aspect of these technologies is the fact that they can be used to initiate an easy validation process of new ideas by peers. Through comments, ratings and labels, an immense amount of data can be structured into a convenient and qualitative arrangement of ideas. By tapping into one of these systems we can easily create innovations and strong feedback mechanisms to harness the lessons learnt from the pool of solutions. An inspirational example is the platform of patientslikeme.com (2005) where patients diagnosed with life-changing diseases are sharing information that can improve their lives.

3. *user self-production can compete with commercial production and distribution.* Designing for one specific user is not new, in fact it is the oldest tailor-made approach we know. The painting “Die Krüppel” by Pieter Brueghel the Elder illustrates the use of a number of simple tailor-made assistive devices in the 16th century by people with disabling conditions. In the age of the amateur professional, Leadbeater (2004) describes the big gap that industrial progress opened up between the professional provision of design and our common competence and readiness to see and solve the problems around us. He declares that out of this gap a new breed of active users emerges, namely Pro-ams, committed and networked amateurs working to professional standards. State of the art technology supports these professional standards and brings DIY back on the map as a valuable business model. Thanks to the rise of the internet and direct digital manufacturing processes, we are capable of making niche products on demand; the long tail of things (Anderson 2008). Some practical platforms built on this phenomenon are ponoko.com, shapeways.com and local-motors.com.

Based on the above observations and literature, the three conditions, which are needed in order to function independently from manufacturers, can be met: (1) disabled users and their caregivers have a high incentive to make, adapt or create new DIY assistive devices; (2) contemporary information technology allows fast and stigmergic communication (Heylighen, 2007) between disabled users and allied healthcare professionals, creating a new form of co-created public service; (3) improvements in technology allow us to produce our own unique DIY assistive devices fabricated with rapid manufacturing tools and standard resources.

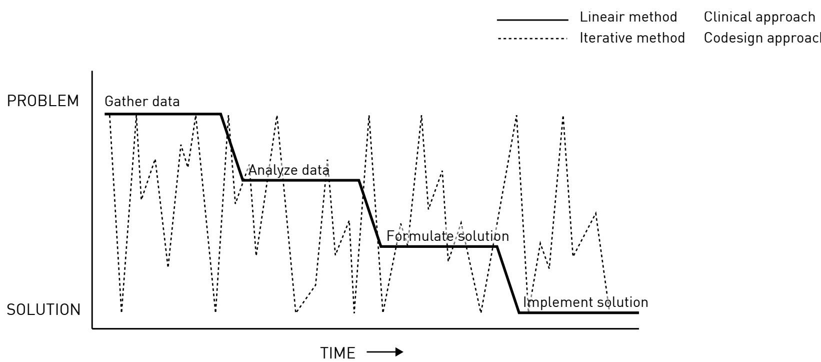

Figure 2. Wicked problems (adapted from Conklin 2005, p.9)

3.4 THE PRODUCT DEVELOPMENT CYCLE

Co-design

The start of the *design for (every)one* living lab (shown in figure 3) focuses on the core of innovation development within the level of community-based rehabilitation. Within rehabilitation institutions and assistive technology companies, teams still tend to have exclusively clinical or engineering backgrounds; the dominant culture is one of problem solving and cost-cutting. Innovation within these fields is mainly technologically driven: it lacks the tools to address social complexity and emotional responses. Traditional thinking that is embedded in these disciplines follows an orderly and linear "top down" process (figure 2), working from the problem towards the solution. Once you have the problem specified and the requirements analyzed, you are ready to formulate a solution, and eventually to implement that solution. This is illustrated by the "waterfall" line in figure 2.

Jeff Conklin (2005) discusses how these linear processes work for tame problems that have a well-defined and stable problem statement (also see Rittel & Webber, 1973; Buchanan, 1992). Although these problems can be technically very complex, they belong to a class of similar problems that have already been solved. However, because a person's health and well-being are part of very mutable systems, these linear processes do not apply to these category of problems build around assistive technology. The interplay between practices, politics and economics has created hidden interdependencies and changing requirements. On top of that we already pointed out that there is no such thing as an average "disabled person" living in an "average context". The World Health Organization (2010, p.1) recognizes disability "as a complex interaction between features of a person's body and the features of the environment and society in which he or she lives". Little can be learned by relying only on objective data gathering and analysis. Problems involving disabled people have a certain "wicked component" which

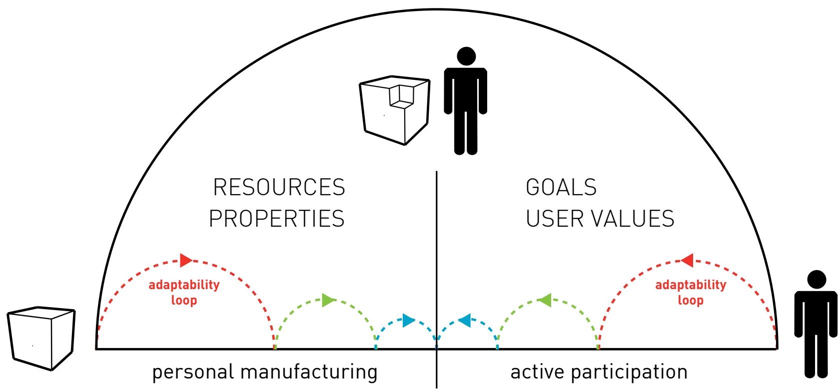

Figure 3. Incremental adaptation: artifact meets user and user meets artifact

demands an opportunity-driven approach, requiring decision making, doing experiments, launching pilot programs and testing prototypes (Dexter, 2014). A certain amount of trial and error is necessary in untangling the physical, emotional and cognitive needs of specific patients. Problem understanding can only come from creating possible solutions by building knowledge collaboratively through validating specific solutions with individual disabled users (Miller & Parker, 2010). This is the point where co-design methodology comes in as a powerful engine for user-innovation. Co-design can be used as a set of iterative techniques and approaches that puts users at its heart, working from their perspectives, and engaging latent perceptions and emotional responses. In a way co-design could very well be regarded as a new type of DIY, adapted to modern times (Hoftijzer, 2009). In combination of physical prototypes (led by designers or caregivers), co-design becomes a tangible pragmatic approach that continuously shifts between “what is needed?” and “what can be built?” This polarity forms the basis of *Design for (every)one*. In every cycle we gain more insights on both levels. This incremental adaptation process makes use of low-end prototyping techniques for translating user-values into product properties and vice versa (see figure 3) (De Couvreur et al., 2011). The main aim is to bring appropriate technologies and users skills incrementally closer through alternation between human-centered design and activity-centered design (Norman, 2005). Creating applications that support the patient and designing the right activity to achieve his or her personal goal. The ideal point where a technology and a user meet 100%, will rarely be reached as users are moving targets with ever changing requirements and evolving skills. In a way, products are never finished. A new way to think about rehabilitation engineering is perceiving it as an infinite design process that stimulates continuous innovation lead by challenges and skills of disabled users, living in continuously changing ecologies.

The keyroles

The key roles in this DIY co-design processes are forming a trialogue around the aspects of DIY assis-

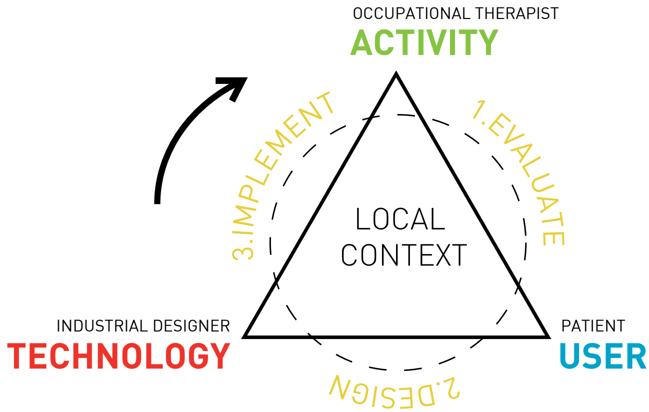

Figure 4. Trialogue between key-roles and iterative actions in *Design for (every)one* living lab

tive technology: activity, user(s) and technology (see figure 4). We prefer to talk about archetypal roles over key players because in some situations one key player can fulfill more than one role. For example, a caregiver can fulfill the role of self-manufacturer, an occupational therapist is in some cases the patient, or a self-manufacturer can meanwhile be the occupational therapist. It is important to notice that there are three roles with different perspectives and each of them creates new possibilities with different skills.

KEY-ROLE ACTIVITY: OCCUPATIONAL THERAPIST

Occupational therapy is as an allied healthcare profession concerned with promoting health and well-being through qualitative occupations (WFOT, 2004). The occupational therapist keeps this overall goal of DIY assistive technology in mind. With his or her clinical background, the key-role occupational therapist sketches the medical constraints and possibilities for each individual patient. Occupational therapists can break down activities into achievable components and they can teach new ways of approaching tasks. Within this activity-centered design approach, activity analysis is an often applied technique. It is defined as a process of dissecting an activity into its component parts and a task sequence, allowing people to identify inherent properties and skills required for its performance.

The occupational therapist detects which type of DIY assistive device the patient needs to achieve his or her goals, and by doing so he or she sets the starting point for the first design – or customization iterations. In most cases the patient and therapist have already physically hacked a universal assistive device; doing so can be seen as a translation of a latent need or a hidden solution for the problem. The therapist evaluates the flow (Csíkszentmihályi, 1990) experienced in every iteration through the behavior and feedback of the patient (De Couvreur et al., 2011).

KEY-ROLE USER(S): PATIENT/CAREGIVER

The patient is given the position of "expert of his/her experience" (Sleeswijk Visser et al., 2005). He seeks assistance in fulfilling a meaningful goal. In some cases, when the patient has difficulty with communicating his or her feedback verbally, the caretaker plays an important role as translator. Depending on the level of creativity (Sanders & Stappers, 2008), patients join the design process by expressing themselves in creating, using or adapting the assistive prototypes. Due to the iterative character of the methodology it is important that patients are cognitively capable of building on past user experiences. The perceived value of a product is critical and determines the strategy of the following iterations. While reducing or eliminating negative experiences and enhancing more positive values, the patient also slowly adapts to his or her new DIY assistive device.Although the nature of an everyday task could look simple, the context in which it takes place is always characterized by intricate interaction patterns between the user, the assistive appliance and the environment. Next to all the user experiences we try to map all these interactions in a user-product-environment model. Who are the stakeholders? What can they contribute? What are their requirements? If they are not included in the thinking and decision-making process, certain stakeholders may seek to undermine or even sabotage the project.

KEY-ROLE TECHNOLOGY: INDUSTRIAL DESIGNER/USER-MANUFACTURER

The industrial designer becomes the technology-facilitator between the occupational therapist and the patient. He or she continuously translates user-values and feedback through behavior into product properties. With this human-centered design approach he tries to augment the skills and ability of the patient through adapting the technology. In this stage, the industrial designer's main job is to ideate and create tools and prototypes, which enable the occupational therapist to communicate on a physical level with a patient. In some "in vivo" test cases it is difficult to obtain full-time engagement because the patient is sometimes too fatigued or in too much pain to complete the user testing. Time is precious, so therefore we have to plan a scenario for each user-testing activity and avoid overloading the patient with too much information. The more varied and pronounced the concepts are, the quicker the user can provide us with converging feedback. When evaluating concepts, it is important to strive for the highest "level of measurement" (from nominal, ordinal to interval) by means of discovering the different aspects that are relevant for the user (see chapter 6) . In most cases aspects of iterated concepts will be perceived as "better", "good enough" or "worse" than the previous iterations. It is task of the industrial designer to document this process and leave as many traces as possible so that the user-community can harness the lessons learnt from the project.

The conversation language - open design artifacts

The shared language in the *Design for (every)one* living lab projects is composed of physical prototypes. The user-manufacturer agent has to be creative with the resources and skills at hand, which leads in most cases to a form of "physical hacking". Product concepts are built and adapted from other re-used devices and basic materials that are available in the local context. Hacking methodologies have been particularly useful in developing nations for increasing the functionality of mobile phones and deploying bicycles to serve other needs. They enclose a natural form of possibility-driven design (Desmet & Hassenzahl, 2012) and are equally useful to address the needs of disabled people in Western culture (Correia de Barros et al., 2010).

During this process, the user-manufacturer slowly shifts from experience prototyping (Buchenau & Fulton 2000, Buxton 2007) to personal manufacturing. He or she keeps track of existing, new and emerging technologies, and gains an overview of available production processes. The design of the DIY assistive devices results in "open-ended artifacts" under creative commons licenses (Lessig, 2008), which other occupational therapists can build on and apply in various rehabilitation contexts. These new licenses enable user-manufactures to make all information, involved in creating and making their DIY assistive artifacts, freely available without losing their copyrights. Like open source software, there is no end point and products become tangible versions of human needs, evolving within the pursuit of meaningful goals. This process of "hackufacturing" as Scott Brunham (2010) calls it, could be the next step in the physical read-write culture of tomorrow. The intellectual property of the source design remains with the designer while the alteration and realization of the final product are anchored in the resources and realities of a local manufacturer. Today, assistive technology and universal design manufactures see this phenomenon as a threat due to the lack of expertise, tension with current legislations and the history of intellectual property protection.

3.5 KEY INCIDENTS - LIVING LAB PROJECTS

This living lab structure has been developed through participatory action research at the Industrial Design Center of Howest University. Several co-design cases have been set up within a living lab around meaningful activities of individual disabled people. Each co-design team within a living lab project consists of a disabled client, a care-giver, a student industrial design, a student occupational therapy and other random stakeholders from the local rehabilitation context. The duration of the process takes approximately 12 weeks (for an extensive elaboration see chapter 2).

The guitar slider (figure 5) was designed with Carla. She suffers from hemiplegia, a condition in which the limbs on one side of the body have severe weaknesses. Her passion is playing the guitar, and together with her occupational therapist she developed an DIY assistive appliance that enables her to achieve this goal. The original object reflects that the principle of sliding is a possible solution for her specific requirements. This "hidden solution" was the starting point of two co-design iterations with an industrial designer. The output is a Do-It-Yourself (DIY) assistive appliance built to professional standards. Some parts are universal whereas others are quite specific parts that can be produced with

Figure 5. Karla "guitar slider", Korneel "badminton shuttle", Sebastian "Ice-cream ring"

the help of rapid manufacturing techniques such as 3D-printing. The strategy in this case was set on patterns between performance, economy and convenience aspects.

The next object (shown in figure 5) represents Korneel's passion for playing badminton. Unfortunately, he has severe problems to return the shuttle to his opponent. Korneel has problems with his hand/eye coordination such that he is slow in estimating game tactics. He does not want to cheat on the playing rules of badminton. In the first brainstorming sessions, several shape variations of the racket and shuttle were made. Based on interactions with experimental prototypes in the gym, altering the shuttle was identified as the better solution. The shuttle was deformed and colored, so that the shuttle makes a spinning movement and slows down doing so. This gives Korneel the opportunity to correct his movements and to return the shuttle several times. The strategy in this case was set on patterns between performance, pleasure and convenience aspects.

The last object (shown in figure 5) is an ice-cream aid designed with Sebastian. During a serious accident Sebastian had a spinal cord fracture and became paralyzed. He transports himself in a wheelchair and one of his favorite all-time activities is eating a certain type of ice-cream. Due to his accident, he does not have enough strength to grasp the thin ice-cream stick. He had already tried some standard existing solutions but in his opinion all of them were very unpractical and stigmatizing. During a co-creation session the prototype of a ring with a small clip inside awoke many reactions: "I would even wear it continuously as a nice piece of jewelry... and still be able to steer my wheelchair while eating." The strategy in this case was set on patterns between performance, identity and convenience aspects.

In each of these trialogues the industrial designer and occupational therapist have been challenging the patient with new possibilities built with available resources in his or her local environment. The only communication tool between all the team members were the physical prototypes, each informed by a particular adaptation strategy. With the *design for (every)one* approach explicit and latent needs rise very quickly to the surface and guide the design process. Another human aspect that we noticed while performing certain case studies is the increasing level of commitment that can be reached by including the disabled users in the design process. In the course of the co-creation process they reveal themselves as real ambassadors of their personal DIY assistive devices. Suddenly the device becomes a part of themselves, which reduces stigmatization and augments the product affinity between the patient and his or her assistive tool. These feelings of pride also evoke a positive behavior towards the activity of sharing information with others in the horizontal user innovation network.

3.6 CONCLUSION, FURTHER RESEARCH

The *design for (every)one* living lab embraces horizontal user innovation networks around DIY assistive devices as qualitative research instrument within the field of design for disability. Manufactures can tap into existing networks or start to design their own. The overall macro interactions map different key transitions in this process, which can be used to categorize new tools and methods for further researching and designing. The first transition, from general problem to specific problem, concerns the redesign of assistive technology elements into accessible and open-ended tools, easier to use by disabled people; allied healthcare professionals and caregivers. The second transition, from specific problem to specific solution, involves designing a community-based rehabilitation platform with a shared language. This implies the use of adaptive prototyping to document the adaptation strategies, validate concepts within local contexts and distinguish patterns. The third transition is from a specific to a general solution. Translating patterns around personal DIY assistive devices into universal principles. These universal principles, in their manner, can set the basis for new creative innovations within the world of mass-production or low volume production. The aim of this research project is start with the engine of the framework, namely community-based rehabilitation which is the core of the living lab. Future in-depth research will focus (1) on the process of adapting assistive devices and (2) the emotional impact of the co-construction process on all stakeholders.

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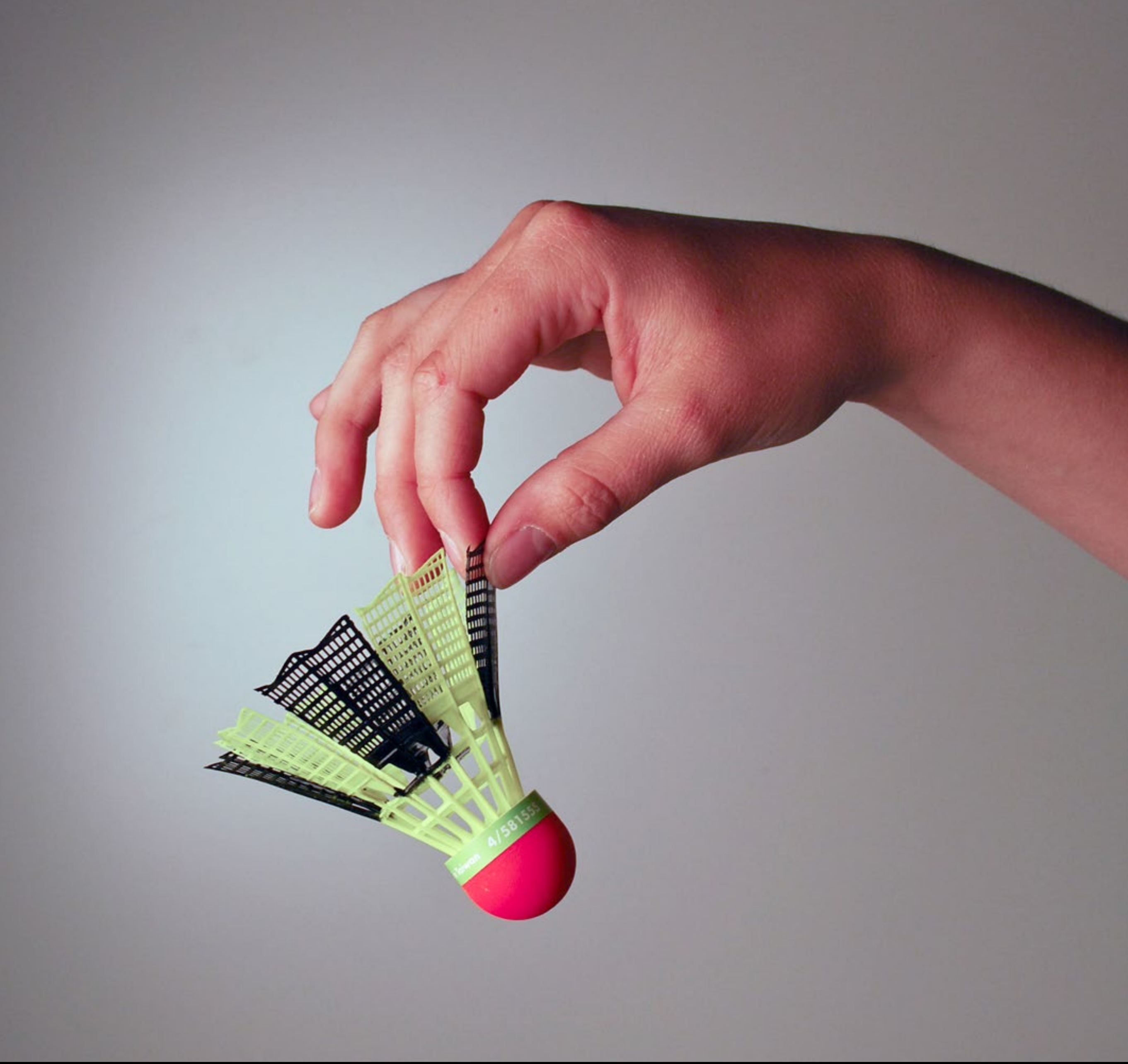


4. PARALLELS

CYBERNETICS AND DESIGN THEORY

“Cybernetics is the theory of design
and design is the action of cybernetics.”

(Ranulph Glanville)

The literature review provided a strong basis for our research and in addition to the set-up of the living lab, the framing of the theory was part of the infrastructure process. Although the literature review has been the object of a continuous effort, it was generally marked by insights that were made through the connection of two fields, namely cybernetics and design theory. The purpose of this chapter is to explore two subjects, cybernetics and design theory, in order to establish and demonstrate a relationship between these two fields with regard to self-directed learning. The main shared propositions between both fields are forming the fundamentals of the framework.

4.1 DESIGN THEORY FOR CYBERNETICIANS

Literally the word design means: "*the action of conceiving and producing a plan of something before it is made*" (oxford dictionary). Design practice is a type of design process applied to ready-made products that are being tailored with the local resources at hand. Approaches to frame anticipating design activities cover a wide range and evolved through history. The first attempts framed design as a complex but essentially mechanical action (Simon, 1969). A process of generating a set of alternatives which might be assessed against criteria (assuming that the criteria can be specified). This vision had an impact on tools, techniques, methods and management. The latter were all concerned in systemizing the design process by providing general representations and formal decomposition which supported the notion of design as a problem solving activity that lives in the world of the complex-yet-definable.

In the 1970s and 1980s, there was a growing recognition that design is not just the solving of difficult problems (Alexander, 1964; Jones, 1970) but embodies a kind of creative process that integrates both rationality and intuition : problem stages do not exist as such (or completely overlap, depending on how you want to look at it), there are never singularly correct solutions, the range of potentially relevant considerations is nearly always unbounded, side effects and interactions deflect even the most considered design moves, and so forth (see Cross, 1984). This vision of the design-methods movement has changed dramatically the focus of design research and has led to what Rittel (cited in Cross, 1984, p. 318) called "*second generation*" design methods: methods that assume distributed expertise, the need for discovery, and the centrality of argument and multiple perspectives in all design work.

At that era Rittel also explicitly linked cybernetics, feedback, and the design process within his writings (1969). Later on his work with Webber (1984) positioned the concept of "*wicked problems*" as a central feature of integrative designing. Rittel deliberately introduces cybernetics as a tool to deal with the dynamical nature of design processes. In addition he criticizes the inadequacy of existing Newtonian-based scientific and professional processes, because wicked problems cannot be solved by traditional and formulaic processes. In his 1972 paper Rittel hints at a collaborative approach which emphasizes two aspects: (1) problem understanding can only come from creating possible solutions and considering how they might work, (2) as well as making people who are being affected by the problem active participants of the process.

Since then many books and studies on trying to capture the essence of design activity have been written which resulted in a wide range of descriptive models on design (for an extensive elaboration see Dubberly, 2005). Generally speaking research in design practice can be seen to fall into two categories (Gedenryd, 1998). The first and largest is the category in which design activities are investigated through perspectives and methods imported from or associated with other disciplines. These approaches bring their own insights but relapse quickly into complex linear problem-solving procedures, containing fixed techniques to reduce avoidable errors and oversights that can adversely affect design solutions. They originated from the perspective of what other domain specific researchers thought designers should do. The key benefit was to find a method that suits a particular design situation.

The second approach holds a more behavioral perspective and focusses on what designers actually do and experience, framing the act as the center of designing (Schön, 1983; Cross et al., 1996; Gedenryd, 1998; Lawson, 1997; Cross, 2011). The impact of Donald Schön's work has been significant. His approach borrows much of its perspective from pragmatist philosophy which links action to meaning (Dewey, 1934). Schön foresaw the ever increasing instability of professional knowledge due to change and complex interdependencies within design activities and introduces an "epistemology of practice". He breaks with an unimaginative and static technical thinking and unifies exploration, collaboration and intuition within reflective practice. This approach suggests that the ideal design model is a cyclic —goal-oriented and involving an experiential feedback—process. The model assumes that participating agents form a learning system which in response to changing situations and requirements is capable of transforming its reactions.

A learning system... must be one in which dynamic conservatism operates at such a level and in such a way as to permit change of state without intolerable threat to the essential functions the system fulfils for the self. Our systems need to maintain their identity, and their ability to support the self-identity of those who belong to them, but they must at the same time be capable of transforming themselves. (Schön, 1973: p.57)

Donald Schön's work on learning systems fed nicely into a very significant collaboration with Chris Argyris around professional effectiveness and organizational learning. For Argyris and Schön (1978), this process of continuous learning generally involves the detection and correction of errors through feedback loops. To explain the mechanism we have to make a distinction between 'single-loop' and 'double-loop' learning. The theory postulates that all human actions within a learning system are governed by a set of variables (Schön & Argyris, 1995). These governing variables are the 'shared truths' of the design collective constructed out of attitudes, be-goals and standards. As a rule for maintaining the viability of the social system, human agents steer their actions to keep these variables within acceptable limits. In other words, chosen goals are operationalized rather than questioned, which leads to a process of incremental change. According to Argyris and Schön (1974), this is '*single-loop*' learning. An alternative response is to subject the governing variables themselves, using feedback from past actions, to question assumptions. Both authors describe this as '*double-loop*' learning. These processes focus on transformational change and lead to an alteration in the governing variables.

Another element of Schön's thinking is the distinction of "*reflection-in-action"*, reflection that takes place whilst you are involved in the situation, and *"reflection-on-action*", this type of reflection involves a stepping back from the situation, meaning that it happens at some time after the situation has occurred (Dewey, 1933; Schön, 1983). In "reflection-in-action":

"*doing and thinking are complementary. Doing extends thinking in the tests, moves, and probes of experimental action, and reflection feeds on doing and its results. Each feeds the other, and each sets boundaries for the other*" (Schön, 1983: p. 280).

We interpret the activities underlying these notions as forms of what situativity authors have qualified as "situated action" and "situated cognition" (Gibson, 1979; Greeno, 1994 ; Norman ,1988). Within this iterative process the design problem and potential solutions "co-evolve" over time with each space informing the other. (Maher & Poon, 1995; Dorst & Cross, 2001; Witsching & Ball, 2013).

4.2 CYBERNETICS FOR DESIGN RESEARCHERS

The history cybernetics dates back to the 1940's and 1950's when thinkers such as Wiener (1948), von Bertalanffy (1950), Ashby (1956) and von Foerster (1949) founded the domain through a series of interdisciplinary meetings (von Foerster et al., 1950- 1957). Cybernetic is apparently a modern science and because the field is still young, there are many definitions. It is the science that studies organization in complex systems. Cybernetics was formed around the same time as the system theory, with similar intentions to create a universal theory of organization. Whereas general systems theory is committed to holism to generalize structural and behavioral features (Meadows et al., 1972; Meadows & Wright, 2008), cybernetics is committed to an epistemological perspective and observes how these features dynamically self-regulate towards a goal (Ashby, 1952). As a discipline, cybernetics represents a convergence of various concepts and principles and it touches virtually all traditional disciplines, from mathematics, technology and biology to philosophy and the social sciences. In its modern use the term became widespread because Nobert Wiener (1965) wrote a book called "*Cybernetics*" , and was subtitled "*control and communication in the animal and machine*". The term itself derives from the Greek word for steersman (kybernetes). The metaphor of the steersman, which steers his ship, to attend a destination is often used to explain the fundamental concepts of cybernetics. Any sailor will attest that simply pointing the rudder will not get you where you want – you have to constantly trim and adjust until you arrive (Pangaro, 2009). This is done by enabling control through feedback. Cybernetics is about having a goal and taking action to achieve that goal. Knowing whether you have reached your goal or at least are getting closer to it requires "*feedback*" through interaction. Control implies also some means by which the intention (control action) can be communicated. All learning systems have this property to attain future goals through present actions.

In cybernetics, theories tend to rest on four basic pillar (Krippendorff, 1986) : (1) *variety*, (2) *circularity,* (3) *process* and (4)*observation*. (1) Variety emphasizes multiplicity, alternatives, differences, choices, networks to describe the limits of a system. In order to deal properly with the diversity of problems the world throws at you, you need to have a repertoire of responses which is (at least) as nuanced as the problems you face. This was defined by Ashby (1956) in his Law of Requisite Variety. Variety as a measure of the number of states a system either might or does take. In order not to restrict behavior, Ashby's Law tells us, the system that is to control must have at least as many states as the system to be controlled. (2) Circularity occurs in its earliest theories of feedback. A circular causal process in which a system's output is returned to its input, possibly involving other systems in the loop. This is another radical concept as the aim of traditional science has been to get rid of circularity and to ignore the insignificant through linear causality. (3) Nearly all cybernetic theories involve process and change, from its notion of information, as the difference between two states, to theories of adaptation, evolution and growth processes. Time is ubiquitous variable in each learning system. On each iteration we act, collecting the history of the iterations in an ever enriching spiral. We do not experience the same spot (twice), although the spot may appear the same at least in terms of location, we don't. Finally, (4) observation including decision making is the process underlying cybernetic theories of information processing. The role of the observation divides cybernetics system into two categories namely first-order cybernetics, systems which are observed from the outside, and second order cybernetics with systems involving their observers (Heylighen & Joslyn, 2001).

First-order cybernetics, will study a system as if it were a passive, objectively given *"thing"* that can be freely observed, manipulated, and taken apart (Ashby, 1959; Krippendorff, 1986; Glanville, 2007; Dubberly & Pangaro, 2015). A simple example of a cybernetic system is a domestic heating system. This consists, in essence, of two elements: the sensor and a space served by a heat source. The situation in the room being heated can be described (assuming some goal temperature) using only two states: it is too hot or it is too cold. The controller (sensor) needs, thus, only to have two states, which can be easily achieved with a (heat sensitive) on/off switch. Even in this simplest of systems (the thermostat), control is effected through a feedback loop, and the sensor is active: it turns the heat source on and off. What is relevant here, is that the form of control is driven by circular causality between the sensor, the heat source and the environment.

A second-order cyberneticist working with an organism or social system, on the other hand, recognizes that system as an agent in its own right, interacting with another agent, namely the observer (Von Foerster, 1992; Krippendorff, 1986; Glanville, 2007; Dubberly & Pangaro, 2015). Consistency demands that we treat the observer of the cybernetic system in the same way that we treat the observer in the cybernetic system; and the observer in the cybernetic system must be active (to effect change), so the observer of the system should be treated as active, in just the same way. As quantum mechanics has taught us, observer and observed cannot be separated, and the result of observations will depend on their interaction. The observer too is a cybernetic system, trying to construct a model of another cybernetic system. To understand this process, we need a "*cybernetics of cybernetics*", i.e. a "*meta*" or "*second-order*" cybernetics. In its present incarnation of "*second-order cybernetics*", its emphasis is on how observers construct models of the systems with which they interact (see constructivism). Cybernetics talk of structure and form, leaving emotion and meaning to the observers interpretation.

There were few cyberneticists who also reach out to design. Nortbert Wiener lectured at the Hochschule für Gestaltung Ulm and Gordon Pask taught in architecture schools, particularly London's Architectural Association School. Pask assumed there were close parallels to be explored between cybernetics and design. He defined a conversation as interaction between two second-order systems (Pask, 1975). This framework distinguishes between discussions about goals and discussions about methods, and it provides a basis for modeling their mutual coordination . Recently there have been several attempts coming from the interactive design and architecture community to re-marriage both fields (Glanville, 2007; Krippendorff, 2007; Dubberly et al. 2009; Dubberly & Pangaro, 2007; Geoghegan & Pangaro; 2009; Dubberly & Pangaro, 2015). The majority of these models frame conversation within design activities as the basic form of genuine interaction.

4.3 RELEVANT CONNECTIONS

Situatedness – learning along with the environment

Professional designers have always been aware of the importance of rigor and chaos in the first stages of product innovation processes, especially for complex and new projects (Buys, 2008). Little can be learned by relying only on objective data gathering and analysis. Problems involving human centered design have a certain "*wicked component*" which demands an opportunity-driven approach, requiring decision making, doing experiments, launching pilot programs and testing prototypes. The chaos comes from the experiential interactions between different stakeholders and their environments. The world is not just the 'play-ground' on which the brain is acting. Rather, brain, body and world are equally important factors (Clark, 1997). Out of the varying interactions some kind of order will emerge which leads to preferences that create more order and stability. The cybernetician Heinz Von Foerster (1961) formulated this principles as "order from noise. This type of self-organization is a principle of evolution (Heylighen, 2001) in which local processes of variation and selection give rise to general organization. Design activities between several stakeholders encompasses a process where a similar structure or pattern appears in a learning system. This is done without a central authority or external element imposing it through planning. This pattern appears from the local interaction of the elements that make up the system, thus the organization is achieved in a way that is parallel (all the elements act at the same time) and distributed (no element is a true central coordinator). As a rule a self-organizing systems performs a selection. In a purely objective sense it rejects some states, by leaving them, and retains some other states, by sticking to it. Within design theory this is called experiential learning. According to David Kolb (1983), experiential learning occurs in a sequence of four stages. First, people experience a concrete event, then they reflect on this experience and decide whether they like that event or not. If they like it , there is a need for learning. So the next stage they start thinking about new concepts they could apply to get better experiences with that concept. By experimenting they will be able to reflect (Schön, 1983) in order to decide if this second experience was better than the first one. If so, they will apply the new concept in future situations. If not they have to design another concept and do a new experiment, and so on. The general concept of a self-organizing system has changed over time. In the early days it was defined as a system which changes its basic structure as a function of its experience and environment. However, it is important to note that an organism does not organize itself independent of its environment. Von Foerster (1960) persuasively argued that only organisms and their environments taken together organize themselves. Later on Ashby (1960) redefined a self-organizing system to be not an organism that changes its structure as a function of its experience and environment, but rather the system consisting of the organism and environment taken together.

Constructivism – actors as subjective observers

Constructivism comprises the philosophy that models are not passive reflections of reality, but active constructions by the subject. Design activities aim to change reality through the adaptation of physical products within a certain environment. In effect, the theory of Schön (1983) denies that we can remove ourselves from our own acts of observing, and thus it questions what we can know of a world from which the observer is excluded. Noting that knowledge cannot be developed through passive observation of what “objectively” exists, but only through active construction combining a variety of subjective experiences. Cybernetics talks of structure and form, leaving emotion and meaning to the observer’s interpretation and insertion. It respects the subjectivity of modelling and may be thought of as providing structures within which it is possible to construct the individual meanings and emotions we chose. Within design practice learning theories on constructionism are gaining more and more interest (Hummels & Frens, 2011; Koskinen et al., 2011; Koskinen & Krogh, 2015).

Constructive design researchers routinely build prototypes that are sometimes very elaborate and that work not only as illustrations of an argument, but also as proofs of a concept. In this context prototyping is equated with a conversation, both are mechanisms to contain a constructivist act. No meanings are passed, rather, they are made by the participants. They are constructed, and the presence of the constructors is always acknowledged. Each participant makes his/her own understanding of what he/she believes his/her conversational partner means, and re-state them to that partner. They compare their own understandings before and after. No theory exists without a reworking of the knowledge associated with it (a point made by Popper (1963), who called himself a constructivist). Piaget (1955) also acknowledge that mental models are not passive reflections of reality, but active constructions by the subject. He describes a process in which we learn about and know in experience. By taking these experiences, and breaking them into parts to create (recurring) patterns and consistencies between them. From a cybernetic perspective Conant and Ashby's (1970) '*Good Regulator*' theorem states that "every good regulator of a system must be a model of that system", with the corollary that modelling is a necessary part of regulating a system's behavior. Designers may not see themselves as 'regulators'–even those explicitly involved in behavior change–but as Scholten (2009-10, p. 3) has argued, an implication of Conant and Ashby is simply that "*every good solution must be a model of the problem it solves*": not too far from Dorst and Cross's (2001) concept of problem-solution pairs (Maher& Poon, 1995; Witsching & Ball, 2013).

Out of control – creativity and consequences

People assume that letting a team self-organize is the equivalent of complete chaos. To avoid getting into such a situation, self-organization requires some constraints. In general, when we use the word unmanageable, we indicate a negative connotation. But in the context of self-organizing systems it is positive. Being in control means defining, in some sense, the range of what will be considered as possibilities. Being in control also restrict the world to what one can imagine. Self-organization assumes that no interaction is equal. Framing prototyping activities as a cybernetic conversation takes into account that not only what was intended by the designers of the prototype will happen but also something different that will emerge (express itself, organize itself) in the chosen context, embodied by the spontaneous behavior of the interacting agents. A basic assumption of conversation is that participants do not transmit or share meanings. It is in the difference that the novelty can be seen as to arise. Every utterance we interact with a prototype, its understanding or meaning will be return as different. Every time my conversational partner expresses back to me his/her understanding, we must assume it will in some way differ from mine (Krippendorf, 2006). Cybernetics is possibly the first study to take error on board as a fact of life rather than something to bemoan and curse. In fact, careful consideration shows it is error that drives the system! Therefore we formulated the above reasoning into the following axiom:

Acting within the real world always implies that
also something different will happen from what was chosen to act on.

In fact, the name prototype originates etymologically from the Greek word "Protypon" (Primitive Form), and consists of two basic terms: "Protos" (First) + "Typos" (Impression). Co-design is the use of prototypes in a specific context to stimulate interaction or impression that is spontaneously raised in that context, and to learn from it. This learning will have an impact on both the designers and the interacting agents. The use of a physical artifact doesn't even require the need for direct contact between agents. In this sense it is a double-blind method. The intended influence (by the designer) on the behavior of the agents (stakeholders) is not made conscious, and certainly not by the presence and influence of the designer. If the intended behavior does not happen spontaneously, the design of the prototype has failed. Moreover, the designer will be able to observe not intended uses and (to the designer new) meanings by the interacting agents because traces will be left during the interaction. A typical aspect of design practice is that different people may interface rather differently with the same artifact. What is a screwdriver for one person, maybe an ice pick, a lever to pry a can of paint open, and a way to bolt a door for another.

These asynchronous conversations with the environment, its agents and oneself through prototyping-interactions is an important way in which the variety of the "*repertoire*" of the designer can be changed. According to Lim et al. (2008) an efficient prototype is a manifestation in its simplest form that filters the qualities in which designers are interested, without distorting the understanding of the whole. Fidelity or resolution in prototypes comes from the amount of properties they are given, but what makes prototypes so exceptionally useful is that some of these productive properties are explicitly given up (Gedenryd, 1998). Or in other words, from a self-organizing perspective, they are randomly filled in by the environment and the emerging meanings or consequences of interacting agents. Therefore a real situation is always complete, everything is present if only you look for it.

Co-experiences – affordances and disturbances

Within design activities there are no absolute criteria. In each project there are no clear specifications: the criteria emerge after the solution has been found and may be seen as being defined by the solution. Design outcomes within activities can only be validated as being good enough, not by being best. In fact, it is often difficult to determine that one design outcome is better than another simply because there is no shared standard against which to evaluate. Still many design teams manage to reduce the complexity and self-coordinated themselves through experiences on prototyping-interactions each of them following a unique path towards a certain goal. This done through a process mutual adaptation, actions followed by reactions followed by responses to these reactions and so on, leading to a desirable state. This goal-directed behavior is understood as a process of regulation that reduces any deviation from the goal by means of negative feedback loop (Powers, 1973). To understand the origin of counter actions better we need to understand the events that initiate such alterations. Within cybernetic literature any change in the agent's situation that makes the agent deviate from its present course of action is called a diversion (Heylighen, 1992). The defining characteristic of a diversion is that the agent has no control over it (although the agent may try to control its subsequent effects): it does not originate from the agent's decision-making, but is unexpected, coming from an initially unknown origin.

The most fundamental distinction within diversions (see side by side overview in chapter 11) is the one between affordances (negative feedback principle, e.g. consequences that bring the agent closer to its initial goal,) and disturbances (positive feedback principle , e.g. consequences that block the agent from his initial goal) or neutral (surprises which do not have an impact on the current course of action) (Heylighen & Vidal, 2008). Disturbances consist of phenomena that, if left unchecked, would make the agent's situation deviate from its goals, i.e. reduce its utility towards that goal. Examples within design activities are design aspects endangering the safety of an agent, a high amount of effort to produce a part or an unexpected loss of an agent. An affordance (Gibson, 1977; Greeno, 1994) is characterized as an unexpected change in the situation that creates an opportunity for the agent to perform an action that increases its utility, so that it can reach its goals more quickly or easily than expected. Affordances can be tools, means or resources (e.g. a new way of using a material, someone that can give advice, reduction in the price or energy) that can help the agent achieve its goals, or to disappear obstacles or certain constraints. Within co-design activities this regulation progress is done by a cohesive group of agents which share a goal. Through collective decisions the group continuously adapt itself to change within the learning system and in its environment. Within design research we use the term 'co-experience', according to Battarbee (Battarbee & Koskinen, 2005), to describe experiences with prototypes in terms of how the meanings of individual experiences emerge and change as they become part of social interaction. Co-experiencing is the process of learning, maintaining, and modifying meaning in social interaction with prototypes. It consists of three similar key processes, or types: lifting up (neutral), reciprocating (affordances) and rejecting (disturbances).

Embodied cognition – explicit and tacit perceptions

Although co-experience treats experiencing as a social process that is done by individuals in social interaction, it acknowledges that experiencing is still subjective and private, but its meanings can be shared and communicated to others either explicitly or implicitly (Battarbee & Koskinen, 2008). As an acknowledge that language does not merely describe the world (Wittgenstein, 1953), design practice explicitly makes use of embodied interactions (Dourish, 2002; Clark, 2010) through prototypes. There is no interaction possibility without observable aspects. If the trail is not perceptible using available sensors and interpretations, it will not be followed. If no affordances (Gibson, 1979; Norman, 1988) are available, no actions will follow. Prototypes address a wide variety of sensory-motor coordinations to evoke a lot of "side-effects" and unfold social phenomena in real time and real space as a part of the world in which we are situated. As discussed above the way we perceive these "side-effects" is essential to increase the variety within a learning system. Perceiving is an activity, and our body and skills are an inextricable part of our perception (Merleau-Ponty, 1958). We perceive the world in terms of what we can do with it, and by physically interacting with it, we access and express this meaning. Perception, through action, precedes cognition: reflection is a consequence of action.

The essential resource within design practice is often *"tacit knowledge"*(Rust, 2004), things that we know but cannot tell because they have become part of our instinctive performance. This term was coined by the scientist and philosopher, Michael Polanyi (1983). We all have such knowledge from life experience but it cannot be extracted or written down, it is part of us. However we can get people to perform for us – acting out real situations, allowing observers to develop new insights. Many design researchers within the co-creation community (Buchenau & Fulton Suri, 2000; Kurvinen, 2007; Sanders & Stappers, 2008; Wood et al., 2009) have elaborated on the work of Ehn and Kyng (1991) who pioneered with the use of mockups as tools for engaging with stakeholders rather than prototypes to be evaluated. Understanding users rather than insisting on one's authority and objectivity is a radically new social situation, which requires a radically different kind of approach to design. In contrast to taking one's own expertise as a measure of the abilities of others, designers must regard others' understanding with respect, regardless how sophisticated it may be (Krippendorff, 2007). Making tacit knowledge experiential through prototyping requires second-order understanding.

4.4 ADAPTATION THROUGH HACK PROTOTYPES

The use of physical prototypes is considered as one of the cornerstones of a designedly approach to product development with the aim to save resources (McCurdy, et al., 2006) and to understand the concept that is being developed (Buchenau & Fulton Suri, 2000; Bødker, Kensing & Simonsen, 2004; Greenbaum & Kyng, 1991). Apart from craftsmanship contexts (Wood et al., 2009; Sennet, 2008) no design methods incorporates the technique continuously through the entire design process. Within traditional product development three-dimensional models are often used in a discontinue manner. At some stages in the design process professional designers make a tangible externalization to make the ideas shareable and open to communication, both externally with clients or users (Bryan-Kinns & Hamilton, 2002; Erickson, 1995; Schrage, 2004; Kelley, 2001; Wagner, 1990), and internally within the design team. Within hacking design activities the modification of physical hack prototypes is the only method used during the entire development process. Besides the role of communication, past research on prototyping within traditional design activities includes themes such as : (1) the conceptualization of prototypes as learning vehicles (Floyd, 1984; Houde & Hill, 1997; Coughlan, Fulton Suri, & Canales, 2007; Buxton, 2007; Kurvinen, Koskinen & Battarbee, 2008), or as tools for knowledge creation (Lawson, 1997); (2) the relation between resolution/fidelity and the reaction of engaging agents (Bryan-Kinns & Hamilton, 2002; Erickson, 1995; McCurdy et al., 2006; Rudd, Stern, & Isensee, 1996; Schrage, 2004; Schneider, 1996) and (3) the effects on the motivational mindset of participants (Jégou & Manzini, 2008; Dow et al., 2009; Dow et al., 2012; Gerber & Carroll, 2012).

To explain the dynamics of adaptation within collaborative learning systems through hack prototypes we made a distinction between hacking spaces and places. These metaphors have been adopted particularly in computer supported cooperative work (Harrison & Dourish, 1996). Hacking spaces frame

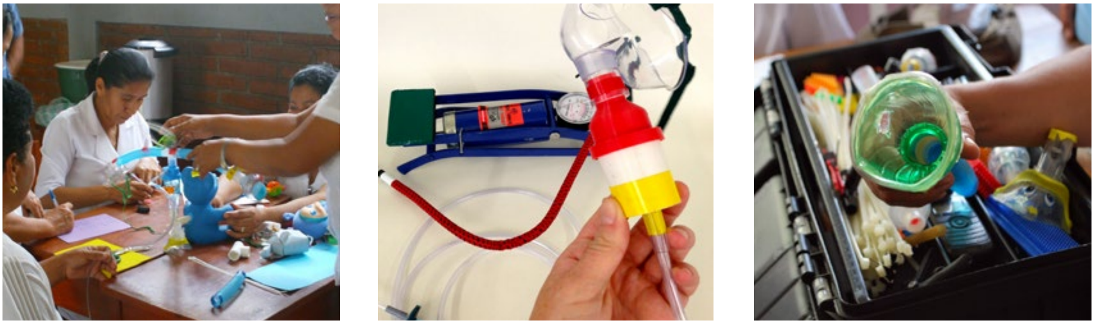


Figure 1. MIT Little Devices lab explores the design, invention, and policy spaces for DIY health technologies around the world. Their main resource are toys as local and globally available materials. Nurses using the Drug Delivery MEDIKit in Nicaragua.

the three-dimensional environment, in which objects and events occur. Hacking places frame the attitudes in which these spaces are used. We use this metaphor to turn the attention away from the structure of space toward the attitudes that take place there. Through this approach we emphasize not how to design a particular hacking space, but how to design for the interaction fostering all the hacking attitude that steer the adaptation process (Dejonghe et al., 2011).

Hacking Spaces

According to the merits of hacking activities (Geydrend, 1998) the variety of spaces in which hack prototypes are used by stakeholders can be divide into three major kinds: *'exploring and challenging'*, *'building and working'* and '*using or testing'.* All of these spaces offer opportunities and constraints through their physical structure, topology, orientation and connectedness. The basic purpose of the hacking spaces is "to permit" simulations of surrogate situations (Blomkvist, 2014; Clarck, 2010). These simulations in turn provide the basis for new affordances or disturbances by which the participating agents can plan new design actions.

PRODUCT HACKING SPACES FOR EXPLORING AND CHALLENGING.

The purpose of these spaces is to use hack prototypes to generate new ideas and push boundaries. This context is embedded in the original hacking culture and has been framed within design research as "*the sandbox culture*" (Koskinen et al., 2012) or "*technology brokering*" (Hargadon & Sutton, 1997). Under the motto "demo or die" ideas are made tangible, modifying off-the shelf products with cheap materials like scrap wood, scrap metal or foam. In theory design hacking requires no training above kindergarten level (see figure 1). Just as in any sandbox, iteration goes on until something survives, with possibility-driven (Desmet & Hassenzahl, 2012) mindset. Within this context the agents seek for natrual affordances, by trying out actions without specific expectation of what the action would bring

Figure 2. Project Daniel is a project created by Not Impossible foundation to use 3D Printers to make local prosthetic arms for children of war in South Sudan.

about, in the hope that one of them would uncover a meaningful interaction.

PRODUCT HACKING SPACES FOR BUILDING AND WORKING

The purpose of this attitude is to use hack prototypes as a dimension to consider how easy they are to build, before they can be used. The use of known affordances in order to maximize the increase in utility they can bring about. The focus lays on how simple they are to create and also to modify or adapt with the available means. This embodies a more economic principle of prototyping: "*the best prototype is one that, in the simplest and most efficient way, makes the possibilities and limitations of a design idea visible and measurable.*" (Lim, Stolterman, & Tenenberg, 2008, p. 7:3). In this hacking context designedly craftsmanship blossoms while optimizing and integrating several design aspects (see figure 2). Richard Sennett (2008) discusses this point in his book '*The Craftsman*', where he puts forward that any craftsman (not to be confused with artisan) has an inherent drive to become better at his work for the sake of getting better; craftsmen have the drive to deal with ambiguity and resistance in order to improve their sense of nuance and quality, extending part of their knowledge to their hands (Frens & Hengeveld, 2013).

PRODUCT HACKING SPACES FOR USING OR TESTING

Proof of concepts are used to verify whether certain spontaneous behavior is actually afforded. User testing serves to test how the hack prototype stands up under realistic circumstances, by having a representative user work with the prototype "live" and on a realistic task in a dynamic environment. It is a test that focuses not on the user, but on the prototype-interaction itself. The user is brought in to make the test of the prototype more realistic. In theoretical terms, she and the chosen environment serves as support, as an additional aspect of the recreated future situation of use. This product hacking context is characterized by a directed drive for corroboration and insight. Often the hack prototypes are simplifications, often details are left out, and only rudimentary aspects and working principles are built.

Figure 3. Adaptive eye care glasses are a liquid-filled alternative whose prescription can be altered at the time of fitting simply by adjusting the amount of injected liquid into the flexible membrane lens.

It informs the design process on the validity of decisions and aims to evoke co-experiences with other stakeholders (see figure 3). The process by which an agent constantly minimizes deviations from its goals, by appropriately counteracting disturbances. Regulation makes use of negative feedback: deviations in one direction are compensated by actions that push the state in the opposite direction.

Hacking Attitudes

In general hack prototypes should be able to reveal a variety of behaviors through rapid trial and error within local environments. If unexpected affordances or disturbance are encountered the stakeholders interacting with the hack prototypes are being changed by the interaction. To fully understand the utility of changing design aspect, agents should be able to re-adapt the hack prototype and see if the evoked behavior is consistent across time and in different choice situations. This asks for a completely new approach of prototyping, because most of the prototypes known in industrial design and product development are not easily adapted and stakeholders are seen as unchanging interactors.

The hack prototype is the changing mediator within the learning process, it is designed using time as a design aspect: as a changing trace of interactions. The fitness of hack prototypes is inherently steered through the dynamics within the environment. To explain the attitudes of hacking designers within this adaptation process we rely on Darwin's 1859 theory of natural selection (Darwin & Simpson, 1962) as key mechanism of evolution. Darwin's grand idea of evolution by natural selection is relatively simple but often misunderstood. One of the key mechanisms of evolution, natural selection, causes "*changing organisms*" to evolve in response to a "*changing environment*" (see figure 4). There is no real beginning or ending, or an environment suddenly changes and affects a specific organism, or there is a sudden variation in traits within a population of organisms which benefits or obstruct within a given environment. The selection we are discussing is purely spontaneous, without plan or design involved.

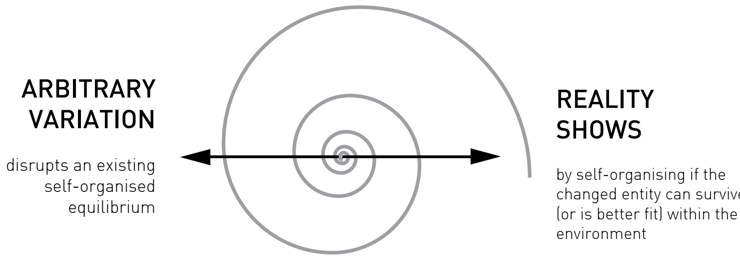


Figure 4. Natural selection

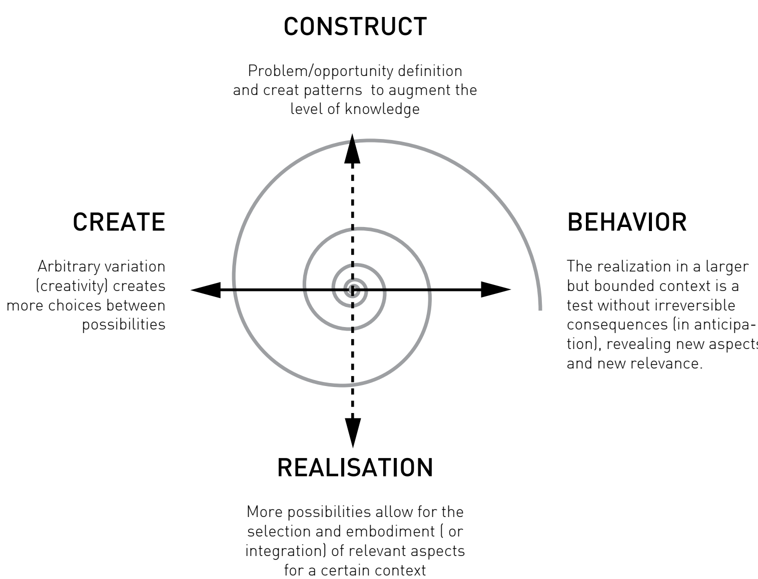


Figure 5. Directed evolution

Both phenomena are driven by self-organization (Kauffman, 1995; Jantsch, 1979). Evolution is often viewed as a biologic process that is general slow. But the power of human exploration & exploitation, both inherently driven by creativity, can also been seen as a type of human evolutionary process. Through spontaneous appearance of novel structures or the autonomous adaptation, environments can be changed in much faster timeframes. The adaptive capacity of human agents is very high, due to the high number of specific actions they can produce and external conditions which can be sensed. To learn efficiently within this random based trial-and-error process we add another axes. This adds a cybernetic layer of control through feedback an makes it possible to detect errors and transform reactions (see figure 5). The model we use is a 4-stage cycle derived from Argyris and Schön (1978) theories of action: (1) reflect-on action and construct a new reality on the action *(construct)*,(2) apply the revised theory of action and create new hypotheses or variety *(create)*, and (3) implement the revised theory through reflect-in-action *(realize)* and (4) finally assess the behavior & consequences within an environment *(behave)*. Just like in the theory of natural selection creating spontaneous ideas and observing the behavior of prototypes within a changing environment are both driven by self-organization. On the contrary, constructing and realizing are conceived as planned actions of the learning system. We can distinguish four mutually exclusive attitudes giving rise to the adaptive loop of hacking design. In all four "phases" hack prototypes are instrumental. We distinguish the four attitudes by the four combination possibilities of the binary distinctions (see table 1):

- selecting (obvious meaning) versus "*something different than selecting*" (this means: "*letting something happen*" or "*letting organize something itself*")
- diverging (obvious meaning) versus "*something different than diverging*" (this means: "*converging*")

The four attitudes are given the following names (see table1):

	Selecting (logic)	***Let it happen (chaos)***
Diverging (deviate)	Construct	Create
Converging (focus)	Realise	Behave

Table 1. Conjunction of distinctions

These four attitudes are distinguished only because these describe the base competences of hacking designers very well. In the very action of designing these four attitudes continuously change and interact.

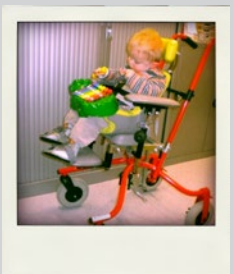
CONSTRUCT – SELECTING/DIVERGING.

Hacking designers are trained to take into account the demands and wishes of all parties involved in a design (these parties are called stakeholders). A hacking designer that is involved within a participatory design process must learn to construct the reality of each stakeholder, and this is the reality as it is experienced from the perspective of the stakeholder. Not in all cases this is explicit knowledge. Designers can handle explicit requirements and tacit wishes. Therefore the hacking designer reflects on traces of existing behavior with products and environments to learn what aspects are implicitly relevant for the stakeholder. These are used as benchmarks. Typically in this phase the hacking designer observes that the behaviour of products and contexts are not what he expected based on generally accepted knowledge. The stakeholder-context system frequently did self-organize differently, based on the stakeholder's particular awareness in his particular context. Hack prototypes (traces of real behavior) are thus used by the designer to structure observations, to order idea's, to leave partly interpreted traces of observations that could get a different meaning only later when more information on relevance is available. The hacking designers need those external traces because their (internal) skills proceed differently than what could be expected from a reliable memory.

KEY INCIDENT: Inneke's Outdoorslipper

Both feet of Inneke were partly amputated. As a result she wears inside each pair of shoes a pair of tailored orthotic inner shoes which are attached to her ankle by a zipper. When walking long distances the orthotic cause a lot of friction, which leads to irritation, calluses and blisters. Inneke reached out to the "design for (every) one" living lab to find a fluffy slipper solution to wear at home. After half a day walking with the orthotics she desperately feels the ventilating of her feet but still needs to protect her feet. Besides within the standard range of mass-produced footwear no pair of slippers that offers a good support to the morphology of her feet exists and creates an experience of comfort as lightness and ventilation. ***The co-design team started immediately to observe the inner shoes as a means to get a grip on the friction area's and the shape.*** *It became clear that attaching the slipper with a zipper system took too much time as Tinneke only uses the slippers to walk small distances. While testing the first hack prototypes several essential design aspect drew the attention of the co-design team: the slipper should mainly support the front of shine bone, provide enough grip and shouldn't look to fancy as it will be only used within private contexts.*

KEY INCIDENT: Dylan's bumboo seat



Dylan, who is 3 years old, was born with cerebral palsy. This affliction means that he has a muscular deficit in his torso and too many muscles in his limbs. This has given Dylan an unstable posture with asymmetry to the left. Sitting upright without support or standing up independently is a real challenge for him. Dylan's behaviour in the kinder garden. Dylan has a sitting brace in which he spends most of his day. But playing in such a brace is no mean feat. ***The co-design team observed that the sitting brace creates too much distance between him and the other children, his involvement with them is insufficient.*** *Despite this, it is important for Dylan's development to maintain contact with other toddlers. Dylan's current chair, the Bumbo Seat®, was a good alternative until he outgrew it. In the redesign, all the positive features from the bumbo seat were integrated into a DIY orthopaedic seats, optimised and personalised for Dylan. More than anything, it had to be something that would grow with him. After the observation the restricted back support height was a deliberate choice so Dylan had to continue using his back muscles.*

CREATE – LET IT HAPPEN/ DIVERGING

An assignment for a design typically cannot be experienced, it just is an idea, full of potentially conflicting requirements. Thus a priori there cannot be a right or wrong solution to the assignment. The hacking designer will have to find “something different”, other ways to approach that reality and to make the relevant aspects available for the experience of all stakeholders. The ability to come up with various and different embodiments for an idea is called creativity. Creativity is a skill transcending the dichotomy of good and wrong. It creates and explores different possibilities, long before the problem or opportunity is understood, and in the interaction only these could be categorized as fit or not fit to a particular context. Usually the result of creativity is a multitude of fit interactions. More creativity results in more emergent aspects that can re-activate a locked-in situation. Creativity can be trained and doesn't have to wait for the emergence of a random variation in a material realization to come up with something new. This is instrumental for the conscious generation of new emergent co-experiences that could show new aspects provoking a different behavior in a particular context.

KEY INCIDENT: Heleen's Puzzelaid

Heleen is confined to her wheelchair. Her service dog Gyproc helps her with many daily tasks as Heleen herself has also a heavy motor disability. Nevertheless she loves puzzling and can spend hours on making jigsaw puzzles that consist of more than 200 pieces. But although the activity is very meaningful to her she still experiences a lot of disturbances when trying to crap and position the small pieces. When a small puzzle falls on the ground Gyproc has learned to help her out. Still positioning and grapping the pieces asks a lot of effort and puts her patience to the test. ***Together with the co-design team she explored a variety of alternatives to grap, stick, suck or roll small puzzle pieces.*** *This resulted in a hacked aquarium pump that is connect with a small vacuum pen through a 3D-printed holder.*

KEY INCIDENT: Oude Melkerij Serving aid

The serving aid has been redesigned to help people with mild motor disability that serve drinks at parties and receptions. The objective was to make an attractive serving aid that prevents glasses from falling during serving. To avoid social stigma during the serving activity it was essential that the serving aid could be placed on all standard trays. ***The co-design team explored several alternatives based on material exploitations, shape explorations and re-appropriation of other products.***

REALISE –SELECTING/ CONVERGING.

During hacking activities one cannot avoid to make decisions based on explicit information or on tacit knowledge. Both can have a high impact (positive or negative) on the variety of future behavior. Hack prototypes are used to communicate/persuade a certain theory of action. Going further, some hacking designers deliberately create novel situations that force their stakeholders to change their behavior and reveal new possibilities or needs to the hacking designer (Rust, 2007). The hacking designer has to interact (not only through prototypes but usually also socially) with the other stakeholders to reveal their tacit behaviour that otherwise could not be understood or even not revealed. Focus is laid on expected/desirable features. A lot of features are suppressed. A hack prototype is unavoidably simplified. Profesional designers are trained to be maximally aware of the presuppositions of theirs and others decisions, and are able to navigate in uncertain contexts. This allows them to revisit the decisions based on newly created evidence. The most powerful documentation of the presuppositions is by leaving material traces (hack prototypes) that could be used later on to reconstruct the path that was followed, but also to (re)construct the nodes where a different direction could now be followed that was not obvious at the first time (this is the so called "*design paradox*" Ullman, 2010).

KEY INCIDENT: Nicole's Bottle holder

Nicole, loves sparkling water, but as she suffers from rheumatoid arthritis, current aids to help her open a bottle, grab hold of it, lift it or pour from it, did not come up to scratch and proved not user-friendly. Nicole noticed that as the neck of each bottle is slightly different, the connection with the aid could not always be trusted. Despite her disabilities, Nicole is an enthusiastic women who is committed to find the right solution. ***The co-design team made a selection of hack prototypes which focused on the main occurring disturbances drawn from their experiences: (1) attaching a clamp around the body of a bottle and (2) finding an upper connection which is applicable for a range of bottles. Through the interaction with this hack prototypes Nicole was able to point the most intuitive design aspects and ergonomic procedures.*** *First, the entire artefact could be slipped over the bottle. In a second step a rubber loop tied around the neck of the bottle finishes the connection with too much tension in her fingers. By means of a spring element, the loop is pulled out, and the bottle is ready for use. The product is operated by the ball of the hand and avoids the use of thumb or other finger tips. Our product is fitted with a bigger handle, enabling Nicole now to hold the aid in different places. Consequently, it is much easier to pour a full or nearly empty bottle.*

KEY INCIDENT: Jan's flute aid

Jan lost his left index finger in a saw accident, but this did not stop him continuing his hobby as a musician. On the contrary, Jan learned to play the recorder again with modified grip and balance in his dominant hand. Besides that, he started actively searching for possible tools to help him. This search led him to "Design For Everyone" living lab. It was Jan's desire to find an assistive tool that gave him the possibility to play different (read bigger) recorders. He can play the soprano recorder, but not the alto - , tenor - and bass recorder. Important factors in the development of the assistive tool were the air-tightness of the material used as well as the angular rotation of the tool. After many hours of prototyping and testing, we have developed an orthese that is easy to attach to the little finger, but also feels comfortable. ***A crucial aspect was the position and the choice of the right material to imitate a fingertip. The co-design team suggested a solution made of standard rubber balloons filled with glue. They made a variation of hack prototypes to help Jan finding the natural experience with playing.***

BEHAVE – LET IT HAPPEN/ CONVERGING

Influenced by prototypes, reality will organize itself: something will happen, what implies that something different will be excluded for the experience (it cannot be chosen to experience, it can happen only). This means that experienced time by the stakeholder will get a different shape: what was impossible previously now becomes possible and what was possible previously now becomes impossible. Typically, hack prototypes are made to be tested double-blind in the intended environment, with the intended stakeholders, only to determine what is relevant in that context. That means that both will influence each other during interaction, and only because of the interaction, and that the traces left by this spontaneous interaction will be used for further development. Doing so the hacking designer, with its limited understanding of reality, does not force reality in his own limited world-view. By his multidimensional skills he provides a leverage for self-organization in partly predictable and continuously evolving interactions. Prototypes are thus used as objects that interact with agents resulting in expected but also unexpected new aspects.

KEY INCIDENT: Henk's Ground lifter

Henk is an active 40-year-old. A car accident resulted in a spinal cord injury, which means that the nerves in the spinal cord had been severed. This is why he is paralysed in his lower limbs, from Th 8, and the muscles in his trunk are also affected. All this means that he is now wheelchair-bound. Henk started his own wheelchair company and is often faced with lifting boxes. In order to lift a box, Henk has to bend down completely, grab hold of the box and pull himself up with one hand on the wheelchair. Since Henk always needs one hand to pull himself up, he cannot lift boxes with two hands. As Henk is a professional basketball player strength is not an issue. Therefore the co-design team suggested some other simplified hack prototypes with belts, straps and hooks. The most promising was a simple piece of tissue that was wrapped around the box. Based on the principle the co-design team explored some new variation but some unexpected problems occurred. The stronger the tissue the more friction it caused which made it harder to slide a box on top of it. A second consequence was the difficulty to create handles within the tissue without damaging the strength. ***One of the co-design agents was a sailor and spotted a Dacron material which was used for Catamarans. New tests with this material revealed some unexpected affordances. The material was very strong and thin enough to slide underneath big boxes.*** *Due to the synthetic quality the fabric could also be lasercutted. This opened up a whole new perspective on the production of the handles, besides cutting the contour the handles could also be melted and not sewed. Later on the team optimized the material of the fabric, with multiple handles and added 2 small iron bars ans counterweights to control the wrapping around a box.*

KEY INCIDENT: Oliviers' Cookie aid

Olivier is a teenager that suffers from spasticity due to a shortage of oxygen during his very long and difficult birth. His spasticity makes it hard to perform fine motor skills. He loves eating little biscuits while watching his favorite television programs. When he watches television with his family there isn't much of a problem as his family members help him out. But when he is alone at his desk on his room he is not able to eat any kind of snack. Since he would really like more privacy, he asked us to design a product that would help him out in an independent manner. The co-design team made a cookie dispenser especially for Olivier. The team tested a lot of methods to reach out cookies so that Oliver could eat them out. For this they hacked a lot of spoons. ***One particular spoon was surprisingly useful as its curvature also positioned the cookies always perfectly at the center. This afforded the team to work further with the hack prototype and take the curvature of the handle also as essential design aspect.*** *Simultaneously they made a dispensing mechanism that Oliver could operate with his chin. When both systems were integrated they added some extra suction cups to the legs of the system as the container frequently flipped over due to the spastic movements of Olivier. Together with loose fit of the wooden connections the hack prototype also absorbs a large amount of the forces that are applied.*

4.5 CONLUSSION

In this chapter we illustrate some relevant connections between design theory and cybernetics regarding experiential and adaptive learning. The main shared propositions between both fields are forming the fundamentals of the framework : (1) product hacking is a situated activity that co-evolves along with the environment, (2) Product hackers are subjective observers that actively construct their own reality, (3) Product hacking is a creative act that is stimulated by serendipity, (4) product hackers steer their process through co-experiences. and (5) by doing so they use both mind and body simultaneously. We distinguished four mutually exclusive attitudes giving rise to the experiential adaptive loop within hacking design : behavior *(what will happen ?)*, construct *(what did I experience?, How do I feel?)* , create *(what are other possibilities?)* and realize *(What will I do?)*. In all four "phases" hack prototypes within are instrumental. All of these actions occur on the interface between agents and their environment. Within the next chapter we will sketch how this loop is triggered through the effect of experiential prototype-interactions and how these interaction have an impact on general and specific goal-directed behavior.

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Part III

FRAMEWORK

5. FRAMEWORK

THE CYBERNETICS OF PARTICIPATORY HACKING

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“The measure of intelligence is the ability to change.”

(Albert Einstein)

In this chapter a cybernetics design approach was chosen to develop a general framework that explains how specific prototyping interactions influence general adaptation in participatory hacking behaviour. Step by step we build up the theory supported by real-life illustrations from case studies on Do-it-Yourself Assistive Technology (DIY-AT).

5.1 THE NEW MAKERS

Design for (every)one is an interdisciplinary living lab and experience-driven training programme straddling industrial design and occupational therapy. By means of action research, the research field bridges the gap between assistive technology and open design. Within their curriculum, students of industrial design and occupational therapy join forces to design Do-it-Yourself Assistive technology (DIY-AT)(Willkomm, 2005; Hurst & Tobias, 2011) on a human scale for just one client with a participation handicap. There is a great need in society for ergonomic tools tailored to the specific limitations some people face. Even though there are no two people with the same disability, the range of universal tools that are mass-produced is relatively limited. Rapid technological developments not only make knowledge available to everyone, the tools to invent and produce the products also come within everyone's reach (Hurst & Kane, 2013; Rajapakse et al., 2014; Moraiti et al., 2015).

A practical illustration of this trend are the fablabs (Ghersenfeld, 2007). A fablab is a public workspace which just about anyone can visit who wants to create something. Thanks to those fablabs, consumers gain access to new technologies with which just about anything can be made. Aided by the advent of digital manufacture and the unlimited amount of knowledge accessible via the internet, everyone can now create and develop tools, an area that used to be the remit of just large factories before. This trend is opening the way to new forms of inclusive product development, where the end users can be involved in the entire development process making their own DIY AT (Buehler et al., 2014; Ostuzzi et al., 2015). A new generation of creators take matters into their own hands, and innovate and produce through co-design in people's homes, in sheltered workshops and local support and residential homes. Moreover, this open design culture allows for the rapid dissemination of personal solutions (Buehler et al., 2014) , which means that third parties can reproduce those products and further tailor them to their own participation context (De Couvreur & Goossens, 2011).

The EyeWriter is the culmination of a co-design project which was originally developed for the paralysed, legendary graffiti artist TEMPT1. Members of the Free Art and Technology Lab (F.A.T.), OpenFrameworks, the Graffiti Research Lab (GRL) and The Ebeling Group communities joined forces with TEMPT1 who, because of his illness ALS, could only move his eyes. Eye movement became the basis for a special open-source drawing device. It allowed him to draw for the first time in seven years. Tempt1 describes what it meant for him as follows: "It felt as if I had been kept underwater and finally, someone was pulling me up, allowing me to breathe." (Tempt1 et al., 2009)

Figure 1. Graffiti artist TEMPT1 with the eyewriter prototype

We see more and more of those organically grown projects, like the EyeWriter, spring up to solve participation problems. The result is unique product adaptations perfectly tailored to the capabilities of the individual clients in their own environments. Each DIY-AT project starts with a challenge or a problem experienced by the client, being the person with a disability who wants to take part in every aspect of society in a way that is meaningful to them. Despite the dynamic tangle of emotional and functional design aspects (Hocking, 1999), creators manage to find solutions that offer a meaningful response to the participation problem. Since, due to the restrictions and capabilities of the clients and others involved, each DIY-AT project is unique, there is no standard methodology or set roadmap which co-design teams can use to reach an actual and successful objective. Existing knowledge, behaviour, skills or values (and therefore learning) are modified for all those involved in the moment in an experience-driven manner. This form of learning has, since Donald Schön (1983), become known as reflective practice, and is frequently applied within research through design (Koskinen et al., 2011).

Our aim in this chapter is, on the basis of case studies, to illustrate the dynamics of reflective practice within participation-related co-design projects. We would, at the same time, like to initiate a dialogue which will hopefully bring about a synergy between research through design and disability studies. In doing so, we focus on the following three aspects to arrive at an initial framework: (1) What are the fundamental elements to learn within a co-design setting, (2) how does autonomy come about in actions, (3) how do people experience these changes within the context of co-design.

5.2 CO-DESIGN EPISTEMOLOGY

Designing is a universal human competence which aims to create change with a view to addressing an undesirable situation or breaking through a stalemate. Within the DIY-AT projects, we always seek to create new opportunities, with due consideration to the constrictions in the viability, but with added value for all agents involved in the co-design group. The end product of new opportunities or possible solutions to any given problem is known in advance. They only occur in the moment and during

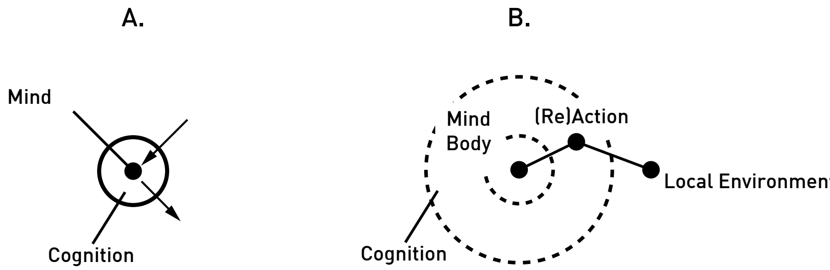

Figure 2. Intra-mental and (A) inter-active accumulation of knowledge (B) (based on Gedenryd, 1998)

interaction. Designing, therefore, is a constructivist activity, where actions, rather than being final, constantly generate new starting points. Knowledge is not just passively absorbed but actively constructed by prototyping interactions in a local environment. A physical prototype is a simplified and tangible realisation of a future product or situation, where certain design aspects are omitted deliberately. (Gedenryd, 1998). Designers use prototypes to externalise their concepts (Blomkvist, 2014) and test out their choices against reality. Figure 2 shows a simplified diagram of the traditional, well-defined display of cognition as a pure (a) intra-mental process (observing and analysing situations), and the wider (b) inter-active cognition (making solutions in situations experienceable) (Gedenryd, 1998). Creating and trying out several prototypes forms the backbone of all co-design actions. By making the prototypes as experienceable as possible, we not only stimulate our minds but also our senses, and thus lower the barrier to participate in the process.

The co-design team acts as an autonomous entity able to make choices to take action within the present environment. Those choices are translated into prototyping actions. They are the consequences based on those actions which give the team a richer picture of possible obstacles/interferences which the client experiences in pursuing his/her meaningful participation. Those obstacles/interferences are often made up of complex relationships between (1) *client*, (2) *aid*, (3) *environment* and (4) *activity-related aspects* (Wessels et al, 2003). In addition to this complexity, we also take into account the fact that all aspects continually change over time. This makes it impossible to apply universal principles without reflective practice in design processes in relation to the meaningful participation of individuals.

No two situations are the same, each co-design team will, in practice, always need to systematically construct, and adjust, its own ‘unique model’. In order to better describe this adaptive learning behaviour, we will call on the help of cybernetics, or the science of communication and control theory that is concerned especially with the comparative study of automatic control systems.

5.3 ADAPTIVE CO-DESIGN BEHAVIOUR

Cybernetics is an interdisciplinary science discipline that deals with the cyclic control (Heylighen, 2007) of biological and mechanical systems using feedback as used in reflective practice. Cybernetics has many applications, in both the humanities (pedagogy, psychology, policy) and exact sciences (biology, aerospace, robotics). The autonomy of co-design teams relies on the principle of feedback – feedback of information about the effects ('output') of prototyping interactions for the co-design system – as a result of which the co-design team can make more accurate adjustments. To better illustrate the dynamics in adaptive design behaviour, we use the work 'design for a brain' by Ross Ashby (1952), one of the pioneers of cybernetics. Ashby describes very formally the elements and conditions necessary to keep autonomous entities viable when they pursue their goals in an ever-changing environment. In this section, we mainly want to demonstrate that this framework can be applied to adaptive co-design behaviour or, in other words, learning by making experienceable prototypes.

We apply a case study based approach with a theory building structure. The sequences of sections follow a theory building logic and are supported with key incidents from DIY- AT projects from the *design for (every)one* living lab (see chapter 2). Essentially, the process involved the collection of significant change stories emanating from the field level, and the selection of the most significant of these stories by panels of staff members from the stewardship team. Through these illustrative descriptions we try to describe the phenomenon itself as well as the context within which the phenomenon is occurring.

The elements of adaptive co-design behaviour

PURPOSE AND IDENTITY

A co-design system is defined as a collection of components connected by relationships. Those components can, in the context of tools, be split into three broad categories, (1) the agents and their skills, (2) the available prototyping resources, (3) participation in related activities.The purpose is mainly driven by a significant activity of a client and the participation issues he/she experiences in relation to those issues in their environment. Action will not be undertaken to make adjustments until the tension between the meaningful activity and the environment is too great. Resistance can be about many things, ranging from purely physical, mental, through to emotional aspects. Each co-design system has its own identity, which is largely determined by the purpose of the co-design system (What do we want to achieve in the environment?), but also tells us about the way in which this is to be done (How will we achieve this in the environment?). Each identity, therefore, addresses a number of relationships between the components of the co-design system. As soon as one of the relationships changes or is modified, the identity will change accordingly. In each co-design project, therefore, the team constantly changes identity by making several prototypes and moving away from situations that have become too rigid.

KEY INCIDENT: Sebastian's ice-cream aid

Due to a spinal-cord injury which Sebastian suffered in an accident, he is paralysed from the waist down and has weakened upper limbs. He has chosen to take part in this project and asked us to design an aid that will allow him to eat a Magnum ice cream on his own again. Objectively, this may seem like an odd choice. You would expect him to ask a different type of question that would increase his independence. The universal aids he uses in his environment are, in his view, adequate enough to help him cope with basic everyday activities. ***The subjective context shows us that Sebastian's quality of life is greatly enhanced by being able to eat a Magnum ice cream with his son, an activity which they enjoyed long before the said accident.*** *This is not compatible with his reduced muscle strength and motor skills, given the lack of aids that address the problem of eating ice cream on a stick in an elegant manner. One of the first prototypes which the co-design team made was an enlarged container which was a great solution for the problem. Sebastian, however, felt uncomfortable with this ostentatious solution. Since the co-design team picked up on this up very early on, it next committed to manufacturing an elegant made-to-measure ring using a 3D printer.*

Each co-design team consists of several agents, each with their input (expertise/skills/motivation). At the *design for (every)one* living lab, those roles are filled by a client and his/her direct stakeholders (carers, relatives, friends, employer, …), industrial designers and occupational therapists. The fourth role is played by the ever-changing surroundings, or context, in which the client finds himself/herself. By means of an autonomous process of trial and error, namely prototyping, several actions ensue simultaneously: (1) The team will collectively determine and test the purpose. (2) In addition, the team will reach a consensus about the strategy/approach to achieve this purpose. (3) By sharing physical, intellectual and material resources, the team creates alternative solutions in order to achieve a new balance. (4) During the process, more and more similarities and differences between the prototyping interactions are discovered, and the team creates its own experience-driven language for the participation problem and the possible solution.

ANTICIPATION AND FEEDBACK

So the co-design system has to take action and trigger mistakes in order to cut itself a path to the goal. This goal is, by definition, in the future, but has a great impact on present anticipatory behaviour. Cybernetics can model this by referring to anticipation or feedforward (Heylighen, 2007). Feedforward is the ability for an agent to build mental models that help him assess the result of actions: 'if ..., then ...'. What is anticipated can also be considered a plan of action relating to the action undertaken. Usually, the action stops when the goal is reached and what is anticipated is being observed. At the start of a co-design project, strong teams will create many different prototypes because of the great uncertainty, but also to better understand and test different identities.

KEY INCIDENT: Gilberte's nail clippers

Gilberte is a lady with one arm and asked us if we could design nail clippers for her. As a woman, she found it very important to be able to look after her own nails. The pictures above illustrate the anticipatory behaviour of the co-design team. In the early stages, quite a few low-end prototypes were made to test different variants of nail trimming. ***The co-design team anticipated by means of prototypes that make use of clipping movements using her hand, head and foot and filing with one arm****. At that point, it was a priority for the co-design team to gain a better understanding of what Gilberte was capable of doing. For each prototype, the team focused on a distinct operational aspect. Addressing those specific aspects, the team managed to build the prototypes very quickly with minimum effort. To achieve this, quite a few other aspects were deliberately omitted, like finish, shape, material, cost, ... When we checked out the prototypes with Gilberte, it was soon obvious which design model proved successful: clipping nails using the head. Immediately, she was able to share that while pressing down, she has a good view of her nail line, but that the button was a little too stiff and the device could benefit from increased stability on the table.*

Feedback is essential to an agent who cannot possibly anticipate or predict everything himself. After all, there will always be something different from what was anticipated and from what was chosen as the purpose of the action. The co-design team can create something with the best of intentions, but does not know how the client experiences it and how effective it is in its contribution the client's wish for participation. Not only what is anticipated can be observed but also what happens unexpectedly (things we do not choose or cannot be predicted). By combining anticipation and feedback, co-design systems manage, despite various environment-related obstacles, to achieve their purpose or function. There are two different types of feedback: positive and negative (see chapter 4 on affordances and disturbances). This label is totally unrelated to the value of the design, only to increasing (affording) or decreasing (disturbing) behaviour towards the specific objective. In the case of positive feedback, an unexpected consequence of an action will reinforce itself and we will move further away from the initial state. In practice, the co-design system will move away from its original purpose. Sometimes, a much better solution is quite unexpectedly found for the problem, or everything will be done to avoid repeating the same mistake. At these turning points, the identity of the co-design system will change by adapting to the consequence. The opposite situation is referred to as negative feedback. As a consequence is weakened, it suppresses aberrations. The co-design system wants to retain the original goal and is capable of integrating all side effects. In the section on experiencing adaptive co-design behaviour, we will elaborate on the emotions or action tendencies caused by the different types of feedback.

KEY INCIDENT: Korneel's shuttlecock

Korneel is an athletic young man, but has poor hand-eye coordination. One of his favourite pastimes is playing badminton. In concrete terms, this translates into difficulty to serve and repeatedly failing to anticipate the shuttle. His badminton trainer asked the students to design a new type of badminton racket with a larger hitting surface but still light enough to handle. In one of the first iterations, the students made a prototype of a large racket head with double hitting surface. ***During the first tests at the sports centre, Korneel displayed highly unexpected behaviour. He definitely did not want to play with a different type of racket because he was self-conscious in front of the group. This positive feedback, namely that the resistance to the current plan had drastically increased, meant that the team moved away from the original plan and eventually decided to manipulate the shuttlecock.*** *Once the path of the badminton shuttle was established, its design was simplified thanks to negative feedback, namely further optimisation, or elimination, of practical side effects. The shuttlecock was cut open and folded outwards, causing itself to constantly brake in the air. In that way, Korneel had sufficient time to anticipate his strokes, and everyone at the badminton club was able to play him without sacrificing any of the enjoyment.*

OBSERVATION AND PRACTICAL PRELIMINARY KNOWLEDGE

Two fundamental components that are needed in order to direct actions are (1) observation and (2) practical preliminary knowledge. The sensors for this observation in co-design projects are the participating agents, each with their own sensitivities, focus and preliminary knowledge. The client's expertise is mainly in terms of their experience, while designers focus on the feasibility of the concept and occupational therapists take the ergonomics of the activity under scrutiny. Carers and relatives are best placed to observe how a client feels. In certain situations in which clients lack the verbal ability to communicate, relatives play a crucial role in the feedback process. They understand what the client is communicating and relay this to the other members of the co-design team.

KEY INCIDENT: Thea's rocking chair

Thea is a 12-year-old girl with Rett's syndrome, as a result of which she is increasingly restricted in certain motor movements. One of her favourite activities is rocking, but her impaired manual dexterity does not allow her to use an everyday swing on her own. A plastic swing tub is currently on the market, which is, in actual fact, an infant rocker for adults, where the user can be fastened in securely. Not only is this model expensive, it also looks very clinical and requires from the carer a lot of muscle power to lift the user in and out. ***In Thea's case, her carers, her father and mother, played a significant role. They can perfectly deduce from her behaviour how she feels in certain prototypes and detect aberrant behaviour.*** *For example, during the initial test with three different prototypes, it was immediately apparent that she had a preference for a canvas variant of a swing. In fact, Thea's non-verbal language made her preference abundantly clear to the designers, too, even when they repeated the tests in different contexts (in the park, at home, at the neighbours, in the care facility...). Since Thea has difficulty stretching her legs, it soon transpired that she was too low down on most of the tested swings, which meant her feet always hit the ground. In one of the prototypes, she spontaneously tipped backwards, which rendered her in a tub shape. In that way, the legs were automatically lifted. It soon became clear that a mobile add-on for every universal swing set would be the most valuable solution, so that Thea could enjoy sitting on the swings of any playground. That is how they came to opt for light and flexible materials at an early stage. Observing the interaction between the user and carer made us consider eye contact during swinging. During the initial test, the occupational therapist noticed that lifting the user in and out (by the carer) was an obstacle which definitely needed addressing in the new product.*

The practical preliminary knowledge present in a team also determines the first anticipations in the form of prototyping actions. We want to draw a clear distinction (see figure 3) between explicit knowledge and tacit knowledge (Polanyi, 1967). Explicit knowledge (know what) can be described as factual knowledge that can easily be transferred irrespective of the context. We use agreed symbols in a known semantic structure. Tacit knowledge (know how), on the other hand, is enmeshed in the

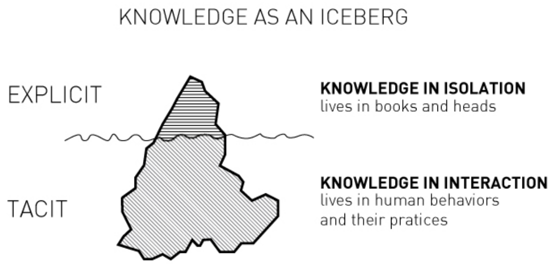

Figure 3. Preliminary knowledge as an iceberg (adapted from Nonaka & Takeuchi, 1995).

interaction and cannot be separated from the surroundings. Forms of intangible knowledge are often related to actions, intuition and routines. In practical situations, there are so many things happening simultaneously that often, people cannot explain exactly what is happening, but do know straight away when something goes wrong. Riding a bike or kneading bread are good examples of this. The co-design team is often split into two: those who can do it well, cannot explain it (any more), and those who are learning can explain it well. They know the theory, but cannot do it yet. Co-design processes are often about making intangible knowledge explicit. The use of prototypes allows everyone to learn from the practical skills of every agent involved. Sometimes, certain design aspects prove too difficult to articulate, but this changes as soon as experienceable prototypes are presented.

KEY INCIDENT: Simeon's trombone aid

Three years ago, Simeon lost his right arm in an accident. He now wears an advanced prosthesis, which creates opportunities in some contexts, but limitations in others. Simeon's greatest passion is playing the trombone, but the prosthetic hand makes it impossible to grab hold of the trombone. ***As with playing every instrument, a lot of knowledge is hard to put into words, but can only be experienced, like the feeling of the correct lip tension, the force that must be exerted on the slider or the difference between two suspension systems around the same neck.*** *By repeating tests with prototypes several times, and making minor adjustments each time, the designers have made this knowledge perceptible for themselves. In an initial phase, the suspension was examined, but at the same time, information was received about the correct force for the mouthpiece and operating the slider. Soon, it transpired that a bicycle tire provides the necessary grip and resilience needed to give the instrument the necessary freedom without compromising the lip tension.*

The operation of adaptive co-design behaviour

The work of Ashby (1952) very eloquently lists the minimum conditions and elements of an autonomous co-design entity in order for it to be able to adapt to changing circumstances. With his holistic thinking, he integrates – unlike Schön – the surroundings as part of the autofocus system by means of two types of feedback, namely single and double-loop (see figure 4).

The first feedback loop, the 'single loop' or first-order loop, is depicted on the left-hand side of the diagram. It mainly plays a role in the dialogue between anticipation (what do we think, and create, to reach our target and indirectly guarantee the identity) and feedback (to what extent have we reached this target with those actions and have we not overlooked any issues). The co-design team tries out several variations of actions one after the other in order to pursue the same goal and find a solution for the client in a certain localized context.

The second feedback loop, the 'double loop' or second-order loop, located on the right-hand side, will only bring about a reaction when the essential variables are reached or exceeded. Ashby (1952) describes those '*essential variables*' as variables that are fundamental to the viability of the co-design system. They are the physiological limits of each agent in a co-design team and determine the impact of mental, physical and emotional efforts. All agents undertake actions to achieve an anticipated goal within the limits of the '*essential variables'* (if not, there would be no co-design team). Despite the fact that everyone can agree on a goal, the experience of 'how achievable that goal is' will be different for everyone. The essential variables of agents are unconscious and exceeding them is always a surprise. When this happens, the team is forced, through positive feedback, to adjust their goals and revisit the identity by integrating a new parameter (a new agent-, design- or activity-related aspect). Ashby's model illustrates that both a changing environment and a changing design activity (feedforward/feedback) can impact on the essential variables. As long as they have not been exceeded, the agents will assume that the goal can still be reached (and so are willing, and able, to undertake the necessary actions through negative feedback). When, however, the essential variables are exceeded for an extended period of time, the co-design system will correct itself in a compelling manner by creating a new 'modified target'. This second-order loop always determines the outlines within which prototyping reactions (the first-order loop) manifest themselves, and is critical for our discussion.

When a co-design project is started, an effort is made to create a consistent picture of the participation problem by using current skills, materials and knowledge (tacit or explicit) via trial and error. Various prototyping interactions are applied to explore the scope within the boundaries of the co-design system. Strong co-design teams use all resources of different agents within the co-design entity in a manner that is effective and offers the least resistance. Each agent has his/her limitations and possibilities. Similarly, designers cannot physically, mentally or emotionally create everything within any context. As long as alternatives can be found to achieve the set goal, the co-design team will always find

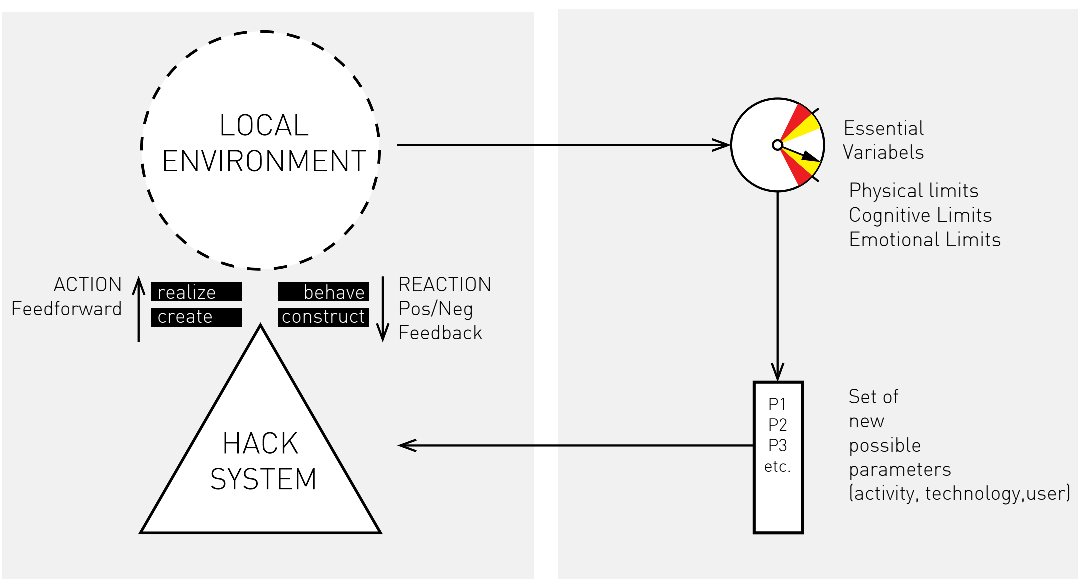

Figure 4. Framework learning within an adaptive co-design system (based on Ashby, 1952)

new stable states within the limits of their capabilities. We call this behaviour incremental adaptation, since the essential variables are not threatened and the co-design system further optimizes its plans using single loop or first-order loop

KEY INCIDENT: Barts' digital photo camera

To this day, cameras are still designed for right-handers. When you, like Bart, have one long left arm, you cannot possibly watch and take pictures at the same time. By adding a handle on the left-hand side of the camera, the problem was solved. ***Even if this solution appears very radical from a technological point of view, the process showed only the characteristics of incremental, single-loop iterations. The 3D-printing technique is one of the prototyping skills which industrial-design students have, and the team goal (taking photos with one hand) was not corrected at any point.*** *There were a number of practical challenges, but the students always managed to bypass those with creative solutions.*

When the client, or one of the other agents within the entity, unexpectedly exceeds his/her limits, there are only two possible scenarios: (1) Either the co-design project folds and the team has reached its natural life or (2) the focus of the plan is shifted to a new goal or a new equilibrium between co-design entity and the surroundings. This new goal is a radical departure and also gives the co-design team a new identity. The agent who perceives his/her limits as having been exceeded – and this can be any agent – should be sufficiently creative (or at least open) to abandon his/her original goal in favour of a new goal (and to respect the co-design team in the process).

Approaching one's limits through experience-driven actions creates precisely the dynamics in the design process. In many cases, those limits, or essential variables, also encourage further design activities. After all, when there is a great deal of tension between the meaningful dimension of an agent and the impact of mental, physical and emotional efforts involving a participation activity, action is undertaken. The same phenomenon can be seen in the prototyping process. When certain prototyping actions require too much effort, the plan of action is questioned. This is not necessarily viewed in a negative way. Often, new, user-friendly solutions spontaneously present themselves, or we look for new agents to help us out in a specific context. Unconsciously, those unexpected events also cause a change in behaviour and create new goals. The confrontation with reality works like an eye-opener for many agents. Sometimes, certain agents expect too much, or too little, of their participation, and they have to adjust their expectations. In certain situations, agents surprise themselves by learning new skills step by step, which opens new doors for them.

KEY INCIDENT: Harry's catheter extension

Ten years ago, Harry started using a wheelchair after an accident at work. He bought an adapted toilet seat which allowed him to sit on the toilet in the opposite direction, simplifying the draining process. Unfortunately, the toilet seat was discontinued and Harry was faced with a problem. He called on the help of our students to replicate a customized toilet seat, which would allow him to use the toilet independently at home. ***During the co-design process, the students experienced how Harry was physically pushed to his limits during the transfer from his wheelchair to the seat. Often, he would even just fall onto the seat, because the effort was too much for him, and he increasingly began experiencing shoulder pains. Harry's occupational therapist urged the team to look for an alternative solution. The team's focus shifted via a double loop, from moving the person to extending the catheter in a hygienic manner.*** *A simple coupling piece was designed and produced using the 3D printing technique, to suit the catheter. Thanks to this aid, Harry was suddenly able to go to the toilet independently not just at home, but anywhere else as well.*

The experience of adaptive co-design behaviour

PEAK EXPERIENCES

Observing behaviour and learning from experience with the accompanying emotions plays a huge role within reflective practice. The most powerful feedback is always experienced as unexpected or surprising. As described earlier, those are moments when co-design team agents engage in experience-driven learning and refocus on other relevant aspects or methods to reach their goals. It is impossible to return to a state of naivety and hard to imagine '*how the insight was not there before*'. Very quickly after the exciting feeling of surprise, people will assess to what extent the event has a positive or negative impact on the targeted process (See Table 1). Only when those moments are experienced inter-subjectively by all agents (or create a co-experience) do they form decisive key moments that bring about incremental and radical adaptation (Battarbee, 2002; De Couvreur et al., 2013).

	Negative feedback (incremental adaptation)	**Positive feedback (radical adaptation)**
Desirable experience	*"Yes, it does appear to work well. Let's refine this further."*	*"Wow, I never thought I would be able to do this! Forget everything else."*
undesirable experience	*"Hmmm, this is disappointing, could we tweak this element some more?"*	*"Sorry, you can count me out. I even refuse to try this out."*

Table 1. Experience-driven nuance difference between incremental and radical adaptation

MOOD

Moods differ from emotions in that they are less specific, less intense and less likely caused by one specific stimulus or event but by a sequence of events. Often, they indicate whether the efforts and tasks related to the co-design activities are evenly spread across the team members. Are the prototyping-interactions challenging enough for the participating agents and to what extent is the goal experienceable?

When a co-design team is faced with too much positive feedback, both in desirable and undesirable experiences, the goal will always change and the system will become exhausted. Positive feedback should be rapidly alternated with negative feedback so that the co-design team gains control over the prototyping activities and ideas can be further developed. The story also translates into a state of 'flow' (Csikszentmihalyi, 1990). Flow is a concept from positive psychology, in which skills and challenges are systematically attuned to one another (see figure 5).

Within co-design processes, this phenomenon is also clearly recognisable from the mood within a team (De Couvreur et al., 2011). Strong teams push the boundaries that give them new challenges and can anticipate the latter in a creative manner. In those challenges, they seek to hone their skills or develop new ones. As soon as the flow channel is deviated from too much, the limits of the team will alter the course.

KEY INCIDENT: David's coat aid

David has a physical disability and is supported by the Vleter-living project in Gits to live independently. A persistent source of frustration for him is the fact that he has difficulty getting his coat on and off without help. It is impossible for him to make the shoulder movement that is essential to take off a jacket in a conventional manner. David had already found his own solution to take off his coat by making use of window sills, something which, ergonomically, was not justified at all. The first co-design team wanted to integrate the two movements (putting jacket on and taking it off) into one aid. ***Their strategy centred on pulley systems to lift the coat up. It required a lot of effort to adjust the prototypes and time and again, they met with minor problems. The build-up of negative experiences triggered a downward spiral for the team, despite their good intentions. It was immediately clear that this challenge was too much for this co-design team.*** *There were too many elements that were tested at the same time, as a result of which the complexity and scale of the prototypes got out of hand. One way or another, the essential variables were not observed by David or the students. The end result was a low-performance and enormously stigmatising device (Lehouck et al., 2012).* ***When we asked David a year later to take part in another trial, he spontaneously suggested to change course. Since he only puts on his jacket when he is picked up by somebody, the students decided with him to find a solution to take his jacket off only.*** *This created a lot of new possibilities. Following many minor variations, the new team arrived at a solution involving magnetic straps attached to David's collar. At home, a magnetic board was attached to the wall where David was able to position himself with his wheelchair. By moving his shoulders to the wall, the magnets 'click' into place on the board. When he gently wheels himself forward and makes a rotational movement, the jacket drops off his shoulders.*

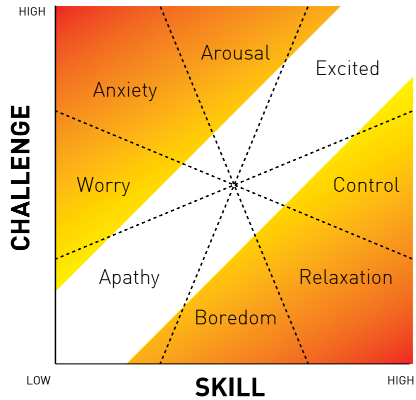

Figure 5. The flow channel (Csikszentmihalyi, 1990)

5.4 VARIETY AND CREATIVITY ARE THE ONLY LIMITATIONS

In this chapter, we would like to promote participation from a cybernetic point of view, involving experience-driven co-design within participatory hacking design. We will do by describing DIY-AT processes that takes emotional, social and technical action as their starting point, and not the end result (see chapter 6, 7 and 8) . If we want to optimize adaptive co-design behaviour, we can do this by approaching various elements of the Ashby model self-critically within our own co-design entity. Ashby mainly uses one basic principle, namely the law of requisite variety. The variety in the co-design system must be greater than, or equal to, the variety in the environment. In other words, can the group observe and check all sources of variety that can possibly occur in reality? If that is not the case, the co-design system will have to adapt in the long term (adjust the goal, seek a new environment, add a new agent to the system,...) in order to maintain the viability or identity. Variety, therefore, is a crucial concept within experience-driven learning and impacts on all the components within the co-design system. Competence to generate variety is referred to as creativity. In the chart below (see table 2), we list a few sources of variety and their impact on reflective practice within the co-design team.

So throughout a DIY-AT project, we constantly experience resistance which fans the team's creativity. If we want to learn quickly and keep the motivation in the project high, we must try to carry out our actions as quickly as possible. Exploring existing means and ways of keeping exertion levels to an absolute minimum during prototyping actions is, therefore, a crucial form of creativity to guarantee the flow within the project. That is why we try to keep the first challenges small-scale and achievable. The first action strategies within a co-design project must follow each other in quick succession, so that the range of options can be mapped out quickly and the client's limits in their participation problem can be established. In order to do this, a fine balance is to be struck between energy and time to keep the process going. Within a design context, students at this stage will want to use as many existing resources as possible, for example by hacking products and copying existing solutions. Only when the solution becomes obvious, can the team start integrating and increase the level of detail by single-loop learning. The prototypes are increasingly adjusted in situ, in the real context, and the team's creativity is called upon to hone or optimize solutions.

Variety Agents	*- Does your team's variety impact greatly on the perception and knowledge accumulation within the co-design entity?* *- Does your team's variety also impact on the types of actions which you as an entity can carry out and perceive?* *- Does your team's variety impact greatly on the ability to establish trust in relation to the client and to allow the actions to take place?*
Variety Environment	*-We need an open environment to perform various actions, and not controlled universal lab setting.* *- At no point is an environment identical. Is it possible, in this local environment with the co-design team, to repeat a variety of actions quickly and at different times and occasions?*
Variety Anticipation	*- Do the team members have sufficient imaginative skills and creativity to push certain aspects into the background?* *- Do the team members have sufficient skills and resources to implement the action?* *- How different should the variety be within the team? Do we have the respect and trust in the anticipations of others?*
Variety Feedback	*- Is there enough variety within the team so that there is more chance that we recognize emotions/behaviours in others and in us?* *- Do we need another agent in the team who can help make implicit knowledge experienceable?* *- Is there enough variety within the co-design team so that we are able to observe the smallest and biggest relevant change?*

Table 2. Sources of variety within the co-design system

5.5 THE FUNDAMENTAL ATTITUDES FOR CO-DESIGN AGENTS

One single action strategy consists of four essential, rapidly alternating hacking attitudes (see chapter 4): (1) Determine and construct what should not change from the point of view of the person with a disability and their agents involved. This attitude is necessary to be able to distinguish unexpected aspects and new knowledge. (2) Create variety, be creative and start from the possibilities, and not the limitations, of a client and his environment. Try to explore the boundaries. Respect them, but try to bypass them in a different way. (3) Choose between alternatives on the basis of co-experiences within the co-design team. What can we make today to accelerate our learning, and what is a priority based on the dialogue with the client and their environment. Reduce the level of complexity and focus on crucial aspects to keep the efforts around prototyping actions as low as possible and still to test sufficient knowledge. (4) Test in reality (allow reality to organise itself) in the hope that during the preparation of the test, the co-design team will make the desired selection and the design model can remain intact. Embrace the unexpected and its inter-subjective experience, respect essential variables and direct the project from that angle.

5.6 CONCLUSION

In this chapter, we looked at the emergence of single en double-loop learning (Argyris & Schön, 1995) in more detail, based on our practical experience with designing aids in various co-design projects. The premise is that unique, customized products are made (incremental adaptation or single-loop learning, see chapter 6) for, and with, clients in their surroundings. In many cases, however, we notice that participants, as the process unfolds, also make internal changes (radical adaptation or double-loop learning, see chapter 7). The tension between the capacities of each participating individual and their goals/expectations within a given environment creates a form of co-evolution (Dorst & Cross, 2001), which means all participants are able to reflect and structure their plans systematically. Double-loop learning implies that information about the action itself and its consequences, about feelings and emotions, should inspire all action. Once you break through resistance about experience-driven actions, everyone stands to benefit and calls into question existing mental models, values and attitudes, In fact, the very exploration of boundaries causes a dynamic and autonomy in the process. Without going through the process in an experience-driven manner, a great deal of intangible knowledge and expertise is missed. The unexpected events which are not consciously elected, constantly challenge the boundaries and the goal. These transformation processes are of a self-organising nature, therefore, and ensure that co-design participants, by acting on a practical level, look at themselves, the environment and their actions totally differently. In any event, we hope that this framework triggers a fresh dialogue on the feasibility of participation processes and the role of creativity within disability studies.

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6. FIRST ORDER

MEASURING THROUGH EMBODIED HACKING-INTERACTIONS

“When you can’t change the direction of the wind – adjust your sails.”

(H. Jackson Brown Jr.)

In this chapter we describe how adapting (or external adaptation) and being adapted (internal adaptation) prototyping interactions influence general adaptation in participatory hacking behaviour. This is done through an in-depth time-series analysis of a hacking design process on DIY-AT. The main goal is to illustrate the self-regulating prototyping dynamics within one single case study.

ABSTRACT

Co-experience-driven design is a method for handling unknown relationships between social-technical design aspects through participatory prototyping within the development of new products. This investigative co-design process fosters the embodiment of new knowledge by means of perceptual outcomes coming from embodied prototyping interactions involving situated stakeholders. Both requirements and design solutions co-evolve around co-experiences derived from making tangible prototypes. This process takes into account that not only events will happen that were intended by the designers of the prototype, but also something different will emerge (express itself, organize itself) in the chosen context. Because all stakeholders experience prototypes in their own way and in their own contexts, and interact spontaneously with the designs using all their knowledge (even if this is tacit), designers should be sensitive to different kinds of perceptual measurements. Stakeholders can contribute in an intuitive way to a design process only by using appropriate prototypes in local environments, and therefore not in a restricted laboratory environment. Seventy years ago, after decades of discussions, Stevens (1946) heuristically distinguished four levels of measurement, going from categorization to observations with full mathematical properties. By means of a case study, we explore how and which levels of measurement can be grounded operationally within participatory prototyping processes.

6.1 INTRODUCTION

The most important competence of industrial designers is to create new artefacts which meet the needs of all the stakeholders that are involved (users and makers) within a given product ecosystem. For this reason, “designing” is in essence an investigative activity which encompasses the integration of stakeholder experiences and knowledge into design practices (Rust, 2009; Boess et al., 2008). This approach resulted in a large number of theories and research methods which have been developed to provide industrial designers with guidance on how to involve stakeholders in the different phases of product development. Throughout design history, the scope has broadened from usability engineering (Dumas & Redish, 1999; Norman & Draper, 1989; Nielsen, 1992) to experience-driven design (Hassenzahl, 2010; Schifferstein & Hekkert, 2008; Desmet & Hekkert, 2009; Forlizzi & Batterbee, 2004). The spectrum of these human centred design methods has been mapped by Sanders and Stappers (2008).

As a result, they clearly illustrate the shift within research methods (from more traditionally scientific to designerly) and the roles of users (from objects of study to active co-designers).

Both these trends are still continuing and within the community of participatory design, the role of making together is gaining more and more attention (Sanders & Stappers, 2014; Wood, Rust & Horne 2009; Servalli, 2013). There are two main arguments for this. First of all, what people experience is often determined by tacit knowledge and is difficult to express in words (Schön, 2005; Rust, 2004; Sleeswijk et al., 2005). Coping with these underlying phenomena requires a set of new methods different from the ones applied in reductionist science. Tacit knowledge is knowledge that people can act upon, but cannot readily express in words (Polanyi, 1958). Or, in other words, the acknowledgment that *"we know more than we can tell"* (Polanyi 1967, p.4). On the contrary, conventional user-study techniques, such as interviews, observations and focus groups (Preece, Sharp en Yvonne 2011), uncover only explicit and third-person observable knowledge about contexts. As a reaction, Sanders introduced generative techniques (Sanders, 2000) to fill this gap in order to gain knowledge about what people know, feel and dream (for an extensive overview see Sanders, Brandt & Binder 2010). Participatory prototyping uses open-ended prototypes to explore, evaluate and communicate in co-design activities. The goal is to simultaneously trigger as much senses as possible to gain rich insights while sharing experiences. Within this chapter we discuss in particular the collaborative making and using of three-dimensional models.

Secondly, technological advances lower the mental and physical effort of designers to interact with non-designers while making semi-professional products on a low-volume and local scale. Today, the maker movement is expanding the participatory prototyping vision with open hardware through a network of fabrication laboratories (Gershenfeld, 2008). In essence, inexpensive and powerful prototyping tools have become available for everyone in shared machine workshops and can be used for model making (Seravalli, 2011). Due to the rise of the internet and the combination with open manufacturing processes, people are capable of making adaptive models on demand (Anderson, 2008) and blur the boundaries between make time and use time. Based on respect for each other's skills and expertise new opportunities and solutions can be experienced on location.

The use of making and evaluating experiential prototypes is considered as one of the cornerstones of a designerly approach to interact with stakeholders. Although participatory prototyping presumes that designers have full understanding of what they are able to make (e.g. a product, service or environment), it is still hard to demystify the inquiry process that translates a variety of needs into detailed design aspects.

This thesis describes an experience-driven approach to practice-led inquiry that puts participatory prototyping with stakeholders at the centre of the research process. The participatory prototyping process is used as a research instrument, but also as an important resource for building new design strategies around relevant design aspects. A case study will illustrate “which” type of measurement processes emerge within participatory prototyping activities through a process of self-directed learning.

6.2 PARTICIPATORY PROTOTYPING AS SELF-DIRECTED LEARNING

Designing qualitative interactions within a given product ecosystem offers challenges for both industry and designers. Meaningful experiences are a result of interactions between the properties of (a) human agent(s) (e.g. personality, skills, background, cultural values and motives), the product itself (e.g. shape, texture, function, and production process), other people and the context (e.g. physical, social, economic) in which the interaction takes place (Desmet & Hekkert, 2007; Forlizzi, 2007). Furthermore, we involve different types of actions and processes such as physical action and perceptual and cognitive processes combining both rationality and intuition (e.g. perceiving, exploring, using, remembering, comparing and understanding) (Dewey, 1980; Cross, 2006). In this thesis, we use the theory of embodied interactions as perspective to frame the abovementioned concepts. Dourish (2001) draws from phenomenology and ethnomethodology to highlight how human beings engage with the social and material world (the emergent context) in order to make sense of their actions. Embodiment is the nature of how a person always acts in the world in-concert-with other people and things, engaging with them as resources in order to achieve some purpose in response to particular circumstances of our situation. Dourish puts the focus on the ongoing actions of creation, manipulation and sharing of meaning that people perform. Embodied interaction is a focus on the action as it unfolds rather than any preconceived mental representation of the action. As Dourish notes, “*The embodied interaction perspective begins to illuminate not just how we act on technology, but how we act through it*” (Dourish, 2001, p.154).

The complex interdependencies and rapidly changing nature of these embodied interactions give an inquiry process through the experiential development of physical models a wicked or ill-defined nature (Rittel & Webber, 1973; Buchanan, 1992). One cannot define “the” ideal design process before the design solution actually has been created. Framing designing for qualitative interactions as problem-solving is a popular misconception. Research on problem-solving traditionally examines tame problems which follow waterfall procedures assuming one can solve the problem by an already known solution. Actual day-to-day product development which involves participatory prototyping is messy and chaotic. Professional designers have always been aware of the importance of rigor and chaos in the first stages of design practices, especially in complex and new projects (Buys, 2008). The designer tries to control any variable he consciously chooses through a variety of prototyping interactions. The act of prototyping consists of making a selection of variables and taking a given arbitrary value at a given arbitrary moment in time. To explain the trail-and-error dynamics within prototyping activities, we can use the example of a complex task by Ashby in 'Design for a Brain' (Ashby 1952, p151).

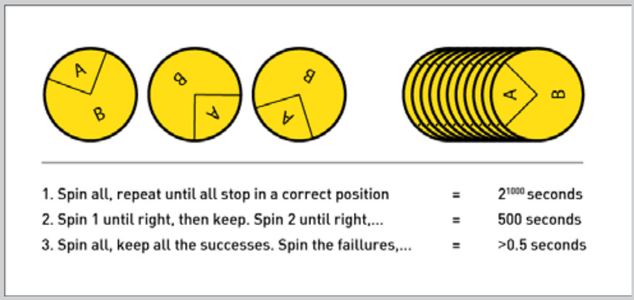
In addition, problems and solutions constantly co-evolve (Dorst & Cross 2001, Witschnig en Christensen, 2013), constraints are often negotiable (Schön, 2005), sub-problems are interconnected (Goel & Pirolli, 1992), and solutions are not right or wrong, only better or worse (Buchanan, 1992). In experience-driven design, the creative process directs the resulting user-experience (Desmet & Stappers, 2011). Within participatory prototyping activities, stakeholders in turn direct this creative process. For this reason design epistemology is in essence constructivist (Koskinen et al., 2011). Knowledge cannot be passively absorbed from the environment, it must be dynamically co-constructed through dialogue with the engaging design agents in their environments (Gedenryd, 1998).

As illustrated in the above section, the adaptive character within participatory prototyping activities is expressed by the fact that individual and collective design behaviour changes as a result of a personal experience (Juarrero, 2000). In this paper, the authors frame such a process as self-directed learning and propose similarities with the science of self-organization which deals with complex adaptive systems (Holland, 1992). Participatory prototyping (PP) teams can be considered as complex adaptive systems, consisting of different stakeholder agents who cooperate while interacting within a shared physical environment. These autonomous systems spontaneously arrange or adapt themselves within a changing environment to increase survivability or to attain a specific goal. Self-directed learning follows an algorithmic equilibrium (expected solution/problem pairs) – disequilibrium (unexpected solution/problem pairs)-pattern (Piaget, 1971), where one goes from one stable state to another, in which the disequilibrium is often the experienced chaos through which one reaches a new state of order. Disequilibria are the driving forces of changing design behaviour (e.g. an ill-defined need, unknown value, a changing consumer behaviour, a new disruptive implementation of a technology). Through a process of mutual adaptation, different stakeholders perceive embodied prototype interactions which construct meaning and fitness for all of them. In most cases, the groups are rather small, up to 2 to 5 people. This implies that the complexity does not result from the number of agents, but rather from the dynamic networks of interactions and relationships (Juarrero, 2000).

Notwithstanding these intricate phenomena successful PP teams manage to deal with the complexity and uncertainty by means of a kind of collaborative reflective practice. Out of the varying interactions with situated stakeholders some kind of design strategy emerges which leads to preferences that create more order and stability. As a general rule, a self-organizing system performs a selection. In a purely objective sense, it rejects some states, by leaving them, and retains some other state by sticking to it. This universal pattern is characterized by the asymmetrical relationship between entropy and information. Entropy is a measure of our uncertainty and variety of possibilities, or our lack of knowledge on the state of a system: the less we know, the larger the entropy. Information neutralizes the lack of knowledge or the uncertainty. Information can thus be defined as a decrease in entropy, or a measurement of constraints and order. The start of PP processes always enables chaos which leads to

THE TASK OF WANTING A SET OF 1,000 SPINNING WHEELS

"Lets' review the complex task of wanting a set of 1,000 spinning wheels to all be stopped in the same position, with the letter 'A' facing up. As in the chart below, there are 3 cases to consider:



There are 3 cases to consider:

- *Case 1 construes the task as completely parallel in nature, starting by spinning all the wheels at once. Should all the wheels end up in the correct position—whose likelihood is 2 to the power of the number of wheels, or nothing short of astronomical—then the task is accomplished. Waiting for this probability to pay off is clearly futile.*
- *Case 2 takes the opposite tack, executing the task completely serially, one wheel at a time until the spin is correct. Each sub-system is taken independently of each other, and each is worked on until correct. The time taken is tractable.*
- *Case 3 is a mixed approach, where every subsystem is started and failures are re-started until all are correct. Clearly this takes more than 1 spin, but less that Case 2 because many subsystems are working in parallel.*

What are the lessons from this simple exemplar of complex tasks? Changing everything at once and hoping that it will all fall into place is futile, as seen in the vast average time taken in Case 1. Every designer can acknowledge that no single design problem involving human agents can be solved in one iteration. Often the problems are, on a interactional level, difficult to define. Many possible explanations may exist. Individuals perceive the issue differently. Depending on which explanation one chooses, the solution takes on a different form. There is always room for more improvement and potential consequences may continue indefinitely. On the contrary a complex task can only be accomplished if broken down into independent subsystems. The examples thus show the reduction in time taken that occurs when the final success can be reached by stages, in which partial successes can be conserved and accumulated. " (Geoghegan & Pangaro, 2009, p6) the already discussed equilibrium - disequilibrium, a pattern exploring a variety of problem-solution pairs. At the end, the PP process gets tame and the outcome of "a" possible solution becomes more predictable.

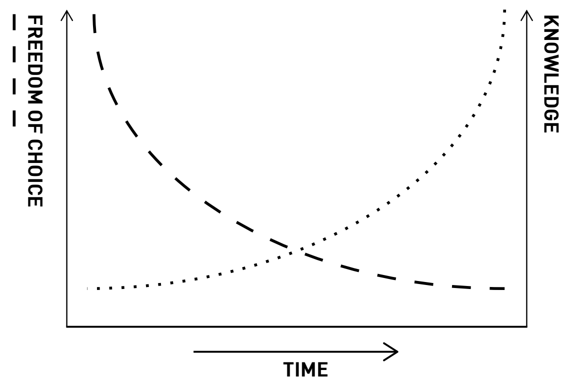


Figure 1. The design paradox adapted according to Ullman (2010)

These dynamics create a design paradox: "The more you learn, the less freedom you have to use what you know. (Ullman, 2010, p.20) Co-design inquiry starts with situations that are ill-defined – that are confusing, uncertain or conflicted. To make progress within a given design practice, we have to make decisions, and therefore restrict the space of all possibilities to take action. Thus, the goal of the design process is to learn as much about the evolving product experience as early as possible in the design process because during the early design phases changes are least expensive. In practice, the PP team uses its ability (1) to distinguish satisfactory from non-satisfactory situations (value or goal distinctions); (2) the ability to prioritize new actions and distinguish relevant properties (means distinctions); (3) to reframe the knowledge about how the different states, defined by the objects, properties and stakeholders are causally connected. All three activities flow in a parallel manner and are mediated through the embodied interactions with prototypes.

6.3 PROTOTYPING INTERACTIONS AS CONVERSATION LANGUAGE

Our approach has followed the example outlined by Ehn en Kyng (1991) who pioneered the use of prototypes as tools to engage with stakeholders. Doing justice to the subtleties and complexities of experience requires a mode of communication that does carry the rich, multi-faceted and highly interwoven structure of stakeholders' environments (Van Rijn et al., 2011; Kurvinen, Koskinen & Batterbee 2008). A participatory prototyping process stimulates the development of experiential prototypes throughout the entire design process, also at the early start. This enables stakeholders to create a meaning in and on prototyping interactions and rebuild frames of reference (Hummels & Frens 2011). PP teams have to make physical models to observe the self-organizing behaviour of stakeholders in their context by triggering all their senses simultaneously. In this paper, we define an experiential prototype as any shared physical manifestation which externalizes an otherwise internal or unavailable vision of a future product aspect (Blomkvist, 2014). An experiential prototype is a representation of the design-in-progress and is equipped with some properties which can be adapted to the specific inquiring process. The prototypes are made very specifically to evoke spontaneous behaviour in a chosen situated context instead of a controlled laboratory setting. The interaction with participatory prototyping activities only makes sense in a very active context, constantly evolving, including different stakeholders, changing meanings, etc... to create order from noise. The PP team "carries forward" its representations using embodied prototyping interactions until the behaviour that is afforded by the prototype is felt appropriate enough by all stakeholders involved. In this way they aim to capture a wide range of relevant knowledge, both explicit and tacit (see chapter 4).

Embodied prototyping interactions in their context are important available "measuring instruments", regardless of the level of the measurement, "qualitative" or "quantitative", to capture both explicit and tacit design aspects. By this interaction only, all stakeholders learn through reflection- on- and -in-action what is and should be designed (Argyris & Schön 1978). Design strategies co-evolve between all participating agents through a double-loop process (Dubberly, Pangaro & Haque 2009) of mutual transactions on shared experiences (Dewey & Bentley 1960) coming from consequences build around embodied prototyping interactions. Out of the constant stream of stimuli joint experiences allow participants to focus their attention on several relevant design aspects which could play a significant role for particular stakeholders. These co-experiences (for an elaboration, see Batterbee, 2004) feed the abovementioned process of self-directed learning by maintaining and modifying meaning in social interaction. Battarbee (2008) makes the distinction between three types of co-experience migrations: lifting up, reciprocating and rejecting experiences. These social mechanisms are the spontaneous feedback loops which actually steer the PP team in creating a common language on prototype experiences. Co-experiences simultaneously steer the co-design behaviour in a self-organizing manner based on respect for each other's skills, values and goals (for an elaboration, see chapter 8).

6.4 LEVEL OF MEASUREMENTS WITHIN PARTICIPATORY PROTOTYPING ACTIVITIES

Designers take a particular place in the scientific endeavour to gather knowledge or to make explicit what is called implicit knowledge or tacit knowing (Collins, 2001) (referring also to Wittgenstein (1953/2010) and Polanyi (1958)). From the early start, the PP design teams have to judge on the relevance of observations or measurements, they are forced to take decisions and they find little appropriate help in the procedures followed by existing reductionist disciplines. Designers indeed have to judge on all kinds of aspects (physical, technical, economic, environmental, psychological, sociological, rhetorical, cultural …). So, they have to master critically the accepted measurements in all those disciplines.

In this publication, we argue that there is no need to make a distinction between "*experiencing something*" and "*measuring*", both are instances of a more primitive concept: "*to act on something*" or "*being involved in an interaction with the environment*". We use this as a unifying concept for all disciplines. Our abstractions of certain phenomena cannot get any value without feedback with real-life experience (Gendlin, 1997). Even though there is no need to make a distinction between "*experiencing something*" and "*measuring*", there is a clear operational need to define different levels of experiential measurements if one wants to repeat measurements on product experiences and predict results with a specific probability. These different levels of measurement first were distinguished within the field of experimental psychology by S.S. Stevens in 1946 (see figure 2) after decades of discussions with scientists of different disciplines (Stevens, 1946). Recently, the scales of measurement were also discussed within the design community (Lawson, 2006). The different levels of measurement (nominal, ordinal, interval and ratio) are adapted within the context of PP by means of a fictional example grounded in the practical experiences of the authors as professional designers.

Scale	Figure	Basic Empirical Operation
NOMINAL	a=b a≠b	Determiniation of equality
ORDINAL	a<b b>a	Determination of greater or less
INTERVAL	a b	Determenition of equality of intervals or differences
RATIO	0 a b	Determination of equality of ratios

Figure 2. The levels of measurement (adapted according to Stevens, 1946)

The Nominal Scale

Every observation is made by an agent interacting with reality. Interacting with reality always changes something, be it "internally" for the agent or "externally" for the agent (usually both internally and externally). An example of an internal change is the increase of knowledge that the agent acquires during the interaction (the level of tacit knowledge too increases when using skills and competences while acting). An example of an external change is that the context after the observation should be described differently compared to before the observation, even when the observing agent did not change his amount of knowledge, or his internal representation during the interaction. Without change, there would not be an interaction and representations should follow the change (Heylighen 1995). Our basic assumption (see chapter 4) is that: "*acting within the real world always implies that also something different will happen from what was chosen to act on*."

The first level of measurement is to draw a clear distinction between "something" (focused on the predefined observation) and "something else". In fact, in order to perform the action of experiencing we have to let happen also something within the real world, and this something is different from the focus chosen, otherwise we only imagined the action.This can be demonstrated easily by throwing a dice. Throwing a dice in reality shows an amount of pips that was impossible to know a priori. But before throwing, one has to make a predefined decision to judge the number of pips showing and not the number of bounces the dice makes or the number of times the dice falls on the table top. Apparently, when we do something real, something else is emerging that we could not choose, whereas, in our imagination, events can happen only when we deliberately choose for it. We can imagine anything, but it is only the interaction with reality (meaning that something different than what we imagined could also happen) that leads us to what we call "acting".

The first level of measurement is making this distinction. A distinction is thus defined operationally. If two agents co-experience the same distinction, they will say "yes" simultaneously during the action, whatever representation they would use internally and this is what we call an operational definition. It is always possible to give a name to (or to assign a symbol to) what is called "something". This means that also a different symbol should be given to "something else" which is the side effect of the interaction.

FICTIONAL DESIGN EXAMPLE:

We dive in a participatory prototyping process which aims to design a new type of pencil grip for elderly people who suffer from arthritis. Pencil grips are a type of assistive technology made for individuals who face some sort of restriction on the handgrip and adversities in motor coordination, making it difficult or impossible to hold objects with reduced dimensions. The initial focus of the design strategy is to thicken the pencils with different diameters. One of the prototypes consists of a pencil which is covered with a PE insulation tube. During the prototype interaction with an elderly stakeholder the prototype receives a lot of attention. The stakeholder suddenly experiences no pain when grapping the prototype with his hand to write some sentences. The anticipated prototyping action was successful, but beside this fact, the stakeholder also mentioned "something else", namely the nice tactile touch of the material. This positive unexpected event has also been co-experienced by other stakeholders; so, the design team adapts its design strategy and decides to further explore the underlying properties of the phenomenon.

The Ordinal Scale

The first level of measurement thus is to draw a clear distinction between "*something*" (focused on at the observation) and "*something different*". However, we have seen that more than one focus, more than one "*something*" is possible. For example, if one observes experiences on a type of white colour, one simultaneously observes surface and colour, in a context where white makes a colour difference The result of the possibility of more than one categorization is that the following operation can be introduced: one can increase the number of focuses which we vary and one can decrease the number of focuses within one categorization.

Increasing the number of focuses means that new distinctions are created within the symbolic categorization. This also implies that they also bring in more chaos into the process as more "different things" than imagined can happen. Decreasing the number of focuses means that there is no need to make an extra distinction. Not all distinctions need to be relevant for the situation at hand, most situations perfectly can be described and handled with a limited number of distinctions. Leaving out unimportant aspects is for the most part what designers intuitively do when they apply low-fidelity prototyping. Ordinal prototyping implies making variants which help one to determine in which direction a parameter can be optimized.

FICTIONAL DESIGN EXAMPLE:

The participatory design team visits a DIY shop and buys several types of new PE tubes. They try to gather a range of tubes with different densities. The density is not explicitly mentioned on the packaging, but together with the stakeholders the group orders the PE from low to high-based on embodied prototyping interactions.

The Interval Scale

Interval measures compare entities and determine that they differ according to a specific property, in the differences an order can be noted within a continuum where a standard entity is defined. The interval scale is characterized by the property that not only a transformation of the scale has to keep the number of distinctions invariable, that the order between the distinctions is kept invariable, but also that the difference between the distinctions is invariable, allowing that this difference can be used as unity of counting.

FICTIONAL DESIGN EXAMPLE:

During the design of the new pencil, the following event illustrates an interval measurement. Every human being who interacts with a new tool adapts his behaviour and changes his expectations, even during interaction. The design team wanted to investigate which parameter combinations of diam-

eter and density have the highest impact on drawing and colouring. As a reference point, we use the time to perform the predefined activities with a normal pencil. Doing so, the participatory design team makes several prototypes (e.g. density-diameter1, density-diameter2 and density-diameter3) and measures the time spans with a unit of 1 minute. As a result, we gain knowledge on how much quicker or slower each stakeholders is performing the different tasks according to his own reference activity. These differences (e.g. density-diameter 1 gains 5 minutes, density-diameter 2 gains 6 minutes and density-diameter 3 gains 5 minutes), can give an indication of the impact of the variation and the chosen product properties or distinctions.

The Ratio Scale

The distinguishing feature of a ratio scale is the availability of a non-arbitrary zero value. Performing ratio measurements with prototype interactions is only possible when we observe the interaction in a controlled and reductionist manner. This is useful when a specific level of quality is agreed upon to convince stakeholders to interact with the product within a given context. Generally speaking, assumptions tend to be less restrictive and data analyses tend to be less sensitive at lower levels of measurement. At each level up the hierarchy, the current level includes all of the qualities of the one below and adds something new.

FICTIONAL DESIGN EXAMPLE:

A common misconception is to conclude that density-diameter2 is performing 20% better than density-diameter1. This is a ratio interpretation of an interval measurement. All of the stakeholders had different reference points and were not trained in performing repetitive behaviour. In some situations this one-minute of time gain can be completely irrelevant as we always have to know what the context is in which the task is performed.

6.5 CASE STUDY

In the sections above, we drew similarities between participatory prototyping and self-directed learning. As described in the theory, self-directed learning follows an algorithmic equilibrium (expected solution/problem pairs) – disequilibrium (unexpected solution/problem pairs)-pattern. In this case study analyses we want to describe the adaptive behaviour by means of a time series analysis (see chapter 2) and explore which type of experiences (or other measurements scales) change the design behaviour within a single case study.

5.1 Context

To validate the level of measurements within the context of participatory prototyping we use a natu-

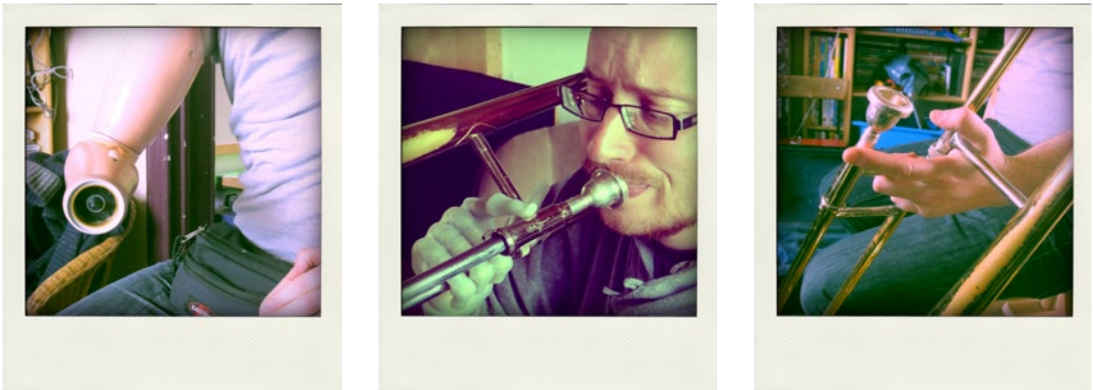


Figure 3. Simeon trying to play his trombone with his prosthetic hand (Maertens & Malfait, 2013)

ralistic case study within a design practice setting. The participatory design case has been set up and took place in a real-life context built around a meaningful activity of an individual disabled person. We deliberately choose the context of disability for its highly idiosyncratic and complex character. Experiencing a degree of disability embraces a temporarily negative state of interaction between the features of a person's body, the activities he or she wants to achieve and characteristics of the society to which the disabled person participates (WHO, 2001).In addition to the interwoven interdependencies a lot of knowledge of disabled stakeholders has a tacit nature. For example, in this case study, the main objective for the participatory design team was to co-experience how it feels to play the trombone with one arm.

Simeon, our main stakeholder, lost his arm in an accident three years ago. He now wears a state-of-the-art prosthesis. Even though this offers him a great deal of scope, he still faces some limitations. Simeon's passion, playing the trombone, has become virtually impossible. It is quite difficult to grab hold of the trombone with his prosthetic hand (see figure 3). In addition, the entire weight of the trombone rests on his prosthetic arm, which strains his shoulder. Finally, owing to the elbow angle of the prosthesis that can only be adjusted to a limited extent, he cannot adopt a normal posture, making it painful for him to play for longer than a few minutes. The goal was to design an assistive device which makes Simeon capable of playing the trombone again in a qualitative manner, coupled to the requirement that he wants to handle the device independently.

Method

The disabled client reacted on an open call from the *design for (every)one* living lab (chapter 2). The aim of this programme is to make open-design assistive devices in collaboration with industrial design students. The context of the predefined assistive devices is always determined by the disabled client and is an important rule to validate the intrinsic motivation of the client. The entire participatory design team consisted of the disabled client who volunteered, a caregiver from the local rehabilitation context, an occupational therapy student and two master students in industrial design.

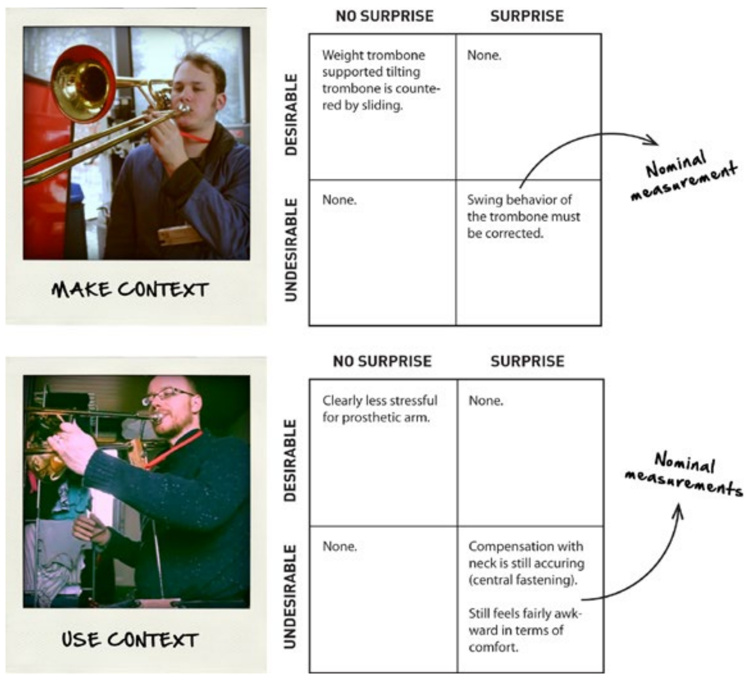


Figure 4. Two different prototype interactions with the same prototype: make context and use context. Each of them revealing different types of relevant aspects (Maertens & Malfait, 2013)

The design process took approximately 12 weeks, during which the group alternates between several design activities within various locations. From day one, the students are only allowed to communicate with stakeholders through perceivable prototypes and report their findings logged in time on a self-reporting shared blog (Maertens & Malfait 2013). The participants were asked to give every prototyping interaction a unique number and log it in the order of materialization or evaluation. Adapting the prototype's specific properties is often the most trivial observable change. Putting a previous prototype in a new physical environment, adding new stakeholders in the same environment or changing the activity in which the prototype is used. All these changes count as new prototyping interactions (see figure 4). Design agents explicitly documented integrations of two or more prototypes.

The procedure of reporting experiences is semi-structured. According to Argyris and Schön (1978) adaptive learning behaviour principally builds on the patterns of reflection-in-action and the remarkable ability of humans to recognize change in the consequences of their actions. Practically, this nominal way of measuring is done by comparing the outcome of actions with the former initial plans. To measure consequences in relation to intention (Schön, 2005; Suwa, Gero & Purcell, 2000), we focus on the act of surprise and apply the Schön matrices (see chapter 8) as experience sampling tool (See figure 5.).

A surprise reaction has its origin in encountering an unexpected event. Surprise is right there on the fuzzy border between two related cognitive phenomena, viz. emotion and attention (Ludden, Hekkert & Schifferstein, 2006). This basic emotion elicits new reality constructions for all participating stakeholders and helps them to focus on new possibly significant variables. The PP team documented this principle through a simple 4-channel matrix (see Figure 5) that distinguishes four frames by the possible combinations of the following distinctions: surprise/no surprise and desirable/undesirable (for an elaboration see Schön(2005)). This was done for each embodied prototype interaction which was co-experienced by all the participating agents.

Analysis

Our main objective is to illustrate how these new unexpected events or reactions, coming from embodied prototyping interactions, steer the design process in a self-organizing manner. Table 1 shows a snapshot of how the raw data were categorized and analysed. Initially, all user quotes were extracted from the matrices. The design strategies were interpreted by describing the specific prototyping means. Subsequently, the concrete information given in these quotes was interpreted and abstracted to general co-constructed goals. Finally, the relationships and sequential of the prototype interactions were adopted according to the numbering on the self-reported blog. Prototype interactions which sequentially build on each other to refine or exploit the same design strategy were noted as [a,b]. When two prototype interactions coming from different design strategies are integrated to form a new one, they are noted as [a] & [b].

Prototype Interaction	*Builds On*	*Design Strategy*	*Means*	*Expected Co-experience*	*Expected Co-experience*
1	[*]	“Dividing weight of the trombone”	Connecting the trombone with the shoulder by means of a strap	*None*	*[-] The strap out of synthetic fabric does not absorb the torque. Not much effect.*
2	[*]	“Biggest problem consists of the fact that the instrument is not brought close enough to be fully retained against the mouth.”	This is a handle with fabric attached to the cup of the trombone. The fabric strap we replaced by an elastic rubber band.	*[+] Supports trombone well.* *[-] Moderate handle*	*[-] The torque should be absorbed better* *[-] The handle does not slide backwards.*
3	[*]	“Reduce the weight and torque on prosthesis”	Fixing a holding block that can be put on the slide of the trombone, connected by clamping. (Test standing straight)	*[+] new way of attaching the handle*	*[+]Cube also as a handle can be used.* *[+]This feels like highly enjoyable , the elbow is not bended too much.*

4	[2]	"Biggest problem consists of the fact that the instrument is not brought close enough to be fully retained against the mouth."	Adding an additional curved handle on the existing handle which was attached to the cup of the trombone.	*[+] The torque is absorbed better.* *[-]strength strongly depends on the rubber binding*	*[-] Still requires quite some physical force from shoulder muscles*
5	[3]	"Reduce the weight and torque on prosthesis"	A wooden block that can be put firmly on the slide of the trombone. At the bottom is a hole where a telescopic pole can be attach to rest the trombone on a chair	*[+] Weight trombone is well supported during play* *[-]Bolts are not optimal for handling the grip*	*[+] Trombone stays in balance.*
6	[3]&[4]	"Reduce the weight and torque on prosthesis and allow a good pressure on the mouthpiece"	Omit the support from prototype 3 and replace it with the handle 4-prototype.	*[+] The arm can be bent further than expected.*	*[+] Handle does not shift around the bolt* *[-]Tension in the shoulder becomes bigger because of the torque.*
7	[6] &[5]	"Reduce the weight and torque on prosthesis and allow a good pressure on the mouthpiece. Balancing the trombone while playing"	Curved handle combined with rest stick	*none*	*[-]Tension in the shoulder increases when extending the handle.*
8	[1]&[4]	"Dividing the weight and torque on the prosthesis and allow a good pressure on the mouthpiece with the help of elastic material."	Using elastic braces and handle	*[-] No ideal absorption of the torque by the shoulder.*	*[-]Trombone gets skewed by elastic tension*
9	[2,4]	"Biggest problem consists of the fact that the instrument is not brought close enough to be fully retained against the mouth."	Various sizes of handles and materials.	*none*	*none*

Table 1:Example of rows showing the data analysis procedure extracted from the self-reported blog (Maertens & Malfait, 2013)

For the graphical analysis, we assume that all information which was documented explicitly on the blog was new and relevant information for at least one of the stakeholders. Each time unexpected consequences emerged regarding a prototype interaction they embody the start of new measurements on a nominal scale which effect a change in the design strategy. In order to illustrate the growth of knowledge, we constructed the increase of predictability curve. On a linear timescale the curve augments each time a design strategy enriches its focus. In practice, a design strategy changes each time a novel unexpected design aspect shifts the attention of the PP team and results in new prototyping interactions that have the purpose to investigate the specific design aspect.

Figure 5 is visualizing a change within a design strategy. At the start of the design process, the most important disturbance that was perceived by the PP team was expressed by the statement that Simeon could not hold the instrument sufficiently close to the mouthpiece. Therefore several explorations had been made to attach an extra grip on the instrument. The abovementioned consecutive prototype interactions embody a change within one design strategy. The prototyping actions 2 and 2' attach a

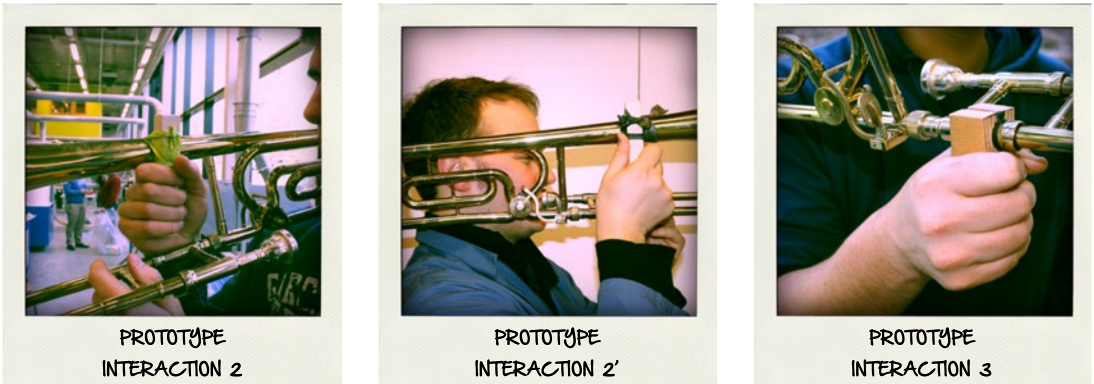


**Figure 5. Change in a design strategy 1 and 2
same action strategy, 3 changes focus and means. (Maertens & Malfait, 2013)**

grip around the cup. They were made subsequently using the same design strategy. We recognize 2 as a typical ordinal prototyping activity building further on 1. On the contrary, prototype interaction 3 clearly shows a change in the design strategy. The PP team picked up a product benchmark which made use of an ergonomic support attached between the body of the player and the trombone. They copied the mechanism in a wooden artefact and attached it on the sliding receiver. The strategy clearly shifts from "adapting the trombone to the posture of prosthetic hand" to "reducing the tension in the shoulder while playing".

Additionally, we constructed the "decrease of uncertainty"-curve on a linear timescale by lowering the curve with one unit when two of more prototypes are integrated or merged in a more advanced prototype (see figure 6). From the perspective of embodied cognition, prototype interactions are vehicles of knowledge. The integration of these literally reduces the freedom of choice as more and more aspects are identified and fixed. We categorized every prototyping interaction according to its spontaneous measurement behaviour with a nominal, ordinal, interval or ratio scale. As discussed in the above section, each unexpected consequence is framed as a nominal measurement

Results

The PP team designed a compact tool that fits easily in the instrument case (see figure 7). The trombone aid consists of three main components: the support component is slipped around the neck and connected to a thin rod by means of a clamp which is permanently attached to the trombone. There is also a shoulder strap that keeps the trombone in the correct position. In that way, it is possible to play the trombone with one arm. Since the prosthetic arm has become redundant, it is, at the same time, free from any form of strain. The aid gives Simeon again the opportunity to enjoy his trombone in a pain-free manner.

Figure 6. Integration of two prototypes 5 en 6 into a new one, 7. (Maertens & Malfait, 2013)

While realizing this assistive device the participatory design team encountered several prototyping interactions (n=44), exploring 14 design strategies. From this number of interactions emerged 36 nominal and 12 ordinal measurements. No interval and ratio measurements were detected or explicitly documented. The nominal measurements were spread equally over “make time” and “use time”. 75% of the ordinal measurements occurred within a use-time context and the positive desirable events were integrated within the final design.

6.6 DISCUSSION

At first sight, the graphical analysis of this case study draws large similarities with the principles of self-organizing systems (see figure 8). Out of the varying prototyping interactions, we clearly observe a self-organizing design pattern which reduces variety or uncertainty, and at the same time increases information or more constraints on socio-technical design aspects. Intertwining problem solution pairs constantly co-evolve within design strategies by means of making and using prototypes. Changes on causal relationships are triggered by unexpected events induced by co-experiences on embodied prototyping interactions. Co-evolution is often viewed as a biological process that is generally slow. But the powers of human exploration & exploitation, which are both inherently driven by spontaneous creativity, can also be seen as a kind of self-organizing design process. By capturing collaborative meaning-making related to co-experiences on prototyping transactions, the design rationale of the PP team becomes more explicit. Several tacit aspects (e.g. the embouchure of the trombone, the strain in the shoulder and non-stigmatizing look and feel of the product) became explicitly symbolized through co-experiences around prototyping interactions. The perfect feel of “blowing a trombone” is not absolute, but depends on contextual factors, as well as on a number of subjective factors. By reconstructing

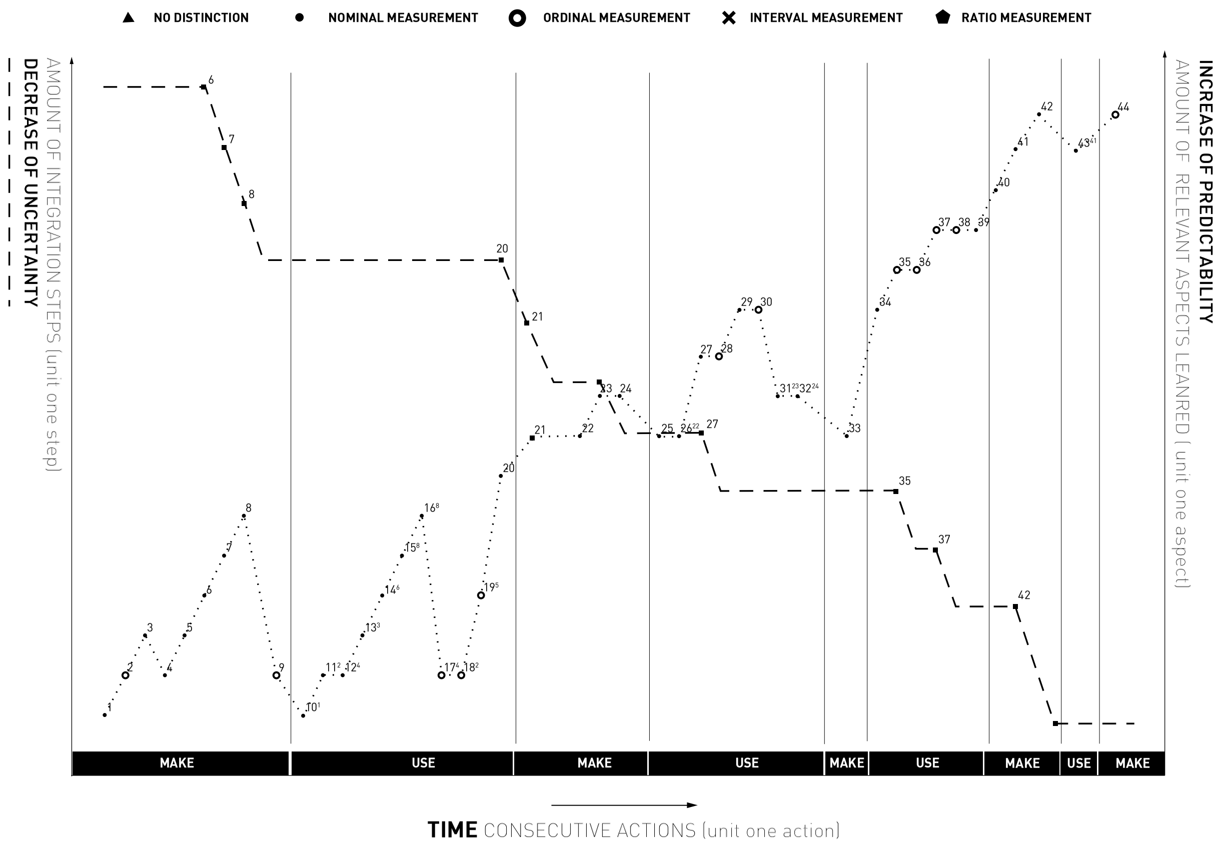


Figure 8. Reconstruction of level of choice and level of knowledge. Level of knowledge: on a linear timescale the curve augments each time a design strategy enriches its focus. In practice, a design strategy changes each time a novel unexpected design aspect shifts the attention of the PP team and results in new prototyping interactions which have the aim to investigate the specific design aspect (see figure 5). Level of choice: we constructed the "decrease of uncertainty"-curve on a linear timescale by lowering the curve with one unit when two of more prototypes are integrated or merged in a more advanced prototype (see figure 6).

Figure 7. Demonstration of the final product

the prototypes step by step the nuances become perceivable and perceptible.

The Knowledge Curve

During the entire process nominal measurements predominantly emerge out of the prototype interactions and prioritize the design strategies followed by the PP team. The relevance of each design strategy depends on the co-experienced consequences and the collaborative sense of achievement in relation to the predefined goal. A striking observation is that no interval or ratio measurements occurred during the entire process. In general, perceiving and making prototypes costs energy. Each stakeholder within the PP team has his own physical, mental and emotional limitations.

Therefore, it is important that the PP team spends its energy wisely to maintain the viability of the co-design process. Augmenting the level of measurement requires more effort and narrows the focus/time investment on a particular design aspect. It is in the PP teams nature to keep the amount of energy spent as low as possible, especially in the beginning of the process when the probability of finding a consistent design strategy is rather low (see 'the task of wanting a set of 1,000 spinning wheels', p.135). A second humble assumption on this phenomenon is that both higher levels of measurements were not needed here as the end deliverable was the production of one personalized product for one particular client. If we would scale up to a context of low-volume or mass production, the interval and ratio measurements could become more relevant. Interval and ratio measurements are needed if one wants to have a greater control of the "use context" (more potential users, more potential variety) or of the "make context" (high probability of reaching the goal when producing repetitively a product instead of one prototype). Nevertheless, within the co-design processes on DIY-AT, this is not the case. Interval measurements are very rare and ratio measurements only appear at the very end of the process if an instructable or building plan is made. Often, they only make use of classic metric systems which are not able to explain the rationale behind experience-driven choices.

Through a back casting procedure, we followed the line of prototyping interactions that were reported as relevant and related by the designers. Through a graph analysis (see figure 10) we described the relationship between expected and unexpected consequences and the subsequent design strategies derived from the prototyping actions coming from the self-report. On a global scale, we recognize two main feedback patterns between changing design strategies and the environment (see figure 9).

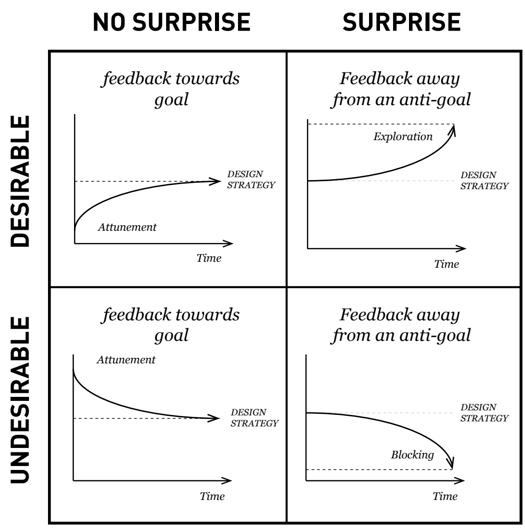


Figure.9 Feedback patterns mapped into the Schön matrix.

Design strategies which lead to consequences that are expected or intended create a feedback loop towards the predefined goal by reducing deviations from the already known action strategy. Only in these single-loop learning situations ordinal measurements appear or the curve stays horizontal. In the contrary action, strategies which lead to unexpected consequences create feedback away from, at that time, an anti-goal. They increase deviations from the actual plan or sense of urgency and stimulate double-loop learning which questions the belief system of the PP team. Such unexpected changes are typical moments of disequilibrium. However, their effect can be dual. Undesirable unexpected events disturb already chosen design strategies. Desirable unexpected events offer new opportunities. If combined with the right prototyping means and creativity, both situations lead to new design strategies and force the PP team to adapt itself to reality.

The Uncertainty Curve

As already sketched in the above section, designing is a process of taking decisions based on very little information. As a consequence, the PP team will always need to make educated guesses complement-

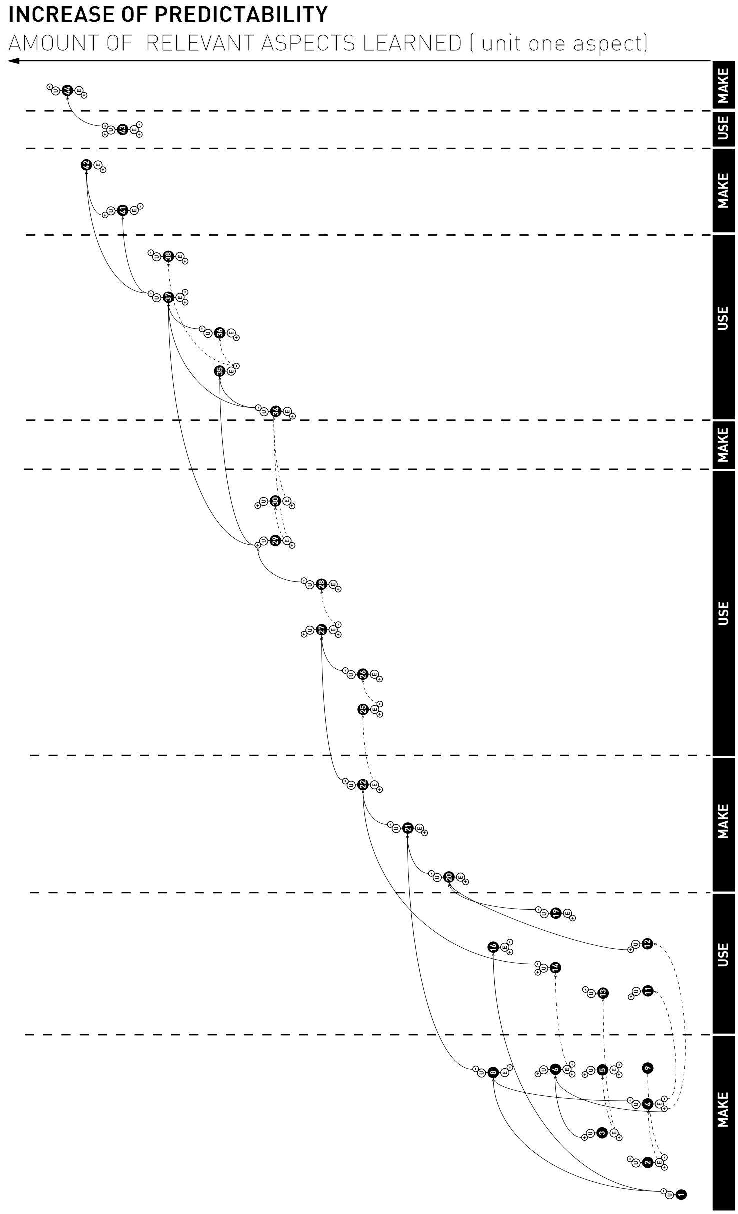


Figure 10. Reconstruction level of knowledge – a graph analysis that illustrated the relationship between expected and unexpected consequences and the subsequent design strategies derived from the prototyping actions

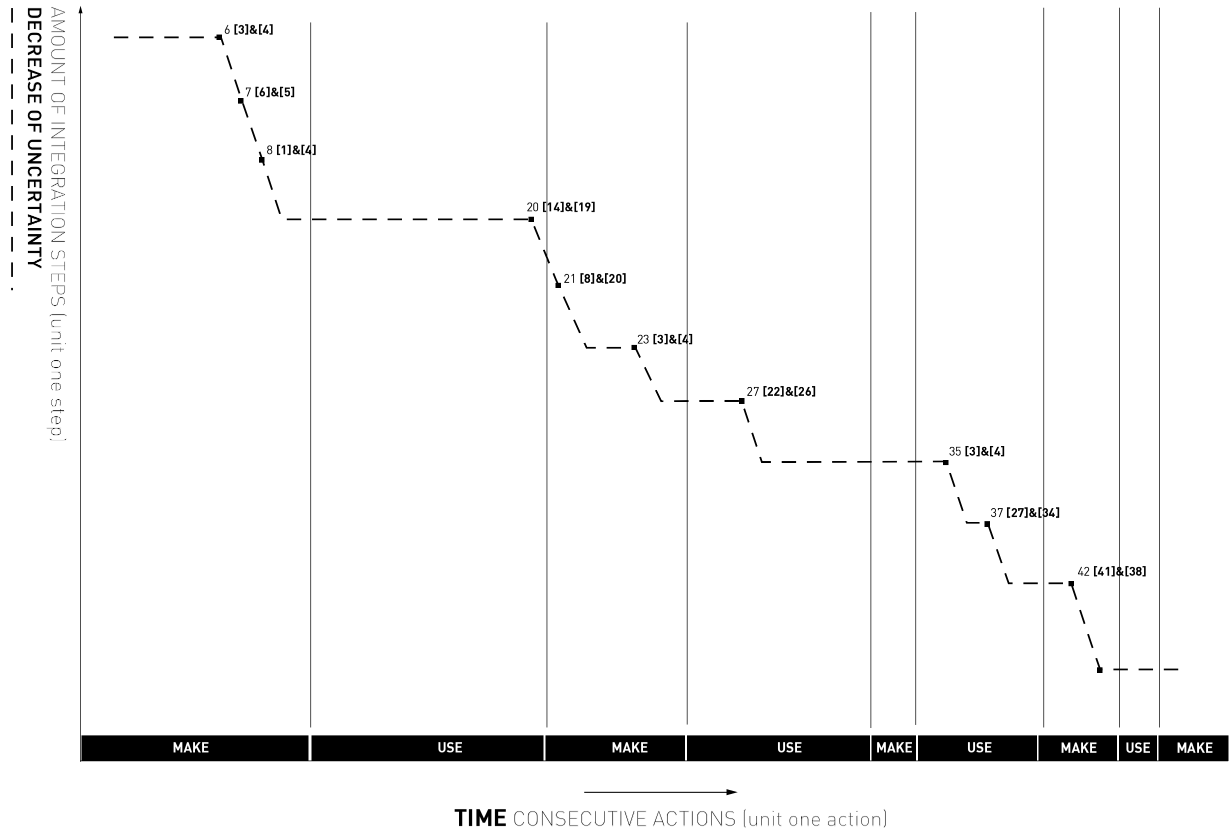


Figure 11. Reconstruction level of integration - we constructed the "decrease of uncertainty"-curve on a linear timescale by lowering the curve with one unit when two of more prototypes are integrated.

ing decisions based on founded criteria and the espoused theory of the whole team. Deciding or reducing the uncertainty means fixing certain design aspects to validate the probability of certain events. In practice, this is effected by integrating prototypes with the intention to retain certain functions and co-experiences. By analysing these events within this design practice we could make the distinction between three different types of prototype integrations related to the observed prototyping behaviour within the case study. This was done by analysing the goals of the prototyping action that involved the integration of artefacts (see figure 11). All of them are closely interwoven and influence the uncertainty curve as they accumulate the constraints of the co-designed product.

Prototype	*Integration*	*Goal extract from the self-report*	*Abstracted action*	*Type*
6	[3]&[4]	*If we omit the support from prototype 3 and replace it by the handle of prototype 4, we get prototype 6. This prototype allows a less curved arm while playing. We note that this resulted in more torque on the shoulder.*	Combining 2 different previous subsystems	interrelation
7	[6]&[5]	*Prototype 7 combines the system of prototype 6 with the tripod prototype 5. As a result, there is support of the instrument and this balance can be maintained via the handle that is easy to grasp.*	Combining previous parts and make small variations	interrelation
8	[1]&[4]	*Support with braces built on prototype 1. Here, an attempt was made to minimalize the weight of the trombone on the support on the shoulder with an elastic band*	Combining an existing previous solution with a new material	exploration
20	[14]&[19]	*We want to achieve more stability and better posture. Moreover, the support here is not put on the chair but on the leg of Simeon.*	Combining small variation between previous parts	optimisation
22	[8]&[20]	*Here, the tilting behaviour of the trombone is restrained by a ribbon around the neck.*	Combining an existing previous solution with a new part.	exploration
23	[7]&[15]&[21]	*There is a handle attached at the side of the trombone in order to obtain an easier and corrective support that avoids rocking of the trombone.*	Combining 2 different previous subsystems	interrelation
27	[22]&[26]	*Here, the elastic band is mounted around the waist instead of the neck. The trombone is supported by the hand.*	Combining previous parts and make small variations	optimisation
35	[29]&[34]	*The inner belt is replaced by an elastic strap that passes behind the neck through the third cross tube of the trombone*	Combining an existing idea with a new material	exploration
37	[29]&[34]	*The inner belt is tied behind the neck like prototype 34, we look at this prototype especially towards the adaptability of the system.*	Combining small variation between previous parts	optimisation
42	[41]&[38]	*The elastic is attached with a knot at the second transverse tube at the rear of the trombone. Tightening the partially woven textile and partly elastic band. The height of the support is adapted by tightening the elastic around the neck. When the proper height is reached, the elastic is pulled upward in the slot and fixated. Let's play music!*	Combining previous parts and make small variations	optimisation

Table 2. Data analysis procedure for prototyping events that integrate.

(1) Integration for exploration: At the start of the design process the uncertainty curve decreases very strongly within the "make context". The design teams uses integration mainly as a means to create more variation in a short time span and to explore the different functionalities which are relevant to counter major unexpected disturbances. In practice, new elements are combined with previous prototypes. On a global scale, we also see recurring patterns within the knowledge curve, especially in the front stage of the process. These patterns occur because the design team has forced itself not to take any decision before encountering another context with their main stakeholder, the disabled client. By bringing all the prototypes in a parallel manner into a new context, they leave more room for spontaneous interactions. As a result, they let the sense of urgency of their action strategies organize itself and build a common ground on reoccurring phenomena. This is done to distinguish satisfactory from non-satisfactory functionalities and causally link the probability of the co-experience with the chosen design actions.

(2) Integration for optimization: When a main function has found a group consensus, a second type of integration takes places. This process steers the PP team in exploiting or optimizing more detailed features or, in other words, finding different ways to optimize and control the function with the resources/abilities at hand. Prototypes are integrated to optimize subsystems into performant and reliable entities. On the basis of the graphical analysis, we can clearly observe that ordinal measurements mainly manifest themselves as situational prototyping actions within this type of integration process. After co-experiencing an unexpected affordance through a nominal measurement, the team is often triggered by the same strategy and changes small details in situ directly with the stakeholder. Once the optimization of a design aspect results in a satisfying co-experience the adaptation gets integrated within the structure of the prototype and becomes habituated, drawing no more attention to the PP team.

(3) Integration for interrelation : The third type of integration is continuously exploring the relationship between, at that time, optimized subsystems to co-construct a stable product system. In some cases prior decisions are questioned again when the integration of a new subsystem creates conflicts by means of newly emerging nominal measurements. A new disequilibrium emerges and the team has to change its design strategy. This action is somehow inherently related to participatory prototyping as the activities constantly switch between different contexts: “make time” and “use time”. Although the focus of the PP team shift constantly all previous underlying decisions are embedded within the integrated artefacts and with each iteration they unconsciously are revalidated, constructing a stable product ecosystem. As a result, it unconsciously forces the PP team to acknowledge the entire product system during the entire design process.

6.7 CONCLUSION

The goal of this chapter was to explore how and which levels of measurement can be grounded operationally within participatory prototyping processes. The theory of co-experiences helps to demystify the spontaneous inquiry process within participatory prototyping activities. Designers are not, and never will be, experts in "the field", whatever field or individual life of a stakeholder is intended. However, designers need to deliver reliable work for current stakeholders. A challenging requirement is that some phenomena are so context-dependent that they only can be co-experienced in the particular dedicated context, which challenges the repeatability. Only if the interaction of the agent-in-its-context can be repeated can all experiences be categorized and the number of experiences in each category can be counted. The physical prototype is the changing mediator in the interaction, and leaves - if well-documented - a changing trace of interactions. Although this designerly approach is used unconsciously in many contexts, we need more research methods to facilitate PP teams to conduct their practice-led inquiry process in an intuitive manner. In the first place, we could invest more time in design research on capturing and filtering meaningful prototyping interactions within naturalistic environments. PP sessions have a spontaneous character (cycles of action on re-action) which makes it hard to reconstruct or even document meaningful events without losing the flow of the process. Furthermore, each level of integration asks for a different prototyping attitude. The implementation of a design strategy is co-experienced as successful if it leaves out unimportant design aspects and efficiently shares the collaborative means (making and perceiving) of all agents. Learning to adapt the prototyping effort and share physical, intellectual and intangible resources are both crucial competences to facilitate participatory prototyping activities. The basic rule is simple: make together and respect the unexpected.

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7. SECOND ORDER

CHANGING TOGETHER WHILE HACKING TOGETHER

“The only true voyage would be not to visit strange lands but to possess other eyes, to see the universe through the eyes of another, of a hundred others, to see the hundred universes that each of them sees, that each of them is…”

(Marcel Proust)

In this chapter we explore how adaptive (or internal adaptation) prototyping interactions influence general adaptation in participatory hacking behaviour. This is done through cross-case analyses on all case studies to show the variety of double-loop adaptations and their practical manifestations within product hacking activities. At first, we untangle the manifestations of essential variables and afterwards we discuss the self-regulation dynamics they can provoke within hacking activities.

7.1 DOUBLE-LOOP LEARNING

As discussed in the introduction of this thesis, hacking design straightens the relationships between all participating agents to a horizontal dialog. This shift implies that the designers are no longer placed above the users when determining what is right or wrong for them. Both are subjective participants in an intensive process in which they themselves are part of the solution. Involving a diversity of agents within hacking activities is an approach that drives on co-experiencing the progress of on-going development through new affordances and disturbances on prototyping interactions. Many scholars have considered the concept of organizational learning as a dichotomy. This dichotomy has been expressed in a variety of terms: *single-loop* and *double-loop* (e.g. Argyris & Schön, 1974), lower-level and higher-level (Fiol & Lyles, 1985), *first-order* and *second-order* (Ashby, Arthur & Aiman-Smith, 2001), *exploitation* and *exploration* (Levinthal & March, 1993; March, 1991), *incremental* and *radical* (Miner & Mezias, 1996), *adaptive* and *generative learning* (Senge, 1990). Although these dichotomous terms stem from different perspectives on organizational learning, a reasonable consensus seems to have been established that they refer to comparable learning processes and outcomes (Argyris, 1996; Arthur & Aiman-Smith, 2001; Miner & Mezias, 1996).

Ashby	Schön
essential variables	governing variables
feedforward	action strategy
feedback	consequences

Figure 1. Parallels between Ashby and Schön.

In the previous chapter, we mainly focused on adaptation from the perspective of *single-loop* adaptation. This form of adaptation, defined by Argyris, is characterized behaviour as controlled, maximize "winning" and minimize "losing" without rethinking the initial goal or the underlying values of the system. The professional designer takes action according to the theories he explicitly espouses (Argyis & Schön 1974). Theoretically, if they keep achieving the intended consequence through their hacking actions they stay within *single-loop* iterations and explore the problem solutions within the given design space (see figure 3). In practice, we saw that this is hardly the case. First of all, few people are consciously aware of the plans or theories they implicitly use (Argyris, 1980). Argyis and Schön (1974) have observed that people are often unaware that their *theories-in-use* are often not the same as their espoused theories, and that people are often even unaware of their *theories-in-use*. Especially craft practices involve skills with a significant element of tacit knowledge (Polanyi, 1967; Rust, 2004; Wood, Rust & Horne, 2009). Engaging agents who fluently master a specific skill cannot explain in detail the reason behind their actions.

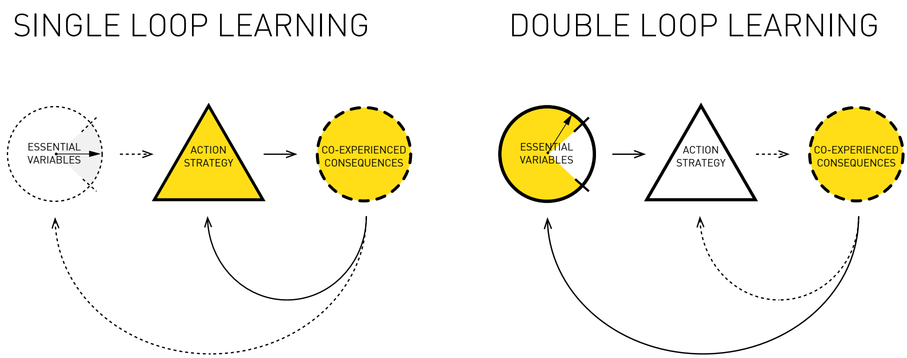


Figure 2. Single- loop vs double-loop learning

In the second place, while performing hacking activities agents also have to change their approach and objectives before they can take new corrective actions. This typical form of adaptation is called *double-loop* learning.

This raises the following question: if people are unaware of the theories that drive their hacking actions (theories-in-use) and constantly change their objectives, how can they effectively manage their behaviour? Argyris (1980) suggests that effectiveness results from a human drive to develop congruence between "*theory-in-use*" and "*espoused theory*". Or in other words, be highly sensitive to changes between both phenomena. In real life, hacking designers have to actively reorganize and reconstruct information to anticipate affordances (or disturbances) for users to engage in the prototype-interactions that are meaningful for them (Krippendorff, 2009). To fully understand the dynamics of *theory-in-use,* Argyris and Schön (1974) developed a learning cycle model which initially looked to three key elements:

1. *Governing variables*: those physical and cognitive dimensions that people are trying to keep within acceptable limits. Any action is likely to impact upon a number of such vari-

ables – thus any situation can trigger a trade-off among governing variables.

2. *Action strategies*: the moves and plans used by people to keep their governing values within the acceptable range.
3. *Consequences:* Feedback on what happens and is experienced as a result of an action. These affordances or disturbances can be both intended – the ones of which the actor believes they will be the result – and unintended. In addition, those consequences can be for oneself, and/or for others.

In this chapter we will dive into the nature and diversity of these events and explain the elements from a cybernetics design perspective within the context of hacking design.

Essential Variables

According to Chris Argyris, the notion of a theory of action can be seen as growing out of earlier research into the relationships between individuals and organizations (Argyris, 1957, 1962, 1964). Argyris (1985) provides the concept of a learning cycle to explain this maintenance in organizations and groups. He distinguishes those which grow, develop and adapt from those which reason defensively and reinforce their "normal" action tendencies. Argyris (1985) uses the terms *single-loop* and *double-loop* learning, attributing their use originally to Ashby (1952). Also within the contemporary cybernetics' community, the theory of Ashby (1952) on the ultrastable system has been used to describe '*organizational design*' and '*learning organizations*' (Geoghegan & Pangaro, 2009). In both models, the authors distinguish the role of governing (Argyris & Schön, 1974) or essential (Ashby, 1952) variables. To get a clearer view on the nature of change in hacking behaviour, we need to clarify this element.

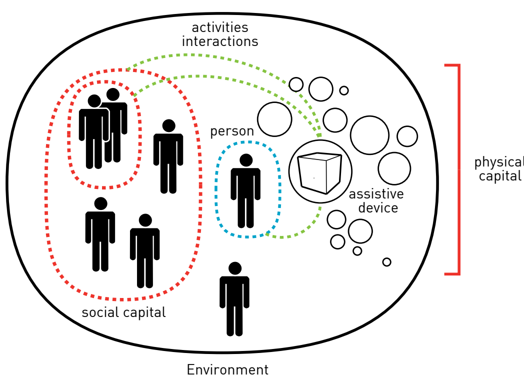


Figure 3. Product ecology derived from Forlizzi (2007)

When a hacking design team interacts with a contextual hack prototype, it conceives it as its contemporary view on the local product ecology (Forlizzi, 2007). This ecology includes (1) *the prototype*; (2) *the surrounding products* and other systems of products; (3) *the people* who use or make it, and their attitudes, disposition, roles and relationships; (4) *the physical structure,* norms and routines of the place where the product is used and made. The relationship of these aspects creates an infinite number of variables that change in time.

KEY INCIDENT: Stefanie's MP3 Player

Stefanie loves music and likes to have music on at the background. Although this does not seem to be easy in the institution where Stefanie spends the day. She is a girl who is diagnosed since birth with infantile encephalopathy, which has resulted in spastic quadriparesis. This means that her mobility is limited as she cannot move without a wheelchair. Since she lacks strength in her muscles, simple movements prove quite a challenge for her. She cannot operate a radio herself, and asking her carers would mean an added barrier for them and for her. To overcome this problem, a car radio and speakers hack have been mounted on Stefanie's wheelchair. Since then, she has enjoyed her self-selected tunes every day, something which her fellow-residents greatly appreciate or dislike too. The success of the radio on the wheelchair inspired us to design a similar system for all types of wheelchairs. The result is a speaker add-on that is mounted on the headrest. ***This hacking design integrates product adaptation which takes into account essential variables coming from the entire product ecology. (1) Adapted to the surrounding product. By using the same materials and colours, the design blends in nicely with the rest of the chair. It serves as a docking station for the mp3 player and also accommodates 2 speakers of 2 Watt each. (2) The norms and routines of the place where the product is used. The carer has instant access to the mp3 player when necessary, and can protect it from rain and bad weather. The on/off switch allows carers to ask Stefanie a quick question or explain something to her. (3) The people who will use it. Stefanie has her own on/off switch on the left-hand side of her chair, which allows her to switch off the music when something urgent comes up.***

According to Ashby (1958) a hacking system is then defined as any set of variables that the observers select from those infinite variables available on the real system. Important to note is that time is not included as a variable of a system. The state of a hacking system at a given moment is compiled by the observed variables at that moment and their perceived values. Through action strategies hack prototypes are realized which control a selection of variables and fix their values according to predefined intentions of the maker. Variations of hack prototypes explore several solutions within a field or state space (see figure 4). Ashby defines the word field as "*a typical way of behaving*", consisting of affordances (or disturbances) that are known or anticipated by the observer. When we translate this model into the setting of dynamic hacking activities, a field consists of the relationship between the proper embodied (physical and cognitive) usage of a certain technology, activity and skills by the engaging agents. In some cases, large initial changes in some variables are followed in the system by merely transient deviations while large initial changes in others are followed by large deviations (read evoke affordances or disturbances) that become ever greater until the hacking system changes to something very different from what it was originally. In the latter situation, a new meaning or use is appropriated to the technology, the activity and the skills. This type of adaptation, owing to the change of a variable, results in the co-construction of a new field or state space.

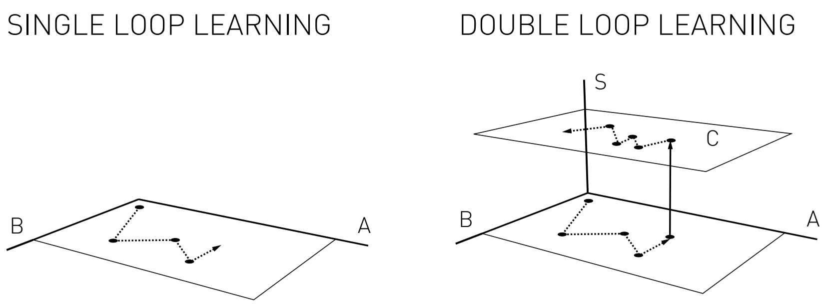


Figure 4. State space single-loop vs double-loop learning

Changing variables that evoke the change of new meaning or objectives are called essential variables, as used by Ashby. These type of variables 'are closely linked to survival and are closely linked dynamically such that marked changes in any one leads sooner or later to marked changes in the others.' (Ashby 1952, p.52).

Essential variables can be experienced through interactions between a variety of elements within the entire product ecology. For the human species, both physiological variables, such as body temperature, level of sugar in the blood, nervous and muscular system etc., and psychological ones, such as feeling of safety, of belongingness, of esteem etc., are all essential variables. The use cybernetics allows us to apply a diversity of variables on different levels of abstraction. According to Ashby (Ashby, 1952) the general rule is simple: *"if an essential variable exceeds its limits, the viability of the entire system is in danger and the system is forced in a compulsive manner to adapt its behaviour by changing its objective and approach*."

KEY INCIDENT: Clair's Reading Aid

Claire loves reading books, newspapers and magazines. However, it is a pleasure she enjoyed less and less over the years, because of the consequences of discopathy, making it difficult for her to bend forward, which is a reflex-action when reading. To make reading more comfortable, Claire came up with a few aids herself. By modifying existing objects, ranging from a folding chair to a drying rack, she developed about eight book holders. However, none of them fully matched her requirements and she still experienced muscular neck pain. She addressed the living lab to find an appropriate solution. ***The pain caused in her nervous system became an essential variable within the hacking activities and steered the co-design process.*** *Since she lives in a house with many levels, one of the criteria was that the tool should be easy to transport to the different locations where Claire likes to read. One day, she likes to relax on the couch in the dining room and the next day she prefers to curl up in the living room on the first floor. She also likes to read at the table or lie in a wicker recliner. This translated in a reading aid that is light and can be folded. Moreover, she likes to switch between a sitting and lying position. Thanks to this reading aid, Claire can enjoy reading again in the way she prefers. The tool is made up of different parts of existing products and is designed to be suited for different reading locations. It is also adjustable in height and thanks to the articulated arm, the text can be angled in the ideal position. Moreover, the built-in lamp provides extra light when needed.*

KEY INCIDENT: Catherine' s Walking Chair

Catherine is a dynamic business woman. As a consequence of multiple sclerosis, Catherine has difficulties standing for a long time, since it is too tiring. She then has to sit down and take the weight off her feet. However, at receptions, this is not always possible or Catherine does not want to sit down. When sitting down, she's no longer at face-to-face level? As a result, she experiences to be overlooked and forgotten about as she is no longer actively involved in conversation. This feeling triggered her to launch a call to the living lab. The solution is a mobile 'hidden' stool that is easy to take to receptions and to other places, such as the supermarket. ***Catherine also stressed that the product adaptation should by no means look like a med-***

ical device as she wants to avoid a stigmatic experience. This psychological variable turned out to be quite essential. *The team checked what was available and what could be adapted to include a seating function. The ideal existing product to start from turned out to be a business trolley. It is a functional object which, in terms of seating height, could prove to be the ideal starting material. The seating object is a separate element that can easily be mounted on the trolley with one click. If the seat is not required, it can be stored in the trolley or left on top, whichever is the most convenient for Catherine. When the user attends a business reception, he/she can easily pack his/her laptop and files in the trolley.*

In social organizations, Geoghegan and Pangaro (2009) argue that '*essential variables*' are the *'shared truths*' of an organization—perturbed by the environment, regulated by participant actions. They also claim the validity of '*social essential variables*'. This notion strongly corresponds with the theory of governing variables of Argyris and Schön (1974). The word "*governing*" is used as those variables literally govern, note the cybernetics meaning, design strategies to reach a certain goal in the future.

Physically or mentally running out of action strategies may push the hacking entity to re-evaluate the deeper and tacit essential variables that make us behave the ways we do. Vice versa, the consequences of a spontaneous action can touch a latent essential variable which drastically changes the design behaviour. Re-evaluating and reframing our goals, values and attitudes is a more complex way of processing information and involves a more sophisticated way of engaging with an experience. Participatory hacking activities confront the engaging agents directly with the consequences of actions and make values and needs, which are very abstract concepts, more explicit by linking them to co-experiences on prototyping-interactions (Sanders, 2002).

Action Strategy

Action strategies are the moves and plans used by people to keep their governing values within the acceptable range. Argyris argues that *double-loop* learning is necessary if practitioners have to make informed decisions in rapidly changing and often uncertain and complex contexts (Argyris, 1974, 1982, 1990). As described thoroughly in the previous chapter we observe designing activities in which design problem and solutions 'co-evolve' in a mutually adaptive manner (Maher& Poon, 1995; Dorst & Cross; 2001 Witsching & Ball, 2013). Agents deconstruct their challenges in subsystems and prioritize them in to actions according to their current repertoire. Each action strategy can be framed as an open-ended integration or separation of several design variables to explore, optimize and interrelate several physical and cognitive features (for an extensive elaboration, see chapter 6).

In each of these prototyping-interactions new essential variables can emerge. It is important to notice that only 2 scenarios are possible when an essential variable exceeds its limitations in a positive or negative manner, through certain prototyping-interactions. (1) The hacking entity stops existing and disintegrates. (2) The hacking entity adapts, reconstructs its knowledge and transforms into another design state space (see figure 4). In practice, this is done by the inclusion of new variables or by the omission of old ones, at the level of technology, activity or the skills of the engaging agents. By doing so, it changes automatically its own identity. Through a new process of problem-solution co-evolution (Dorst & Cross; 2001) it further explores different stabilities within the current state space.

Consequences

Consequences are the end effects of our action strategy for ourselves within a specific environment and the effects of the response it engenders in others. They afford what we feel obliged to do, or prevented from doing, as a reaction on a changing environment. Strong feelings or emotions can be generated when consequences arise on abundant incongruence between espoused theory, those things one knows or are espoused to ourselves, and *theory-in-use*, the things one does not know. Within participatory hacking, the process of creative actions directs the resulting experience of the engaging agents. But these agents in turn redirect this creative process based on their effect. The overall direction thus generates a cycle, in which experience plays a part at a variety of levels. Although the *double-loop* theory of Argyris and Schön brings intuition and emotion to the foreground, it was hardly explored from this perspective within the context of making together.

7.2 THE APPRAISAL APPROACH

For Dewey (1971), emotions are a pervasive quality that serves to shape experiences. In earlier work, Dewey characterized emotion as 'physiologically, the adjustment or tension of habit and ideal and the organic changes in the body are the literal working out, in concrete terms, of the struggle of adjustment'. The relationship between adaptation and emotion has been studied comprehensively within the field of psychology (Lazarus, 1991). The basic Darwinian presupposition that emotions fulfil some sort of function is implicitly shared by all psychologists (Frijda, 1994). In the late 1990ies user emotions have been an integral element of product design discourse (Overbeek & Hekkert, 1999). Since that time, the design and emotion community has explored the role of emotions within product experiences (for an overview, see Desmet & Hekkert, 2009). In general, there are three main approaches : (1) *the pleasure approach* (introduced by Jordan, 2000),(2) *the process level approach* (introduced by Norman, 2004) and (3) *the product appraisal approach* (Desmet, 2002).

From all of these perspectives, the appraisal model is probably the only theory which strongly emphasizes the role of emotions as feedback and control towards human goals. Appraisal researchers (Roseman, 1991; Frijda, 1986; Lazarus, 1991; Scherer, 1988) argue that emotions are not evoked directly by events, but indirectly by our personal interpretation of those events and their relation to our well-being. The individual agent therefore has to grasp this event and its importance in some way; afterwards, he or she has to appraise the event's relevance for his or her wellbeing. For this reason, an appraisal is (in this context) a non-conscious sense-evaluation that 'diagnoses' whether an event has adaptational

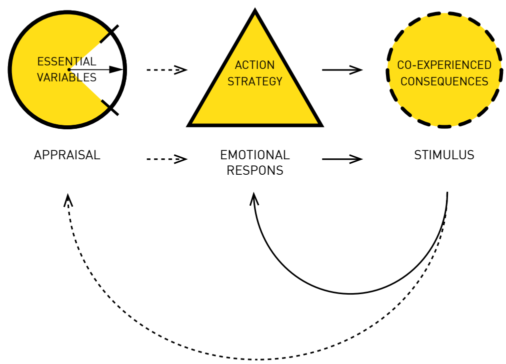


Figure 5. Mapping appraisal theory on to double-loop learning

relevance to the individual. It is this personal significance of an event, rather than the event itself, that causes the emotion (Lazarus; 1991; Scherer et al., 2001) and possible action tendencies. From this perspective, emotions are not random unprompted actions but responses to perceived changes within prototyping-interactions: something happens, someone says something, some detail comes into sight, a thought pops up. It is important to note that emotions are not elicited by these perceived changes as such, but by the 'situational meaning' of these changes (Frijda, 1986). An appraisal has three possible outcomes: beneficial, harmful or not relevant for personal well-being. These three general outcomes result in a pleasant emotion, an unpleasant emotion, an absence of emotion.

A basic appraisal process consists of 3 key elements:

1. *Concerns:* An appraisal process consists of the disposition of a number of latent or active concerns ,which are more or less stable references for certain states of the world.
2. *Emotions:* The second variable consists of the emotions themselves as a result of congruence or incongruence between the human concern and the interpretation of the stimuli.
3. *Stimuli:* The generic process starts with a stimulus. According to Frijda(1986), any perceived change or event in the environment has the potential to elicit an emotion.

The concept of "emotion-as-affordance" helps us to frame second-order understanding and to disentangle relevant govern variables of all engaging agents in a specific environment. By introducing the appraisals into *double-loop* learning processes we aim at understanding spontaneous product adaptations in a much richer and comprehensible context. Although social sciences have embraced the experiential phenomenon we call emotion for a long time, it truly originated from the domain of our everyday experience, and therefore it is a layman rather than a scientific concept. Desmet (2002) argues "*we all have emotions, and thus, from experience we know what they are*". Our implicit knowledge of emotion comes with the advantage that hacking practitioners do not need to theorize or define the phenomenon as such, but can instead focus their attention on relationships between design-relevant stimuli and the emerging consequences of hacking experiences within a given situation.

7.3 RESONANCE THROUGH CO-EXPERIENCES

Although emotions can be classified into universal categories (Ekman, 1994 ; Plutchik, 1980; Russell, 1980), we should be aware of relying too much on the common sense concept of emotion because these intuitive concepts or interpretations of changing interactions differ between people and their environments. Again, it is important to note that emotions are not elicited by these perceived changes as such, but by the 'situational meaning' of these changes. Depending on the dynamic context and the human concerns of the engaging agents, the same event can elicit good feeling because it is useful from the perspective of one agent, or bad feeling because it because it is experienced as painful through the eyes of another agent. For this reason, it is risky to use predefined emotional appraisal patterns as a standard container terms (for a discussion, see Demir, Desmet & Hekkert, 2006) to unravel experience-driven learning within participatory prototyping activities. Sanders, who describes experience as a moment of action with reflection on the past and anticipation of the future (Sanders, 2003), suggests using observation as tool of learning about the immediate present, and talking for finding out about the recent past and near future and emphasizes the role of collaborative making, i.e. co-constructing, to actually address these experiences from the past and dreams of the future. Batterbee and Koskinen (2004) go even a step further and state that to learn together with other people is the basis of making sense of any experience within co-design. All the prototyping actions and consequences are observed in the context of social interaction. Therefore, all participating agents create a common sense within the learning system through their ability of resonating on individual appraisal checks. Still, this collaborative meaning of making of experiences will change and evolve in unpredictable ways. Yet, if actions can be repeated over time, these interpretations become consistent within the learning system. This aspect of user-experience as social interaction, called co-experience (see Batterbee & Koskinen, 2004), considers experiencing as a process that is done by individuals in social interaction. Experiencing is still subjective and private, but its meanings can be shared and communicated to others either *implicitly* (by sharing tacit prototyping-interactions) or *explicitly* (by sharing meaning verbally). Only joint experiences on essential variables steer the group to prioritize their actions and adjust their action strategies.

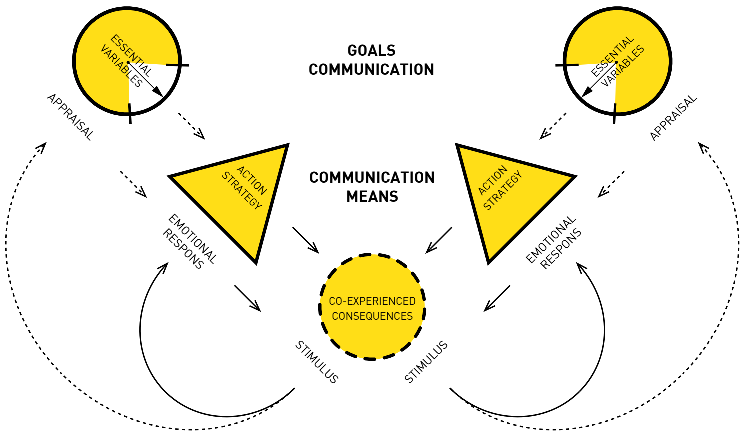


Figure 6. Co-experience stimuli events through collaborative reflective practice: interaction between two hacking systems

Hacking practitioners need to create a deeper understanding of the relationships between the govern variables of their fellow stakeholders and their social surroundings. Especially when they are confronted with the design of product adaptations for specific activities in which they themselves have no experience. Good hacking practitioners connect with this deeper understanding through a sensitivity that goes beyond "tact" and embrace *double-loop* learning through the perception of emotions as a form of user empathy. In general, empathy involves understanding the emotional states of other people. The problem of understanding standards, beliefs and goals has a central place within participatory design and user-centred design (Koskinen et al., 2003; Kroupie & Sleeswijk, 2009). Empathic understanding goes beyond the cognitive level of intelligence. When empathizing, hacking practitioners do not judge, they '*relate to the engaging agents and try to understand why certain experiences are meaningful to other stakeholders*' (Battarbee, 2004).

The act of being empathic comprises a relation that involves an emotional connection between two or more agents (Battarbee & Koskinen, 2005) at the level of govern variables. In general, empathic techniques within design practice cover direct contact (McDonagh-Philp & Bruseberg 2000; Mattelmäki & Battarbee 2002; Fulton Suri, 2003b), communication (Sleeswijk et al., 2005) and stimulating open-ended interpretations by enhancing imagination through experiences (Buchenau & Suri, 2000; Mattelmäki et al., 2011). Participatory hacking activities blend all three techniques in the pursuit of realizing a specific product adaptation: all participants have, at different moments and places, direct contact with each other and the hack prototypes; these hack prototypes are also used as communication tools to share and capture decisions on design variables with other indirect stakeholders.

The product hacking activities are by definition both physically open-ended (always new features can be added or removed, a hack is really never finished) and emotionally open-ended (the engaging agents do not respond to the physical qualities of things but act on what they mean to them in different situations). The arising of meaning occurs during the design process. All engaging agents are participating from a first-person perspective while intermittently also taking a third-person perspective. By doing so, the participants sense the limitations of themselves and each other within a given environment. Through co-experiences on prototype-interactions they modify or reject their goals, standards and attitudes and co-construct new meanings around product hacks

KEY INCIDENT: Sofie's Communication Book

Sofie is a 20-year-old student. She uses a wheelchair and communicates by nodding/shaking her head in combination with her communication book. The book contains all kinds of words and small phrases. Through a few questions of her parents and friends, Sofie indicates with her head the word or sentence she wants to communicate. You never see Sofie without the communication book. It is a direct way of communication and she uses it a lot. Nevertheless, the current copy contains laminated sheets, is difficult to make, and allows for little change. Moreover, the book is far from weatherproof and not exactly compact to carry. The sharp edges cut into Sofie's skin. ***Although the hacking practitioners had the skills to make a digital version on the bsis of the eyewriter project, they immediatly noticed that Sofie did not want an extra device mounted on her head. When they tested the first hacking prototypes, her assistants and the hacking practioners clearly co-experienced this meaning and decided to respect her wish.*** *The adapted book is made of fabric onto which prints have been ironed. It can be washed and ironed. Its mobility is superb, as it can be rolled up and folded. It is impossible for Sofie to cut herself to the soft material. Pages can be turned by moving one thread. New prints can be ironed on existing ones. An ironing and cutting aid was also made. This is an aid that can be used as a template when cutting and ironing on new prints. In the end, this project offers a total solution, from the software package, aids and instructions to the final product.*

KEY INCIDENT: Greet's Raincover

Greet enjoys life to the fullest. She tries to live as independently as possible,


even though it is not always as simple as it sounds. She moves in an electric wheelchair, does her own shopping and enjoys the occasional night out. The rain is her greatest enemy. As she cannot deploy her raincoat or umbrella herself, she often returns home soaking wet. She often sits in front of the fire for hours, to dry herself, before someone can come and help her to change her clothes. She is not the only one who has that problem. ***Already from the beginning Greet put forward the idea of a flexible roof system adapted on the basis of a convertible car system. For the hacking entity, this challenge was experienced as too high and impossible to manufacture due to the high complexity and the lack of resources. While Greet did not accept any alternative and kept coming back to the electric convertible roof system****, the hacking practitioners did not manage to adapt themselves by looking for new resources or skills. This blocked them to find any new co-experiences. Therefore, the cooperation stopped half-way the project. Part of the team still tried to find a simple and efficient solution to install a rain cover on a wheelchair. The final system they came up with consisted of a low-tech rain cover that is unfolded in just one simple step thanks to the springs provided. But Greet was never capable of using the assistive device.*

7.4 SOURCES OF PRODUCT ADAPTATION

Drawing on the appraisal theory, Pieter Desmet (2002, 2007) developed a foundational model of product emotion that distinguishes three types of concerns and three types of product stimuli. The model connects the levels at which prototypes can impact human prototype-interaction as stimuli with the human goals, standards and beliefs of its creators. Concerns are the dispositions that we bring into the hacking process, and stimuli are construed as relevant only in the context of one's own concerns. There are three types of concerns: (1) *goals*: what we want to achieve or see happen. (2) *Standards*: how we believe or expect we and others should behave and (3) *attitude*: the prevailing tendency to like or dislike qualities. Although the works on affect and emotions identify underlying universal processes, such as appraisal processes (Scherer, 2001), the basic input of these processes are user concerns, some of which are innate and some of which are acquired and subject to cultural and temporal influences. Desmet (2002) nuances that concerns can be latent (sleeping) or active (awake). Concerns are asleep as long as the circumstances hold no threat or possibility to their fulfilment. Some concerns can be expressed explicitly, others are hard to describe in words and have a more tacit nature. In the scope of this thesis, we believe that human concerns act as govern variables within hacking activities. The emotional and affective responses on hacking activities are always situated, meaning that they are dependent on these situational and contextual variables and on users' active and latent concerns (Frijda, 1986; Ortony et al., 1988).

STIMULI \ CONCERNS	Rightfulness Appraisal (Standards)	Pleasantness Appraisal (Attitudes)	Usefullness Appraisal (Goals)
SELF FOCUS	**What I should be** + *"I should be responsible for my dog."* − *"I shouldn't be so fixated."*	**What I enjoy being** + *"I enjoy being creative."* − *"I don't enjoy being pampered."*	**What I want to be** + *"I want to be a good parent."* − *"I don't want to be inactive."*
ACTIVITY FOCUS	**What I should do** + *"I should have acces to that building."* − *"I shouldn't have to pay more for my assistive device."*	**What I enjoy doing** + *"I enjoy eating ice-cream."* − *"I don't enjoy the pain when sitting to long in the same position."*	**What I want to do** + *"I want to listen actively to music."* − *"I don't want to pack and unpack the assistive device."*
PRODUCT FOCUS	**What the product should be** + *"Easy to clean."* − *"Not break easily."*	**What I enjoy the product to be** + *"Is elegant and stylish."* − *"When it is not making irritating noise."*	**What I want the product to be** + *"A good speech recognizer."* − *"A poor cutting knife."*

Figure 7. Nine sources of product emotions (adapted according to Desmet, 2010)

The last key element in the basic model of product emotion is the role of products as stimuli. Generally speaking, any perceived change or event has the potential to elicit an emotion (Frijda, 1996). Desmet (2010) makes a distinction between three types of stimuli which have a distinct relationship with emotional product responses, namely: (1) *an artefact focused stimuli*, (2) *activity focused stimuli* and (3) *identity focused stimuli*. Firstly, perceiving hack prototypes is the most straightforward stimulus event. Perceiving (seeing, touching, hearing and smelling) an artefact as such is an event in itself and can evoke strong emotional responses. The second type of stimulus events is instrumental interaction. Using or making a hack prototype is also an event in itself, which can be divided in many sub-events of action and reaction. Each prototype-interaction is used to "*get something done*" in some situation. The third type of stimuli focuses on the identity of the interacting agent. Using, designing or making a hack prototype can affect an individual's self-perception and how he or she perceives others.

When the three concerns and the three stimulus types are combined, they create a nine-source matrix of product emotions which trigger adaptive behaviour (see figure 7). This matrix can stimulate a second-order mind set among hacking practitioners to define govern variables within hacking activities from an emotional, and therefore behavioural perspective. The matrix can be used in two ways. (1) First and foremost, to clarify the initial start of each hacking project. Implicitly, the start of each participatory hacking activity is in fact a second-order process in which an agent has not enough variety of common actions within a certain environment to keep one or more govern variables within certain limits. This evokes strong emotions and new action tendencies to invite new stakeholders and even change their espoused theory on a certain technology, activity and skill. (2) Secondly, the matrix helps all agents to gain deeper understanding of new govern variables that pop up within the dynamics of the actual hacking design activities. As the hacking design is driven on action through making designing and using artefacts, most product emotions are established by appraisal checks coming from the centre of the matrix, using the activity of prototyping as stimuli while focusing on new useful aspects to achieve the goals. Through these activities they implicitly connect with the entire product ecology and its appraisal checks of all the agents. The matrix can help agents to localize the emotions by taking into account not only the hacking entity itself, but also its super-system and subsystems in time and space.

As long as the consequences of prototyping-activities are kept within the limits of the essential variables of all engaging agents, the hacking entity pursuits its activities through '*single-loop learning*'. If a new unexpected event exceeds an essential concern all the engaging agents should be able to co-experience it and anticipate the reaction with a new adapted action strategy. When the event is not co-experienced it endangers the viability of the entire hacking activity. Through the matrix it is possible to take the role of the environment into account, as Ashby denotes in his definition of self-organizing behaviour, in which the stimuli and appraisal checks take place. When we "feel" strong emotions we have met a conflict between our concerns and situated affordances/disturbances on real prototyping-interactions. As second-order events are unpredictable and only have a nominal character (they just happen or not), we will illustrate al nine segments with some key incidents out of the range of community-based practices. An example of the dynamic role of govern variables in a full-length hacking design process can be found in chapter 8.

Analyses

As illustrated in chapter 6, essential variables can only be measured on a nominal scale. To determine the essential variables of a case we applied a back-casting method. We analysed all the cases (for an overview of the dataset, see chapter 2) by back casting the weblog until the moment that the breakthrough adaptation was visible in the hack prototype. The antecedent unexpected co-experience insights in the Schön-matrixes and the progress reports from the team were analysed and triangulated with memoranda from open-ended interviews and direct observations. If no significant breakthroughs through prototyping-interactions were detected, experiences from the zero measurement (or the first meeting) with the client were analysed.

Table 1 shows a snapshot of how the raw data were categorized and analysed. Initially, insightful user quotes (1-5 sentences) were extracted from the remarks in the Schön-matrixes. Subsequently, the concrete information given in these quotes was interpreted and abstracted to form representative concern statements (a goal, a standard, or an attitude). Finally, selected concern statements were categorized using priori-coding (Miles & Huberman, 1994) according to the model of Desmet (2010).The results were discussed with the stewardship team (see chapter 2) and a selection was made using the most significant change technique (Dart & Davies, 2003) combined with the overall goal of illustrating a large variety of different contexts within the dissertation.

CASE	Volume	Abstracted essential variable	Appraisal Type	Relationship level
prismabril 1.7	*"By making use of two separate sets of mirrors we can operate much closer to the eyes, so that the whole has become a lot more compact."*	Is compact and performant.	Useful	Product
loopschip 1.3	*"The solution is something that satisfies Lukas, but also his parents. This means it has to be therapeutically correct and really fun to stand in it, But the parents need to be comfortable and at ease when placing him in there."*	We do not enjoy seeing our son attached to a medical device	Pleasurable	Self
oprijvalies 2.3	*"With the ramp we have access to all shops, homes, restaurants and other buildings where you have to take a flight of stairs to enter. "And there are many. Too many!"*	We should have access to all public spaces	Rightful	Activity

Table 1. Three example rows showing the data analysis procedure

Results

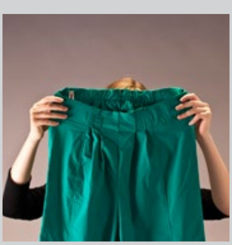
RIGHTFULLNESS APPRAISAL

The first source of product adaptation is afforded by an appraisal check of praiseworthiness and legitimacy. The concerns involved in this appraisal check are our standards. Standards are our beliefs, social norms or conventions of how we think things should behave or act.

Self-focus

At the first level of identity we discuss owning and using products which have an influence on the individual's self-perception and how this is perceived by others. These appraisal checks are central for the experience of the so-called self-reflexive emotions, such as pride, guilt and shame. Being proud to co-create your own DIY AT device or experiencing a stigma by the reaction of bystanders at the sight of your assistive device.

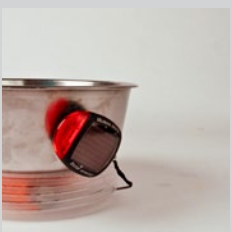
KEY INCIDENT: Bernoux's Harness Clothing



Bernoux is an enthusiastic 16-year-old girl who likes to hang out with her family. It is hard for her to find appropriate and cool clothes that fit over the diaper harness and look good at the same time. ***The essential variable which triggered the product adaptation in this case was clearly the social stigma that her father experienced during outdoor activities in a public area. The father could not accept that there is no standard clothing available that his daughter can wear and that hides her harness in a respectful manner.*** *Together with her father, we looked for a solution to ensure that Bernoux and her father can make stylish trips in the wheelchair. We opted for Chinos, a contemporary brand of trousers that has trousers which are slightly wider at the hips and taper down to the feet. The pleats*

at the top hide the diaper, while the skinny legs of the trousers accentuate Bernoux's slender legs. By providing a sufficiently high waist, we underline the constriction in the harness at the waste, so as to obtain a female shape. Moreover, the high waste ensures that, despite the rigid armour, Bernoux's trousers do not slip in a sitting position. Brace clips were added to attach the trousers to the shirt. In this way, everything is kept in place. With a bit of clever styling, a lovely outfit was created, an outfit that no longer puts the harness in the spotlight, but Bernoux herself.

KEY INCIDENT: Bengo's Drinking Bowl



*Some daily tasks seem obvious to us, but are not that evident for the visually disabled. Kathleen has an assistance dog, Bengo, who is ready to help her at any time of the day. Their relationship is very intense as they have spent many hours together. K**athleen had the practical problem that she could not estimate visually when the drinking bowl of Bengo was empty.** As Bengo is trained only to bark in specific situations, he does not indicate to Kathleen when he is thirsty. **When these situations occurred, Kathleen was overwhelmed by a lot of guilty feelings. She saw herself as the number one person who should be taking care of Bengo. This essential variable made her contact the living lab and directed the process into a signaling bowl.** The hacking design consists of a DIY balance system which is placed under the bowl. When the weight of the water in the bowl is not heavy enough, a simple electrical contact is made that kindles a red light driven by solar energy. This signal immediately attracts the Kathleen's attention when passing through the kitchen and reminds her to refill the water bowl.*

Activity-focus

At the second level of activity, the rightfulness appraisal check involves standards of performance. For instance, one should not hear a rattling sound when driving a new wheelchair, or an eye-tracking device should not crash without a warning.

EXAMPLE : Marc's Drinking Aid

Marc can no longer close his mouth, which has implications for his eating and drinking habits. Food is administered through a tube, but this is not a viable solution for drinking. As a result, Marc had to learn a different way of drinking: he sprays liquid directly to the back of his mouth, where he collects the liquid before swallowing. Marc used small syringes to drink out of Aquarius bottles which he could squeeze easily. These have a special sports cap, much like a drinking bottle cap, and this was the starting point for the project. The team started the process with an open mind. Very quickly, they ran into a few additional design requirements. Each of them gave the project a new turn. ***The essential variable that steered the product adaptation was the fact that the drinking aid should be easy to clean and disinfect because Marc is very susceptible to mouth infections. Moreover, the Aquarius bottles did not meet the food-safety standards when they were re-used.*** *That is why we started with a drinking bottle which Marc found easy to use and to clean in a steamer. By using a laser printer to apply a pattern on the bottle, we reduced the wall thickness, thus making the bottle softer. This has made it easier for Marc to control. The colour and print of the bottle have been chosen in mutual agreement. We changed the cap so that a tube can be put through it. For Marc, this is the ideal bottle to drink.*

EXAMPLE : Damien's Cutting Aid

Since Damien has less strength in his right hand than most of us, he has more difficulty to carry out everyday activities, such as cutting up his food. ***As he likes to visit a restaurant from time to time, he would still like to eat independently like all other people. This literally meant with the same type of knife and the same type of movement. This essential variable had an effect on the entire hacking design process****. The knife hack offers the strength and stability required to cut with minimum effort. Since grabbing hold of the knife gives some difficulty, it is strapped to his arm. This is done by attaching it to the underarm at two different places. In this way, the wrist is sufficiently supported when cutting. The knife is attached to the arm with Velcro straps, something Damien can also do by himself. The design also includes a protective plate which reinforces the grip and protects*

the fingers. In that way, the cutting force comes from the arm instead of the wrist. By positioning the knife in a different way, it is possible to apply more force with the arm. Moreover, the angle of the knife is adapted to the person using it so as to reduce the required cutting force to a minimum.

Product-focus

The third level mainly focuses on the sensory perception of the product interaction. We have standards on how products should look designed and produced. In many cases the products are appraised as the outcome of some person or institute. For instance, why should a particular assistive device only be available in one standard colour?

KEY INCIDENT: Eveline's Ramp Suitcase

Julien and Eveline love shopping together, but they often felt disrespected *during this activity. Julien Scheers invented a ramp suitcase for his wife Eveline. The essential variable which triggered the further product adaptation in this case study was the lack of universal access for people with electric wheelchairs on many locations. The result is a two-piece ramp aid to help Eveline move with her heavy electric wheelchair across the thresholds of different local shops. The following properties were important during the hacking stage: reducing the total volume and weight and guaranteeing simplicity in operation, both during installation and use. The result is the two-piece ramp suitcase, a multi-functional and user-friendly aid that is tailored to Eveline's requirements. For example, the ramp aid has the perfect 17° angle, allowing her to get on and off the ramps without any problems . The rubber at the base absorbs the bumps in the road surface and the non-slip finish provides sufficient resistance when negotiating ramps. Thanks to the reduction in volume and weight, and the fact that the ramp suitcase can easily be folded down into a handy carrying case, it is not only user-friendly for Eveline, but also for the people helping her out.*

KEY INCIDENT: Karel's Intellikeys

Karel, who is 14, has had dyskinetic cerebral palsy since birth, which means that he cannot always control his muscles that well. That is why Karel is in a wheelchair. Karel attends a business course at a regular school and is helped by 2 assistants, a laptop with the necessary adapted software, a special keyboard (intellikeys) and a joystick (to navigate). ***He needs all these separated tools to follow his classes, but he has to re-install them each team he switches to another classroom as there exists no standard and ergonomic way to attach the gear directly to his wheelchair.*** *Therefore, our task was to make life at school for Karel significantly easier by attaching the hardware to his wheelchair in a sturdy, ergonomic and compact manner. Once the configuration was determined, we looked for a solution to attach all the parts to the wheelchair, compactly but securely. We opted for a welded solution which is easy to mount and take down, with a sliding surface over the intellikeys and joystick made from Plexiglass, which allows Karel to move from one class to the other in one smooth movement. Moreover, the laptop can be easily folded in and out, because we made good use of a retractable trolley handle.*

PLEASANTNESS APPRAISAL

Emotions evoked by intrinsic pleasantness check have in common that they are independent of the motivational state of the person (i.e. goals or motives). How pleasant or unpleasant is the stimulus event? The concerns that serve as point of reference in this appraisal are our attitudes. They embody our personal overall tendency to respond to the intrinsic pleasantness of situations.

Self-focus

The highest level of stimulus events (self-focus) covers those emotions that are elicited by the consequence of using (or owning or making) the product. For example, the enjoyment of exploring new places with your children, or the tranquillity on experience while interacting with certain animals, or the consequence of finding the right assistive device for a relative can evoke also feelings of relief.

KEY INCIDENT: Jana's Tennis Ball Launcher

The relationship between Jana and her assistance dog Rinja is a very close one. Jana is diagnosed with ALS, which makes walking and stretching out the arms impossible . Rinja helps her out 24 hours a day and is trained to

do work or perform small, but essential tasks. ***Besides the independency the dog has giving her, she also just enjoys playing with the dog while having a walk. Throwing the ball and challenging the dog amuses her as she knows that Rinja loves it too. This intrinsic feeling of pleasantness is the essential variable within this product adaptation.*** *Jana can only throw a ball backwards with a dog ball thrower, but only a couple of meters far and the ball bounces immediately on the ground. This approach is often not challenging for the dog and Jana misses all the interaction. The tennis ball launcher that was created by the team is inspired on a professional baseball/tennis ball thrower. There are two wheels which are made to spin by one electromotor and two gears coming from hacking old drilling machines. The tennis ball is pushed through these wheels and accelerated: the ball is then airborne for several meters. It was important for Jana to be able to attach and detach the launcher to the wheelchair in an easy way and to still be able to pass through doors. With the attachment claw-system she does not have to lift the weight by herself and makes use of her own wheelchair.*

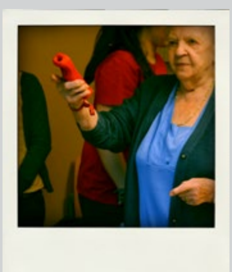
KEY INCIDENT : Ludwinne's Painter's Aid

Ludwinne is paralysed on the left-hand side of her body and sits in a wheelchair. She can only use one hand and sees through only one eye. ***But Ludwinne loves painting and would like to paint the pond in the garden, the woods, you name it, but she is unfortunately unable to do so because she is wheelchair-bound. She does have a regular easel, but it is difficult to open from a wheelchair, or to transport it when she wants to paint a scene outdoors.*** *This limitation makes it an extra challenge to find a solution for her problem. The Paint Aid was developed with the help of Quick-step laminate. The idea behind this product is that it is a hack, which means that it is an existing product that has been turned into a different product. Three planks are used to create a base which is attached to the wheelchair with standard attachment systems, and one plank serves as a mixing tray for the paint. Thanks to the pouch attached to the side of the wheelchair, this product is easy to move. Another aspect that is very important is the handles that are attached to the Quickstep planks. These make the aid much easier to handle with one hand.*

Activity-focus

The second stimulus level, viz. using the product, can also involve sensations that are appraised as pleasant and unpleasant. For example, the consequence of placing children with autism in a "snoezel" environment is that they experience relaxation while exploring their sensorial preference, such as the gestures that are required to play a music instrument or the forces that are felt while handling a cooking knife. In those cases the act of using or making can also involve a sensation that is appraised as intrinsically pleasant or unpleasant.

KEY INCIDENT : Helena's Wii Bowling Aid



Helena suffers from dementia and lives in a home for elderly people. Together with her friends she loves to play Bowling on the Wii-console but has difficulties with the coordination and controls of the game. ***The essential variable in this case study was to maintain the gesture of swinging and to find a new way of releasing the controller. Together with the hacking entity she designed an accessory which can be 'plugged' on the Wii controller.*** *This add-on makes it easier to play since the user only has to swing the device and there is no need for any buttons or controls. By using a stiff elastic, the B-button of the Wii-controller is switched on and off and releases the bowling ball in the game. The timing of the release point is depending on an elastic rope attached to the plate on which the user is standing.*

KEY INCIDENT : Oceane's Vibrating Toys

Océane is 3 years old and in full development. Due to a respiratory arrest, Océane has incurred multiple disabilities. ***While her vision and motor skills are less well developed, she enjoys toys that stimulate her auditory and tactile senses.*** *By designing a product family of five cuddly toys, the 'Snuffles', this sensory stimulation is further trained in a very pleasant way. When Océane touches the cuddly toys, moves closer to them or touches them, they will make a sound by way of 'reward'. Since Océane is very per*

ceptive when it comes to vibrations, one of the cuddly toys is fitted with a vibrating mechanism, which starts when she moves her hand in the direction of the cuddly toy. Moreover, the cuddly toys are also designed to visually stimulate her. She first has to focus, then make a movement and then she is rewarded with feedback. This is why the shape, colour and material of the cuddly toys are kept as neutral as possible, except for the location of the trigger, which is in bright colours and a soft material. It is important that the cuddly toys give Océane feedback to each of her specific movements; if not, she would soon give up 'playing' with them. Consequently, the 'form follows function' principle is applied, even though the use of colour and material restores the balance. The cuddly toys are a simple basic shape, over which is pulled an attractive cover.

Product-focus

In the case of the most concrete stimulus level, the stimulus is a physical manifestation of the product. The evoked emotions can be related to visual, tactile, olfactory or auditory design aspects. Several features or properties of products can be appraised as pleasant or unpleasant. As a result, one is attracted to the sensuous shape of a new prosthesis or one feels aversion to the texture of a plastic assistive eating product.

KEY INCIDENT: Lukas' Walking Ship

Lukas, who is 10 years old now, was born with multiple disabilities. Because of his severe scoliosis and kyphosis, he has received orthopaedic support throughout his life. Mainly to correct his posture, there are many walking aids, braces, chairs, etc. available on the market. He uses these especially when he is at 'The Sunflower' centre. At home, however, he should also spend some time in these therapeutic aids. That is why Lukas and his parents have been looking for an aid to use at home which is therapeutically suitable, but which includes different game elements at the same time. None of the existing appliances met his exact requirements. ***The essential variable within this case study was mainly the parents' attitude towards the look and feel of orthopaedic braces as they wanted to create a non-medical atmosphere within their own home environment.*** *Most products on the market were looking unattractive and their main aim was only to improve his posture. In the final product the wooden design still offers the support that is needed to be justifiable from an occupational therapy perspective, but in a shape that is favoured by the parents as it feels* *more fun and pleasant. A deliberate choice was made in favour of wood, as it is more reminiscent of an attractive interior design element than of a standing aid.*

KEY INCIDENT: Elisabeth's Toilet Lifter

The toilet lifter has been designed for the 94-year-old Elisabeth who had trouble standing up after using the toilet. In other situations, for example when seated at the table, this lady uses a walker to stand up. However, this is, due to space restrictions, not an option for her visits to the toilet. ***Elisabeth lives with her daughter and her family and the toilet is used by quite a few other people.*** *For that reason, the objective of this project was translated into designing an inconspicuous product which, whilst being an aid for Elisabeth, could also fulfil different functions for the other people using the toilet.* ***In this instance, what we wanted to create, more than anything else, was an aesthetic look without any hospital connotations. The toilet lifter is a rigid element, made from brushed aluminium, which is integrated into the toilet interior.*** *This aid is a lifting aid, but also a holder for toilet rolls, towels and magazines. In that way, it can be of use to the entire family. By integrating all these functions, Elisabeth is not given the impression that an aid was installed especially for her. Moreover, visitors who use the toilet do not immediately notice that the toilet has been adapted for a person with restricted mobility. The toilet lifter is an eye-catching device which surely adds value, both aesthetically and functionally, to every toilet!*

USEFULNESS APPRAISAL

The usefulness appraisal is represented by an appraisal check of motive consistency: to what degree does this stimulus event help me to attain my goals. The goals that people try to satisfy people are ranged between abstract goals and aspirations, such as the goal to have a successful life, and goals as concrete and immediate as the goal to catch a train.

Self-focus

The consequence of (using or owning) may thus be appraised as the motive consistent (e.g. being satisfied with a voice based navigation system for as it helps you blindly through a new city) or motive inconsistent (e.g. being dissatisfied with the installation of an AT device as I takes to much time).

KEY INCIDENT: Peters' Transport Walker

Peter has been diagnosed with multiple sclerosis and experiences some neurological effects as a result. Some activities require more focus than others. Peter would like to be as independent as possible and is currently on crutches. It is not that easy or safe to move objects at home or at work with these crutches. The starting point for the co-design process was the following: ***Peter would like to cook for his family and would like to serve the food without any problems or support. The essential variable within this product adaptation is Peter's drive to be a good father.*** *Peter also helped us to design this aid with his technical feedback on the prototypes as he has a background as a technical engineer. The user can independently attach the aid to, and, if required, take down the aid from, the walker. The dimensions of the kitchen furniture were used to adjust the walker to the work environment. All the parts are made of materials that can be washed and the tray is made of a heat-resistant material. The activities which used to be a challenge for Peter can now be carried out in a customised, simple and safe manner.*

KEY INCIDENT: Henk's Scale

Henk is an active young man who was involved in a car accident at the age of 32. As a direct result of this accident, he became an acute traumatic spinal cord injury patient, which means that the neural structures of the spinal cord have been disrupted, resulting in paralysis. Because of the injury, Henk has little trunk stability and his lower limbs are also paralysed. This is why Henk has been in a wheelchair ever since the accident. ***Yet, this has not stopped Henk from being actively involved in sports. He is a professional sportsman and plays, among other things, wheelchair basketball at a national level and does hand biking. This active sports life requires that Henk checks his weight on a regular basis.*** *He uses a regular set of bathroom scales to do this, but this is no small beer. Henk has to transfer his weight to the scales, lift his legs from the floor and try to read the display of the scales all at the same time. It is relatively easy for Henk to transfer from a wheelchair to a regular chair. That is why it is a logical choice to develop scales that can be placed under the legs of a chair. The scales had to be* *compact and easy to use. In addition, it was important for Henk to have a support surface for his feet. The final design consists of a narrow surface area with two folding aluminium legs. The surface area has an integrated display. It also serves as a surface on which can rest his feet and the front legs of the chair. The angle at which the aluminium legs can be rotated can be selected, so that the scales are compatible with different chairs. Rubber strips are attached to the top, so that the chair cannot slip.*

Activity-focus

When people are using products, people are involved in goal-directed behaviour sequences. If the sequence is blocked in the interaction, people will typically experience frustration. For instance, the feeling of not being able to operate an ATM from a wheelchair, or the feeling of not being able to pour yourself another cup of coffee.

KEY INCIDENT: Hilda's Raised Toilet Seat

For people who are less mobile, simple, everyday activities, such as going to the toilet, become a chore. Sitting down and getting up require a certain strength from the legs, abdomen and/or the arms. A prosthesis, a painful joint or weaker muscles all complicate these, and other everyday tasks. Thanks to existing aids, including a raised toilet seat, handles on the wall and a support frame, toilet visits can be done independently and more easily. These are all effective, but bulky aids, and not that easy or comfortable to transport. Hilda has a knee replacement. This, along with a few more age-related conditions, makes a visit to the toilet a challenge. This is why she has a raised toilet seat at home, which is attached to the ceramic toilet bowl. This elevated seat and wider opening make it easier for Hilda to sit down and get up again. ***The essential variable within this case study has a goal-driven character. She experiences a lot of negative emotions when she goes outside her home when none of these aids are available.*** *Some public toilets are already equipped with handles, but the position does not always meet everyone's expectations. In those cases, Hilda calls in the help of one of her friends, but it goes without saying that this is not a pleasant situation. We have opted for a honeycomb structure, as it can expand, and offers solidity at the same time. The large segmentation ensures the equal distribution of pressure which also feels soft to touch. The slot is placed* *over the existing toilet seat, while the lower rim of the booster is clamped between the ceramic bowl and the toilet seat. This, and the weight of the user, secure the aid and prevent the booster seat from slipping. The selected materials and compounds are water-resistant and can be cleaned with soapy water. When we fold the structure, Hilda can carry it in her handbag.*

KEY INCIDENT: Damien's Sauna Wheelchair

Damien is a wheelchair patient who enjoys life to the full and would like to remain as independent as possible. For example, he loves going to the sauna, just to leave the hustle and bustle of life behind for a while. Despite the fact that the sauna has been designed with wheelchair users in mind, ***Damien is unable to enjoy a long sauna visit, as he has to endure it in a shower wheelchair, which, as it is made of synthetic materials, does not offer the necessary comfort in a hot and humid environment for longer periods of time. As time elapses, Damien slides off the chair, which cuts off his blood flow.*** *This problem has led to the development of the sauna wheelchair: a wheelchair that has been converted and adapted for use in the sauna. The chair, made of cedar slats, has naturally insulating and water-resistant properties, as a result of which the chair is ideally suited for use in both the sauna and shower. Moreover, every effort has been made to cover up the connections, and contact with metal parts is avoided. The chair still has all the functionality of a regular wheelchair, like foot supports and brakes, but a few parts have been adapted to make the sauna experience as pleasant as possible. For example, the inclination of the backrest has been altered, and lumbar support is provided for maximum comfort. The backrest is extended into the headrest, so that Damien can enjoy the sauna leaning back.*

Product-focus

In the case of a product stimulus driven event the goal at stake involves the product as such, which can be the goal of owning, sharing, restoring or repairing a product or any typical function the product has to fulfil.

KEY INCIDENT: Cornelis' Riser Unit

Cornelis is 26 and has a hereditary muscular disease, as a result of which he uses a wheelchair. Cornelis is very active and creative. He often makes useful things that solve everyday problems. One such thing is a riser unit which he built himself. Since he no longer has the strength to get up himself, the riser unit helps him to stand up after he fell down. The idea behind it was that by rocking back and forth his body, it is possible to raise to chair height and then from there to stand up without help from others. His first riser unit did not function as expected, and so it was up to us to improve the design. ***The essential variable in this product adaptation was to make Cornelis' DIY product more performant and to share his invention with other people.*** *After much deliberation and brainstorming, we decided to switch to an electric solution for the riser unit. Cornelis was in favour of the idea, because the effort required on his part is little compared to the considerable upward force that is developed. Since we decided to attach a motor to a walker, which is, in itself a stable structure, the riser unit is also easy to transport and offers much support when getting up. The motor is operated from the grips, as Cornelis holds onto the grips to keep his balance. When Cornelis presses the button, the motor starts to run. A strong piece of rope, attached to a shaft (of the motor) raises the seat. To help Cornelis to get up, the seat is lowered onto the floor so that he can put himself on it without any problems. Even though the seat is relatively stable thanks to the ropes, there is some leeway so that Cornelis can decide to move from the riser unit to the wheelchair should he wish so. The seat can easily be stowed so that the walker can still be used for walking purposes.*

KEY INCIDENT: Sharon's Hands-free Crutch

The hands-free crutch is a product hack for Sharon who moves around on crutches. She cannot stand up without the use of crutches or other support. But some actions still require both hands, and when, as a result, the crutches have to be released, difficulties are experienced when doing so: the crutches either fall over, or the user tries to hold on to the two crutches with one hand. Whichever way, both scenarios result in awkward situations. ***We wanted to create a standalone crutch when released by the user. The crutch had to be stable, light and effective.*** *The team eventually settled on*

a folding tripod. When Sharon comes to a standstill, magnets push two legs against the crutch. By means of a simple squeezing movement, the magnetic connection is lost. When the crutch is subsequently tilted, two more legs fold out, resulting in a stable device with 3 points of support. Upon leaving, the legs will retract and be locked again. The product can be mounted on a standard crutch and, thanks to its small dimensions, it is not conspicuous in any way

.

7.5 ON THE EDGE OF FLOW

As previously discussed in the above section only the co-experienced consequences of prototyping-interactions within a certain environment steer the hacking design process. Through a closed-loop feedback with the concerns of the hacking entity new events afford new actions or reinforce a current action strategy. In fact, the only way to learn and coordinate within a self-organizing design process is (1) to deliberately cause new design actions and (2) embrace these spontaneous unexpected events that unravel hidden interdependencies. In this section, we would like to discuss the accumulation of unexpected events and their impact on the general willingness of the hacking entity to engage in the product adaptation. Accomplishing each hacking activity asks for a certain amount of energy, attention and emotional commitment. In cybernetic literature this concept is called bio-cost and is defined as the effort (or resources) a hacking system expends to achieve a goal (Dubberly et al., 2009).

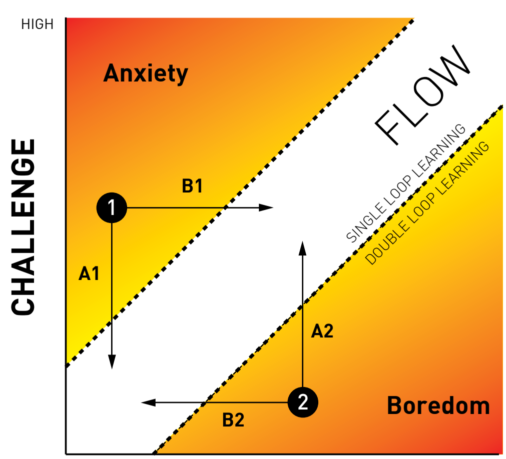


Figure 8. Flow Channel (adapted according to Csikszentmihalyi, 1990)

From a behavioural perspective, the regulation of resources is characterized by the overall mood (or long-lasting emotional state, for an elaboration see Desmet (2015) of a hacking entity and can be framed as a function of the co-experienced demands of energy and attention for attaining a given goal. Hence, a good hacking activity is the product of a successful trade-off between motivation and ability from the perspective of all engaging stakeholders within the hacking entity. Finding the right balance between both aspects brings hacking entities collectively within a general mood, called a flow (Csikszentmihalyi, 1990). A flow is a state of complete absorption in the present activity and is characterized by maximum fulfilment. During this process, the hacking entity is able to reduce uncertainties by co-experiencing constraints on hacking possibilities in a qualitative and enriching manner. Csikszentmihalyi (1990) identifies "skills" and "challenges" as the two key variables in the flow experience, placing them on the respective X and Y axes of his mental state graph (figure 8, see chapter 5).

	DISTINCTION DESTRUCTION	DISTINCTION CREATION
CHALLENGE OVERSTEP	**A1** goal standard pleasure	**B1** agent technology activity
RESOURCE OVERSTEP	**A2** agent technology activity	**B2** goal standard pleasure

Figure 9. Regulating a challenge or skill overstep

He describes occupational moods as the relationship between the perceived challenges of the task at hand and the experienced effort of skills. A sequence of prototyping consequences which exceed skills will result in a state of anxiousness. Alternatively, when a certain skill set exceeds the proposed challenge a series of appraisal checks will lead to a state of apathy or boredom. Both anxiety and boredom drive the participating agents to frustration and drive them to adapt action strategies or their resources. If they are not able to do so the co-design process will eventually fade out and stop. The flow channel in-between embodies a state of mind that makes us stay focused on a certain action strategy while maintaining the balance between the challenges and resources.

The model of Mihaly (1990) also illustrates the cybernetic design perspective in a behavioural manner. The unexpected consequences that evoke a resource shortage or excess leave the flow zone and steer the team in a co-evolutive manner towards adaptation. The illustrated diagram (see figure 8) is not intended to be a measurable graph, but more a visual aid, a representation of this concept. While exploring a current state space hacking practitioners search the boundaries of new possibilities applying their espoused theory and common modus operandi. By doing so, they bounce on new unexpected events which create meaning and challenges on relevant variables within the entire product ecology. The nature of these unexpected events defines the adaptive behaviour of the hacking entity.

As discussed in the previous section we make a distinction between consequences which stay within the physiological and psychological limits of the hacking entity (or stay within the flow channel) and those which exceed their mental and/or physical capacity. The first category of emotions on unexpected consequences are perceived as manageable and can be countered by reactions out of the hacking practitioners' repertoire. These '*single-loop'* adaptations instigate motivation to explore and to challenge certain elements within the boundaries of the group's current assumptions. Their starting point is the current set of activities, skills, engagements, relationships and contributions. Through a creative process, new combinations are made without questioning the initial scope. '*Single-loop*' prototype activities happen within the flow channel (Csíkszentmihályi, 1990), balancing between skills and challenges. Participants who undergo these activities have a sense of autonomy and control towards the actions within a certain environment. The *theory-in-use* is characterized by defensive reasoning (Argyris, 1990), in which practitioners stick to plan and manage to deal with consequences. Despite of the negative connotation, these defensive actions can be productive (e.g. if they do not inhibit true learning) as they protect the actors from harm or failure. Defensive reasoning relies on the idea of deterministic causality, the claim that "A will cause B" and amplifies the choice of the current adaptation strategy.

The second category of unexpected consequences has a more compulsive character. Their experienced effort exceeds the limits of the engaging agents (physically or mentally) and therefore either terminates the collaboration or refocuses the team obligatory on new variables coming from interactions with activities, skills and technology. In these events, the hack entity is forced to jump into another state space in order to keep its organization viable. Once there, the engaging agents have to revalidate all the current information and make new choices together. In these reflective transformations, tasks are controlled jointly and the theory-in-use is characterized as productive reasoning (Argyris, 1990) which involves minimal interpersonal defensiveness. The engaging agents co-experience that while the risk of openness is potentially embarrassing, threatening, or frustrating, the same open-minded attitude is also necessary to increase trust and find an appropriate solution to deal with the uncertainty of a new state space offer. Other than in *single-loop* learning this productive reasoning relies on the idea of probabilistic causality, the claim that "*A will probably cause B*." By slowly adapting the adaptation strategy the hacking entity tries to enter a new flow channel. In normal conditions *double-loop* learning typically occurs spontaneously, or may occur by chance. We believe that it is the task of hacking practitioners to grasp these moments and turn them into meaningful product adaptations by means of creative thinking. By doing so, goals, standards and attitudes change, and thus passively also the identity of the hacking entity.

The diagram of Csíkszentmihályi, (see figure 8) posits that as the skill's levels increase, challenges that call upon those skills must increase in difficulty, to achieve a state of continuous flow. If something is too difficult for our current skill level, it will produce a mood of anxiety (number 1 in the diagram). Conversely, if something is too easy, it will create a mood of boredom (number 2). Although it is hard to disentangle both phenomena, we will discuss them more in depth within the context of hacking design and some key incidents.

Analyses

To illustrate a variety of flow regulations we conduct a cross-case analysis of the general flow level of each team. This was done for each project year (the progressions of each team were intuitively compared to those of the group in general) from a third-person perspective and effected by the stewardship team. When essential variables are neglected too long, the co-design process fades out.

Case 2009	*Mood*	*Key-incident*	*Overstep*	*Reaction*	*Regulation*	*Type*
ijsjeshulp 1.12	balanced	/	/	/	/	/
spraakcomputer 1.7	anxiety	Wanted to change technology but the mother did not allow it	challenge	Integrated transport feature and focused on product aesthetics	distinction creation	skill
MP3-speler 1.4	bored	No real teamwork, one member was taking too much the lead. skill	skill	Split up the work	distinction destruction	skill
opzettafel 1.9	balanced	/	/	/	/	/
handsfree kruk 1.8	anxiety	Too much fixated on a lifting system	challenge	Change the activity from downward motion to tilting movement	distinction creation	activity
serveerhulp 1.12	bored	Found their solution quite fast	skill	Challenged themselves to make a finished product and make the product-interaction as intuitively as possible distinction creation	distinction creation	standard
drinkhulp 1.5	balanced	/	/	/	/	/
rugzakhulp 1.11	aroused	Did not find a proper hinge mechanism that can carry the load challenge	challenge	No proper reaction	/	/

Table 2. Showing the data analysis procedure for one project year.

Table 2 shows a snapshot of how the raw data were categorized and analysed. We labelled the case studies that slacked or even abruptly stopped and described the key incidents (anxiety, balanced, bored) according to the model of Csíkszentmihályi (1990) together with their corresponding antecedent reactions (see Table 2). Finally, the reactions were categorized using prior-coding with the adapted model of flow regulation (see figure 9).

Flow Regulation

REGULATING A CHALLENGE OVERSTEP

When sequential consequences of prototyping-interactions lead to a challenge overstep, there are two possible regulating reactions. The first reaction is achieving a new state of flow by lowering the challenge (see figure 8, arrow A1). In this situation, the team faces its own limits and therefore disputes the truth or validity of its espoused theory (on goals, standards and attitudes) within a certain environment. In practice, the hacking entity performs an internal distinction destruction and focuses its attention on the most dominant appraisal checks. The entity re-prioritizes its actions and makes a collaborative trade-off out of all co-experienced consequences. Often, individual agents have a certain fixation on certain concerns which should be dealt with first. Key incidents (A1) on ***goal regulation*** (pick-up aid), ***attitude regulation*** (dishcloth squeezer), ***standard regulation*** (home trainer).

Usefulness Regulation

KEY INCIDENT : Els' Pick-up Aid

Els moves in a wheelchair. She has spasms and struggles with stability and grasping, because she only has one functioning hand, the left-hand side one. She often drops things and each time, she has to ring her carer to pick up the object. Els would like to be able to pick up things herself, but the tools that are currently available are all designed to be controlled with 2 arms. When the hacking activities started, the team discovered that there were two different situations in which Els needed an adapted pick-up aid. When the hacking activities started, the team discovered that Els mainly preferred to be more independent in two different situations. The first situation occurs when she has to pick up her cloths out of the washing machine and the second situation is while she delivers letters and brochures in the mailboxes. At the beginning, Els did not explicitly express a preference and hoped that the designers could fix both problems with one assistive device. Unfortunately this was not the case. ***The longer the team integrated both goals, the less progression they made and the more frustrated they became. Apparently this challenge was too high for the current hacking entity and they were forced to refocus on one situation****. The final pick-up tool focused on gathering clothes.*

Pleasantness Regulation

KEY INCIDENT : Bart's Dishcloth Squeezer

For Bart, who has one functional arm, squeezing a dishcloth is difficult. The wring motion often used to dry a dishcloth requires two functional hands. An option to dry the rag with only one hand is to squeeze it with one hand or push it against the sinkhole. The hacking entity thought they had found a solution by using a mortar system. ***They love to craft objects in wood and made the final hacking design out of one piece of wood on a turning lathe. Although the object looked very nice and it was fun making it, Bart disapproved it as he still used the same amount of energy while squeezing the dishcloth.*** *A disadvantage of the chosen method is that it is nearly impossible to get the rag dry enough and the squeezing motion with one hand can be painful or even cause convulsions. This consequence forced the team to omit woodturning although it was their favourite production technique and to build a totally new functional design based on a hack of a tin can crusher.*

Rightfulness Regulation

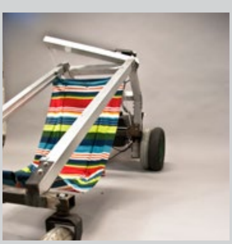
KEY INCIDENT : Joost's Home Trainer

Joost is a 37-year-old, very sociable guy who likes to go out with his friends to watch his favourite football team, SV Roeselare. In his spare time, he often enjoys a game of bridge on the computer. However, Joost occasionally also needs some exercise to keep fit. Due to a restriction on the leg muscles, he has difficulties moving. While outdoors, Joost prefers to use his tricycle, at home he uses an old exercise bike to strengthen his muscles. Given his impairment, the team was surprised that Joost can mount and ride this tatty exercise bike at all. The condition of the current exercise bike makes it very dangerous for Joost to use it on a regular basis. To replace it, a more attractive and safer exercise bike has been made to suit Joost's personal requirements. ***During the hacking process, Joost clearly expressed his appraisal regarding the look and feel of the standard exercise bike. It took a while to convince him that the design team was not able to deliver an assistive device with the looks of a professional home trainer.*** *The new exercise bike is almost completely made of plywood to highlight the DIY aspect* *of this project. Eventually, the team ended up with a smooth exercise bike created out of straight surfaces. This bike can be seen as a low-cost, sturdy basis that can be made for everyone. Specific problems can easily be addressed with add-ons. In the case of Joost, we mainly concentrated on the mounting and dismounting activities, the position of the feet and the general posture.*

(2) Every challenge needs the right skill set or resources to create new actions. A second approach to achieve group flow when the overall challenge is too high is by enriching the skills and resources of the hacking entity (see figure 8, arrow B1). In some situations, the fixation on a certain essential concern truly inhibits the ability of the hacking entity to explore a new solution space. A spontaneous reaction to attain a certain challenge while keeping the current essential variables within acceptable limitations is opening up the hacking entity towards new agents, reframe activities or allowing new appropriations of technology. This is a form of distinction creation, we seek new elements that enrich the hacking entities' resources and therefore the constraints of the entity also change. Key incidents (B1): ***agent regulation*** (beach mobile), ***activity regulation*** (teeth-cleaning aids), ***technology regulation*** (activity-centre).

Agent Regulation

KEY INCIDENT: Michiel's Beach Mobile



In collaboration with Michiel, a six-year-old boy, the team developed the beach mobile. Michiel was born with spina bifida and is paralysed below the waist. He moves in a wheelchair or crawls on the floor. Michiel loves paddling in the sea. On the sand, he is pushed along in a cart. He cannot operate this cart himself and once he is sitting in it, he can no longer touch the sand. He is dependent on others if he wants to go somewhere. Already at the beginning, the team was aware of the large dimensions of the desired assistive device. Once they had assessed his wishes and needs, they came up with a beach mobile with which Michiel will be able to move around on the sand and will be able to get in and out independently. ***To make this kind of vehicle, they clearly co-experienced their own limitations regarding resources and skills. They looked for help outside the hacking entity: the aluminium was sponsored by a company, the welding equipment and skills were brought in the process by a technical school. Furthermore, the mother of Michiel used her social network to find people with specific***

skills on electrical driving. The battery, wheels, joystick, electric motor and piston were donated through recycling an old electrical wheelchair from a rehabilitation centre. *All these agents had an impact on the overall design process and steered the team in to the flow zone. The result is an impressive hacked beach buggy that Michiel can operate on his own (see movie; De Bie et al., 2013). Starting from the sand next to his sand castle, he rolls onto a blanket that is spread out on the sand. By means of a joystick, he can lift the blanket which is attached to an aluminium frame via cables. Once Michiel is suspended in a comfortable sitting position, he can proceed to the driving mode via a menu on the joystick.*

Activity Regulation

KEY INCIDENT: Freddy's Teeth-cleaning Aids

Freddy contacted us because cleaning his teeth is a daily struggle. The original question of Freddy was to adapt an electrical toothbrush so that he could use and control it. ***As soon as the team observed his activity they co-experienced a lot of other barriers, particularly what happens before and after. Getting the cap off the tube, getting the toothpaste on the brush, moving the brush to his teeth, rinsing the brush, ... These are the actions that Freddy finds hard to perform and make the overall challenge of cleaning his teeth independently too complex. They reduce the challenge with a few simple tools. The chain of actions was simplified so that it could be done more easily.*** *For example, there is the toothpaste tray, into which he can dip his brush. Thanks to this aid he can get the toothpaste on his brush more quickly and has more control over the amount of toothpaste he needs. Table clamps have been used to attach the tray securely to the bathroom worktop. A lever has been attached to the toothbrush, which makes it easier to move the brush to his mouth, because Freddy has difficulties placing his finger on the button. The lever makes that he can press across the length of this lever instead of having to aim for a little button. In addition, there is the charger holder which makes the surface area of the charger larger. This ensures that the charger no longer falls over when Freddy wants to put his toothbrush back on the charger. All these tools or actions are simple, but together they are invaluable for Freddy.*

Technology Regulation

KEY INCIDENT: Bernoux's Activity Centre

Bernoux is an enthusiastic 16-year-old girl but with developmental disabilities. She is always looking around and exploring the world for new sensorial stimuli. Her occupational therapist wants to encourage this spontaneous behaviour by making a multifunctional sensorial board which Bernoux can explore by pushing buttons, listening to music bells, or looking into mirrors. ***While testing the first prototypes, the hacking entity really underestimated the physical strength of Bernoux. In no time she manages to break all prototypes. This co-experience forced the team to leave the solution space of a board system and switch its focus to a digital projection system, called ReacTickles.*** *The overarching goal of ReacTickles is to allow users to playfully explore the magical possibilities of a smartboard system without prior knowledge or skill in technology. They made a DIY smartboard with a Wii Remote Controller (which tracks Infrared light) that recognises the position of an Infrared pen. The only product that Bernoux is handling is the IR pen, covered in an aluminium casing coming from a pocket flash light. Now, Bernoux can play a huge variation of sensorial games.*

REGULATING A RESOURCE OVERSTEP

(1) Every skill set needs the right challenge. In practice, when prototyping experiences lead to boredom and apathy, the co-creation team can undertake two types of actions. The first reaction can be perceived as a skill-regulation (see figure 8, arrow A2). The hacking entity can adapt itself by distinction destruction at the level of resources, agents and activities. In practice, this is effected by trimming the team or distributing tasks among different agents. Hacking practitioners can merge activities into new components or they can think of new ways to approach tasks simultaneously. At the level of technology, the hacking activity can also reduce the number of tools needed to realize the product adaptation.

Key incidents on (A2) ***agent regulation*** (anti-tilt glasses), ***activity regulation*** (jar-closing aid), ***technology regulation*** (laptop holder).

Agent Regulation

KEY INCIDENT: Yoeri's Anti-tilt Glasses

Yoeri is 17 years old, he experiences unusual "tightness", stiffness, or "pull" of muscles as result of a spastic cerebral palsy. When Yoeri sits in his wheelchair these spasms cause problems with the positioning of his glasses. A common sports strap for glasses does not work as the uncontrolled movements push the frame of the glasses against his headrest and indirectly dislocate the spectacles. ***The team also added a professional optician to the hacking entity. This technical practitioner informed the team on the constraints when one designs, fits and distributes corrective lenses. The first prototypes were all discussed together, but as the project progressed the knowledge of the optician was integrated and his contribution was no longer needed.*** *The final glasses exist of 3 main parts, the spectacles, the nose mask and the elastic connections which allow a certain impact and always reposition the spectacles back to their original position.*

Activity Regulation

KEY INCIDENT: Carine's Jar-closing Aid

De Achtkanter is a sheltered workplace where people with intellectual disabilities work on small business projects. One of the products they produce is self-made eggnog. Within the sheltered workplace it is Christine's task to close the jars when they are filled. She has a lot of problems with the strength and pressure that is needed to close the lid. At the start of the project, the team made very simple and efficient tools with bigger levers and non-skid surfaces. ***While testing the first prototypes with Christine, the team co-experienced more barriers. Christine experienced difficulties in positioning the tools and grabbing the jars and was not fully aware of how far she had to turn the lid without damaging it. Although the team had simple individual solutions for all of the activities, they entered the***

flow zone by forcing themselves to integrate all of them into one assistive device. *The end result is a product hack of a silicon gun system which is used to generate the pressure onto the lid and the jar. The basic frame contains laser cut templates which fixate several types of jars and give Christine feedback on the rotary motion of the lever.*

Technology Regulation

KEY INCIDENT: Catherine's Laptop Aid

Cathérine has cerebral palsy. She can move her arms and neck relatively well, but all the other major movement are difficult. Despite these physical restrictions, she is mentally very competent. As a qualified barrister, she works in her parents' law firm. For this job, she spends a lot of time on her laptop. During the day, this is mostly done at her desk, but as this strains her neck after a while, she often has to rest in bed. She would like to continue working on her laptop while she is in bed, but none of the bedside tables meet her requirements. ***Very soon in the process the team found an appropriate solution in the form of an easel-like structure. It provides the ideal angle, tailored to her visual needs and physical restrictions. To enter the flow zone again, they forced themselves to make the product as easy as possible with only a few resources and materials****. With one type of wooden plank, a saw and a drill you can build this design and customise it to your own requirements.*

(2) A second type of reaction is augmenting the challenge by exploring more concerns and sometimes even solve contradictions or conflicts among some of them (see figure 8, arrow B2). People have an endless number of concerns associated with everyday activities. This regulation through distinction creation at the level of concerns challenges the hacking entity to find a new homeostasis within the hacking activity. Many hacking activities start from a usefulness perspective but throughout the process all integrating extra challenges through ***goal regulation*** (auticlock), ***pleasure regulation*** (knitting aid), ***attitude regulation*** (folding aid).

Usefulness Regulation

KEY INCIDENT: Clement's Auticlock

"When will Daddy be home?, When does school finish today?, How long before I can get up?, How much time have we got left?". These are all questions which Clement, who is diagnosed with autism spectrum disorder, asks himself and his environment every day. Clement often uses the Time Timer and is familiar with the way time is displayed by this timer. By making a few adjustments to the principle of the Time Timer, the concept of the adapted product has been translated into the 'Day Timer', a concept that visually displays day and night including an indication of several everyday activities. ***As the team had more resources at hand, it challenged itself by making simultaneously an analogue and digital version of the new clock concept. The analogue version was based on a product hack of the 'Time Timer' and the digital version started from a low-cost digital photo frame.***

Pleasantness Regulation

KEY INCIDENT : Ann's Card Folding Aid

Ann is a young woman who loves making greeting cards, lots of them. Her hand motor skills, however, prevent her from folding or cutting them herself. To Ann, cards are a way of communicating with friends and family since oral communication is often too tiring for her. In the past, she asked her carer to fold and cut the cards for her, after which she put the cards in the envelopes. She mainly needed assistance because she found it difficult to match the corners when folding and because she could not use scissors. The two problems were solved by two different aids, since one dual-purpose aid would be too large and too complex. For the aids, use was made of a standard A4 sheet that had to be folded lengthwise and cut widthwise. In the case of the folding aid, the sheet has to be placed on top of the anti-slip surface, in the corner of the appliance. The corners can then be matched with one hand and a crease is created. In the case of the cutting aid, the folded sheet has to be placed in the cut-out U-shape, after which the blade has to be lowered to cut the sheet in two. ***To keep the challenge in the hack-***

ing activity, the team searched for other means to integrate the assistive device in Ann's environment. Through an extra personalisation process, they added Ann's favourite flower into the shape of the folding aid. The back of the cutting aid has been decorated with a proverb that was chosen by Ann, so that it does not look out of place on her desk. *The aids designed for Ann allow her to fold and cut her greeting cards independently, so that she can complete the entire process from idea to end product.*

Rightfulness Regulation

KEY INCIDENT : Carine's Knitting Aid

Carine loves knitting for her grandchildren. Because of hemiplegia, knitting is becoming increasingly difficult as she can only use one arm. At the physiotherapy centre, tests were carried out with an aid that holds one of the needles, with no success. Additionally, Carine has low vision and neglect because of the left-hand-side paralysis. In short, knitting became a problem. The idea behind this design is partly based on an existing technique, called spool knitting, and partly based on the agent's own experience coming from hacking activities. The team started with a knitting frame that has two rows of needles around which the thread is wrapped. The principle of French knitting is applied to create stitches. ***Although Carine could knit again with one arm, the team created an extra challenge in guiding her in the process of learning different standard stitches with this new knitting aid. On the basis of this device, they created the end product: a modular knitting aid that holds all the stitches, much like a knitting stick. Accompanied by an extra manual to make stitches and a few example projects.*** *Moreover, it is possible to convert 'regular' patterns to a pattern for Carine's knitting frame, which means she can knit anything she wants, ranging from woollen caps to scarfs.*

7.6 CONCLUSION

In this chapter we described how adaptive (or internal adaptation) prototyping interactions influence general adaptation in participatory hacking behaviour. This is effected through cross-case analyses on all case studies to show the variety of *double-loop* adaptations and their practical manifestations within product hacking activities. As mentioned in the above section, *double-loop* processes on tangible prototyping-interactions have a transformative impact and change the internal perspective of all the participants in a compulsive manner. Sensing and respecting essential variables is a crucial act to maintain the viability of each co-design project. The unexpected consequences are the driving mechanisms that propel the actions and steer the team in a circular manner towards new perspectives or re-appropriations of current resources.

These moments immediately instigated new *single-loop* actions and cultivate alternative ways of framing possibilities outside the precedent solution space. Responsive and attuned actions, repeated over time, lead to a positive relationship among the engaging participants. Only in this maintained relationship, the feeling of trust can arise and grow. Trust provides a fertile ground for change and nudges agents to step out of their comfort zone and change their attitudes, goals or values towards prototype-interactions. All *single-loop* hacking activities mainly drive on voluntary prototyping activities. Therefore, the hacking entity searches for equilibria between resources (local skills, activities or technology) and intrinsic motivations of the group (attitudes, goals or standards).

Within these *double-loop* learning experiences, conflicts and choices shift from the level of product-related aspects to a broader perspective of activities and be-goals (Hassendahl, 2010; Desmet, 2011). By exploring solutions at the level of identity and be-goals, the hacking entity can afford and validate new possibilities that diverge from the current situation. These explorations help the hacking entity to co-experience if each concern is truly essential within a given environment.

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Part IV

CAPTURE TOOLS

8. SELF-CONSCIOUS TOOL

THE ROLE OF SUBJECTIVE WELL-BEING IN PARTICIPATORY HACKING

“The moments of happiness we enjoy take us by surprise. It is not that we seize them, but that they seize us.”

(Ashley Montagu)

In this chapter we describe within a single case how the reflective Schön matrix serves as an explicit self-regulation tool that helps hacking practitioners to document their momentary co-experiences explicitly together with their prototyping interactions. As discussed in chapter two, the design tool and its variables are explicitly used from 2011 until 2015 within the living lab projects. The design trajectories and events it has elicited through case-based research are used to build up the theory and illustrated key aspects in chapters four to eight.

ABSTRACT

In this paper we explore the role of subjective well-being within the process of making together a personalized assistive device. Through a process of social product adaptation, assistive artifacts become part of occupational therapy and co-evolve with clients. Personal digital fabrication tools enable small user groups to make and share their one-of-a-kind products with the world. This approach opens up new possibilities for disabled people and their caregivers to actively engage with their own skills and challenges. The paper describes a case study of an inclusive participatory design approach, which leads to qualitative occupational experiences within the field of community-based practice. The aim is to show how the process of collaborative designing, making and using artifacts fosters several elements of subject well-being in itself. The starting point of this open design process is a threefold interaction involving industrial designers, patients and occupational therapists within their local product ecology. Co-experience driven design is an intersubjective process that enables all individual stakeholders to work on a common phenomenon in respect of each subjective experience. Participatory prototyping is applied as a mobilization medium that (a) coordinates and (b) motivates design actions towards collaborative well-being equilibriums. This form of artifact-mediated participatory design embodies simultaneously (1) a communication language between all stakeholders that identifies meaningful goals, (2) an explorative process to attain and challenge these goals, (3) a selection of meaningful and engaging prototyping activities and (4) an appropriateness process with local skills and technology. By implementing this creative process, disabled people and their carers become conscious actors in providing collaborative maintenance of their own physical, mental and social well-being.

8.1 INTRODUCTION

Assistive technology enables people with disabilities to accomplish daily living tasks and helps them in communication, education, work or recreation activities. Despite all the efforts and good intentions, the majority of assistive devices are often not a source of happiness (Hocking, 1999; Wessels, Dijcks, Soede, Gelderblom, & De Witte, 2003). Apparently, the language of acute medical conditions and universal design are ill-suited to maintaining well-being over a lifetime. In these frameworks, disabled people are perceived as medically not normal, and “being normal” – not better or worse – is the desired objective (Correia de Barros, Duarte & Cruz, 2011). Based on unidirectional and standard interventions rehabilitation engineering aims to reintegrate disabled people into society. As a result, the central strategy focuses more on the interdependency of primary activities than on the quality of life. On top of that, the variety of products and functions is rather limited, compared with those that are mass-produced.

For this reason, disabled people and their caregivers are forced to adapt their goals and activities to the limited choice and static character of these products. When this adaptation process demands too much cognitive, physical or emotional effort new actions emerge on a local scale. At present, the authors recognize two main scenarios. (1) The most frequent scenario is that of non-use. In many cases, expensive devices are rejected and end up in the back of closets. The disabled client becomes resigned to the need to find another product variation of the device or has to fall back on an allied health professional to perform the activity. (2) The second scenario includes a more bottom-up and bi-directional process. In certain conditions, spontaneous design activities emerge between local agents, leading to the production of self-made assistive artifacts (De Couvreur & Goossens, 2011). Existing devices are adapted, or even reconstructed from scratch to create new possibilities around unique skills and meaningful activities of disabled people. Objectively, these self-made and humble artifacts cannot compete with the standards of mass production, but from the perspective of all engaging stakeholders they deliver profound happiness (Norton et al., 2012; Hook et. al, 2014). In the course of several design activities, participants reveal themselves as proud ambassadors of their personal assistive devices and in some cases radically transform their self-image. A substantial part of the happiness itself stems from the physical and social experiences within the process of making together (Seravalli, 2013).

These experiences correspond with some main results coming out of happiness research (Lyubomirsky, Sheldon, & Schkade, 2005) and identity-driven design (Desmet, 2012; Zimmerman, 2009). Both lay the emphasis on the potential of our daily actions that are under our voluntary control and advocate for a possibility-driven approach (Desmet & Hassenzahl, 2012). In our opinion, this is exactly what caregivers and disabled people are spontaneously striving for when they start adapting their own activities and products. They create new possibilities with local technology, which unlock the potential of contributing to human flourishing. As an illustration, the case study shows a creative process of making together which has a positive impact on both interdependency and the quality of life. All stakeholders participate in meaningful activities that help them become the person they desire to be. At the same time, this pragmatic process is able to co-evolve beliefs and values with local skills and resources, but within the world of assistive technology the dynamic of these transformation processes is often unexplored.

In this paper, we define subjective well-being as a function of human adaptation — a state of mental health in which individuals challenges their own potential (see Ryan & Deci, 2001). We show how an inclusive participatory design approach, grounded on our experiences with self-organizing design activities, can affect the subjective well-being of the engaging participants in many different ways.

8.2 MAKING TOGETHER WITHIN PARTICIPATORY DESIGN

One can argue that people are disabled by the context they live in and not directly by their impairment (Pullin, 2009). The WHO (2001) defines disability as "a complex phenomenon, reflecting an interaction between features of a person's body and features of the society in which he or she lives". Individuals requires a different approach to reach the goals based on their personal skills and disabilities. Multiple changes within social contexts and direct environments are emergent and not predictable in time. Making personalized assistive devices while coping with these dynamic aspects requires other situated methods than those applied in traditional participatory design. The latter is a familiar approach in which users and other stakeholders work with designers in the design process (Sanders, Brandt, & Binder, 2010) as a way to envision encounter 'use-before-use' (Redström, 2008), that is, before the action takes place in people's life-worlds. As critics have accurately pointed out, "Envisioned use is hardly the same as the actual use, no matter how much participation has been in the design process" (Ehn, 2008, p.95). We argue that the same reason applies to happiness-driven design and advocate the use of open techniques that lead to reflection and learning on the spot.

In contrast to traditional participatory design, meta-design (Fischer, 2011; Fischer & Giaccardi, 2006) suggests deferring some design and participation until after the design activity, that is, design at use time or 'design-after-design' (Redström, 2008). Within the design literature there are several attempts to deal with the challenge of meta-design on a pragmatic level. A similar approach is the idea of a continuing design-in-use (Henderson & King, 1991). In a broader design perspective, this also corresponds to visions and notions like continuous design and redesign (Jones, 1983). In such approaches there is also a strong focus on how users appropriate a given technology (Verbeek, 2005). Of particular interest here is what designers do and how this relates to unforeseen users' appreciation and appropriation of the object of design into their life-worlds. When conducting this approach within community-based practice we noticed that more than just meaning emerged. Several elements of well-being (Seligman, 2011) such as sense of accomplishment, positive relationships and increasing engagement were noticed among the participants' behaviour. For this reason, the process of making together becomes a meaningful activity in itself, turning the negative notion of critiquing (Fischer, Lemke, Mastaglio & Morch, 1990) into a more positive perspective.

Many of these original meta-design theories have their origins in the field of end-user development and HCI. Today, the maker movement is expanding this participatory prototyping vision with open hardware through a network of fabrication labs (Gershenfeld, 2008). In essence, inexpensive and powerful prototyping tools have become available for everyone in shared machine workshops (Seravalli, 2011). Due to the rise of the Internet and these direct digital manufacturing processes, we are capable of making niche products and adaptations on demand: the long tail of things (Anderson, 2008). With these tools and infrastructures, meta-design becomes a powerful engine for handling idiosyncratic aspects. Designers and occupational therapists can use these mediums to make custom-made solutions for individual clients within their own local context. Assistive devices become part of therapy and co-evolve with clients. Our design for a well-being approach is grounded in this meta-design framework through the implementation of fabrication labs.

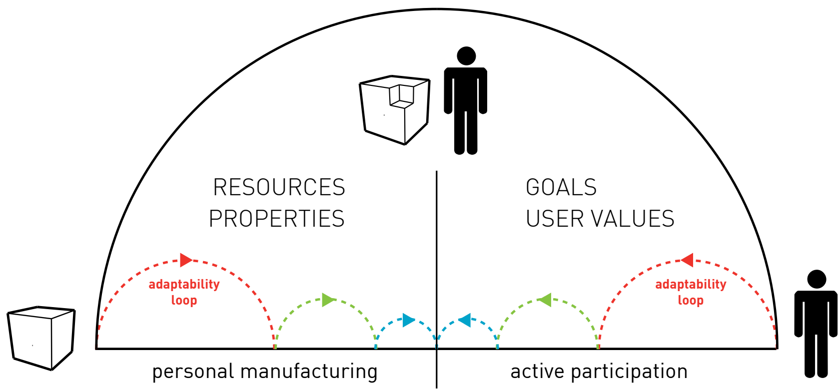

Figure 1. The co-evolution of user and assistive device

Both makers and disabled users are seen as designers, much as in participatory design, but they are participating asynchronously in time and space, taking different roles and attitudes. Basically, this approach works in two ways; personalized assistive products are adapted to the skills of participants and participants adapt their values and beliefs through the making of their products (figure 1). The power of this method lies in its highly iterative character and the acceptance of unexpected events, opening up new ways of thinking, feeling and acting.

8.3 THE DYNAMICS OF CO-EXPERIENCE-DRIVEN DESIGN

Self-organizing design activities embody the opposite perspective of “disability”, which is defined as “functioning” and denotes the positive aspects of the interaction between an individual (with a health condition) and the individual’s contextual factors (environmental and personal factors) (WHO, 2001). Many of these phenomena can be considered as complex adaptive systems, consisting of different stakeholders, which cooperate while interacting with a shared physical environment. In most cases, the groups are rather small, up to 3 to 5 people. This implies that the complexity is not derived from the number of agents, but rather from the dynamic networks of interactions and relationships. The adaptive character is expressed in the fact that individual and collective behavioural changes as a result of personal and group experiences (Juarrero, 1999). Each agent finds meaning through a dialogue with the subjective experiences of his own actions and the interaction of other participating stakeholder experiences. It is important to notice that the creative process built around these artifacts directs the resulting user experience and vice versa. Meaning as such is created and re-created within a social-technical interaction, not prior to it. The output of such interactive systems is consequently unpredictable, yet exhibits a form of self-organization that emerges between the participating agents and their environment. To explain the dynamics of these situated activities (Suchman, 2007) between humans, we would like to bridge two concepts: co-experience and 'double-loop' learning.

Katja Battarbee (2004) first coined the term co-experience, which has origins within human computer interaction. As a design researcher, she noticed a missing perspective within the research field of user experience. Various existing approaches (for more extensive discussions, see Hassenzahl, 2010; Schifferstein & Hekkert, 2008) only focused on the individual having the experience and neglected the kinds of experience created together with others. The research resulted in an expansion of the interactionist perspective on experience (Forlizzi & Ford, 2000). This pragmatist model explains the different dimensions of experiences (experience, an experience, and co-experience) and how they arise out of different user-product interactions (fluent, cognitive, and expressive) (for an elaboration, see Battarbee, 2004). Co-experience is the process of learning, maintaining, and modifying meaning in social interaction. Batterbee makes the distinction between three types of co-experience migrations: lifting up, reciprocating and rejecting experiences. These migrations, built around user-prototype interactions, allow participants to focus their attention on several sources of product emotions (Desmet, 2010), which could play a significant role in the process of designing for happiness.

Other than in professional product development, we do not recognize consecutive stages of gradual refinement within self-organizing design activities. The design behaviour principally builds on the patterns of reflection-in-action (Dewey, 1933; Schön, 1983). For Argyris and Schön (1978) learning generally involves the detection and correction of errors through feedback loops. When a situation is uncertain, vague or ambiguous, the main strategy of a participatory design group is to construct a lifelike prototype and see if their theory-in-use is congruent with their espoused theory (Schön, 1983). Decisions within a certain adaptation strategy are therefore always conditional, while critical decisions are based on insufficient information, but are taken according to the best of the group's intersubjective experience and common knowledge at that point.

A fundamental aspect within this form of inquiry remains openness to the discovery of unintended phenomena. What happens as a result of an interaction with a prototype can be perceived as both intended and unintended (Schön, 1983). The nature and intensity of these co-experiences will determine further action strategies or even change the belief system of all engaging stakeholders. To illustrate the impact of these processes, we have to make a distinction between 'single-loop' and 'double-loop' learning. Human actions are governed by a set of variables (Schön & Argyris, 1995). These governing variables are the 'shared truths' of the design collective constructed out of attitudes, be-goals and standards. As a rule for maintaining the viability of the social system, human agents steer their actions to keep these variables within acceptable limits. In other words, chosen goals are operationalized rather than questioned, which leads to a process of incremental change. According to Argyris and Schön (1974), this is 'single-loop' learning. An alternative response is to subject the governing variables themselves, using feedback from past actions, to question assumptions. Both authors describe this as 'double-loop' learning. These processes focus on transformational change and lead to an alteration in the governing variables.

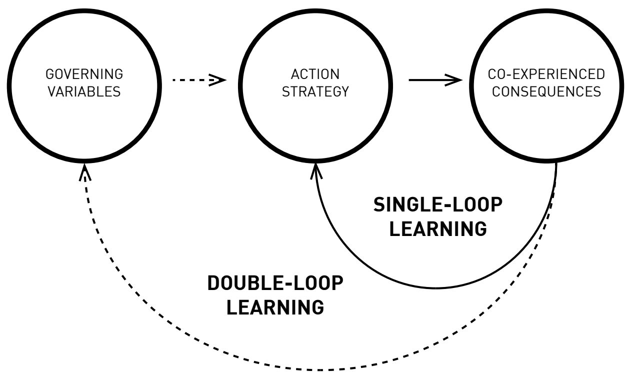

Figure 2. 'Double-loop' learning, adopted from Argyris and Schön (1974).

In this section, the authors argue how Argyris and Schön's formalisms can be applied within the context of participatory design for subjective well-being. As already mentioned, we frame happiness as a function of human adaptation within self-organizing design activities. Conversely, a number of researchers and thinkers have argued that the ability to be happy and content with life is a central criterion of adaptation (e.g., Diener, 1984; Jahoda, 1958; Taylor & Brown, 1988). Findings from positive psychology illustrate the importance of intentional activities (Lyubomirsky, Sheldon & Schkade, 2005) that comprise a balance between skills and challenges (Csíkszentmihályi, 1990). Each participatory design activity (making, using or learning) can be perceived as a meaningful activity that challenges the skills of all engaging participants. Making products together can be framed as finding the edges of each other's physical, mental and emotional potential through incremental 'single-loop' adaptations. As long as the governing variables stay within their limits, the same ingredients (attitudes, be-goals and standards) are challenged and optimized within a 'single-loop'. However, once conflicts arise between the physiological edges and the governing variables, a 'double-loop' learning cycle is triggered. As a result, one or more ingredients change, which results in new adaptation strategies. In practice, the group adapts or changes its belief system and perceives its goals, skills or values from a whole new perspective through the interaction with the environment.

This co-construction process (Oudshoorn & Pinch, 2003) therefore examines situated prototype adaptations as instigators of change. The use of lifelike prototype activities in a specific real-life context subsequently creates a shared language and common ground on the limitations and possibilities of each participant. Subtle product adaptations can provoke a lot of negative or positive emotions and steer our social design behaviour implicitly towards new insights into design for happiness. We believe that co-experiences evoked by unintended prototype consequences can play a key role as triggers for sustaining happiness in changing environments. Through a reflective conversation with the situation, the design collective reciprocates (or rejects) spontaneous co-experiences which have the capacity to shift their attention from a problem-driven approach to a possibility-driven approach. It is important to notice that co-experiences cannot be predicted or orchestrated; they have a spontaneous and emergent character. The openness of the situated context and the empathic skills of all participants can have an impact on both single and 'double-loop' learning.

8.4 CASE STUDY

To exemplify concrete dynamics and emergent characters in design activities, we use a case study. We focus on events that steer product adaptation strategies and challenge stakeholders to explore new possibilities. From a meta-design perspective, we consider subjective well-being as a function of the adaptation process built from co-experiences around design, make and use activities. Taking into account the perspectives of all engaging stakeholders. Generally we believe that this approach can contribute to the quality of design participation by making designers more aware of several subjective well-being elements enclosed within participatory design. In this case study, the design actions are mentioned in very descriptive manner. Our main purpose is to illustrate clearly how a variety of practical events can be linked to sources of happiness through direct contact. Simultaneously, we aim to make this approach accessible for both design researchers and practitioners in the field.

Method

This framework has been developed through action research (Brydon-Miller, Greenwood & Maguire, 2003; Swann, 2002) at the Industrial Design Center in Kortrijk (see chapter 2). Over the last five years, several participatory design cases have been set up in real-life contexts built around meaningful activities of individual disabled people. Each participatory design team randomly consists of a disabled client, a caregiver, an industrial design student, an occupational therapy student and other stakeholders from the local rehabilitation context. The process takes approximately 12 weeks, during which the group alternates between several design activities within various locations. From day one, students are only allowed to communicate using tangible prototypes and report their findings on a self-reporting shared blog (Bellens & Stubbe, 2011). Our notion of adaptive prototyping builds on the work of Ehn and Kyng (1991), who generally used mockups as tools for engaging with stakeholders rather than prototypes to be evaluated. Later on, this prototyping focus was further elaborated with the work of Buchenau and Fulton Suri's (2000) notion of experience prototyping and prototyping for social action (Kurvinen, 2007). All prototyping actions were executed in line with the following conditions required for studying social interaction for the purpose of subjective well-being: (1) create social setting with more than one person, (2) use naturalistic research methods, (3) maintain openness for observing unexpected interactions, (4) observe the behaviour within a sufficient time span and (5) generally focus on the sequential unfolding of events (for an elaboration see Kurvinen, Koskinen, & Battarbee, 2008).

Analysis

We generally want to observe the impact of unintended consequences through user-prototype interactions. To measure consequences in relation to intention, we focus on the act of surprise. Surprise is right there on the fuzzy border between two related cognitive phenomena, emotion and attention (Ludden, Sheldon, & Schkade, 2006). A surprise reaction has its origin in encountering an unexpected event. This basic emotion elicits new reality constructions for all participating stakeholders and helps them focus on new possibly significant variables. We documented this principle in various co-experience driven design cases through a simple 4-channel matrix (figure 3), which distinguishes four frames by the possible combinations of the following distinctions: surprise/no surprise and desirable/undesirable (for an elaboration see Schön, 1983).

	EXPECTED EVENT	**UNEXPECTED EVENT**
POSITIVELY EVALUATED	Make Design Use	Make Design Use
NEGATIVELY EVALUATED	Make Design Use	Make Design Use

**Figure 3. Reflection on action -
the Schön matrix (Schön, 1983) .**

For each use time encounter, the students were asked to fill in the matrix together with their client. Observations were filmed and subsequently analysed with the Schön matrix from the perspective of the participatory design team. Design-time experiences are attached to the corresponding open-ended prototypes which all have a unique number. Ideally each individual agent should fill its matrix from a first-person perspective and also observe the group from a third-person perspective. The combination of all matrices, linked to anterior and posterior tangible prototypes, illustrates how the co-experience patterns gradually emerge among the participants.

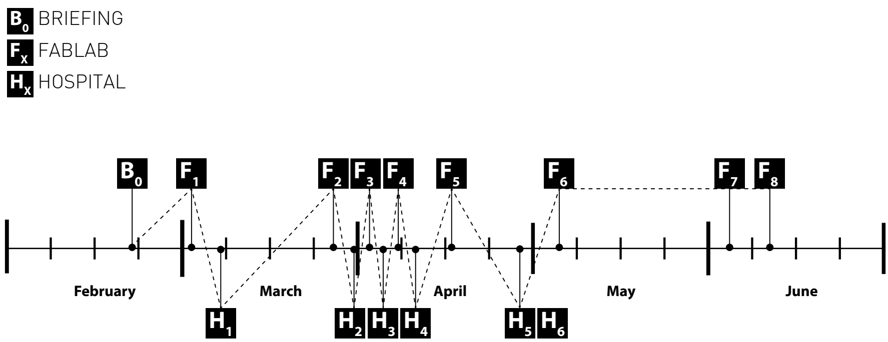

Figure 4. Oscillation between Fablab-time and Hospital-time reports.

To illustrate the process, we discuss the co-experience driven approach through key incidents (Emerson, 2004). All the posts from the self-reporting blog have been coded in Fablab-time or Hospital-time categories (figure 4) referring to context where the action takes place in time. Both can contain make and use design activities. The starting point is a design brief (B0) formulated by the occupational therapists. Insightful user quotes and notes on prototyping activities from each blog report were compiled (1-3 sentences) from the Schön matrices into thick descriptions.

Key Incidents

INITIAL CONTEXT

The participating client was Fred, a middle-aged man who works in a hospital as head of the sanitary nurses (see figure 5). With his technical staff, he is responsible for keeping the hospital free of bacteria. At the age of 23, Fred was diagnosed with ankylosing spondylitis. This disease, also known as Bekhterev syndrome, mainly affects joints in the spine and causes rigidity. Fred cannot lift his head entirely upwards due to this disability. His field of view slowly decreases each year. At the start of the participatory design session, he was no longer able to see the top of a door. This state of dysfunction causes considerable friction with some daily activities and reduces the contribution he can make in his working environment. Some practical examples are replacing lamps, reaching for material from high cabinets, or setting up the beamers. In his quest to find a solution, the participant has not found any professional assistive device that could help him in his familiar surroundings

Figure 5. The participatory design team

BRIEFING

Fred initiated the start of the process. He clearly was unhappy with his current situation and had a rather negative attitude towards assistive devices. Apart from having many practical skills, he has not found a way around the negative interaction between him and his working environment. Fred changes his personal values to find a solution independently. He decides to change his action strategy and calls in the help of other stakeholders. This event is a distinct illustration of a 'double-loop' adaptation. The consequences of multiple actions somehow exceed Fred's physiological limits and conflict with his current governing variables. This provokes a change in his belief system. By altering the perception of his values and skills, he takes a personal risk and opens up the way towards a contributing and a new relationship with other stakeholders.

FABRICATION LAB REPORT 1

Before visiting the client, the students respond to the design brief and externalize their prior knowledge into three low-fi prototype variations (figure 6). Each of them integrates mirrors into wearable glass concepts. We consider this a 'single-loop' process in which the students find it pleasant to engage with their current skills. By doing so, they show Fred their enthusiasm. To reduce the design effort in time and energy, they decide to re-use old parts and waste material located in the workplace. This keeps them in a state of flow (Csíkszentmihályi, 1990). While using one of the artifacts themselves (Figure 7), they report being surprised at the fact that the relationship between the eye-mirror distance and the experience of controllability are so strongly correlated and have a strong effect on performance. This event, which occurred within a prototype-use interaction, reciprocates their actual action strategy. The co-experience stimulates them to start an extra 'single-loop' adaptation and make a fourth prototype, which refines the aspects. These positive emotions steer them concretely towards two reactions—dividing the mirror into two parts and moving it closer to the eyes—giving them a sense of accomplishment within this design iteration.

Figure 6. Design time Report 1 prototypes (Bellens & Stubbe, 2011)

WORKSPACE HOSPITAL REPORT 1

The group first met together at the hospital. Fred evaluated all the prototypes within his working environment without being given any explanation about how they worked (figure 7). The test with the *periscoop 2.0* revealed that Fred used the prototype in a completely different way to that anticipated. Instead of handling the two mirrors to correct his field of vision, he only manipulated the farthest mirror to gain an eyeshot of the space right above his head. He regarded the prototype as a useful solution

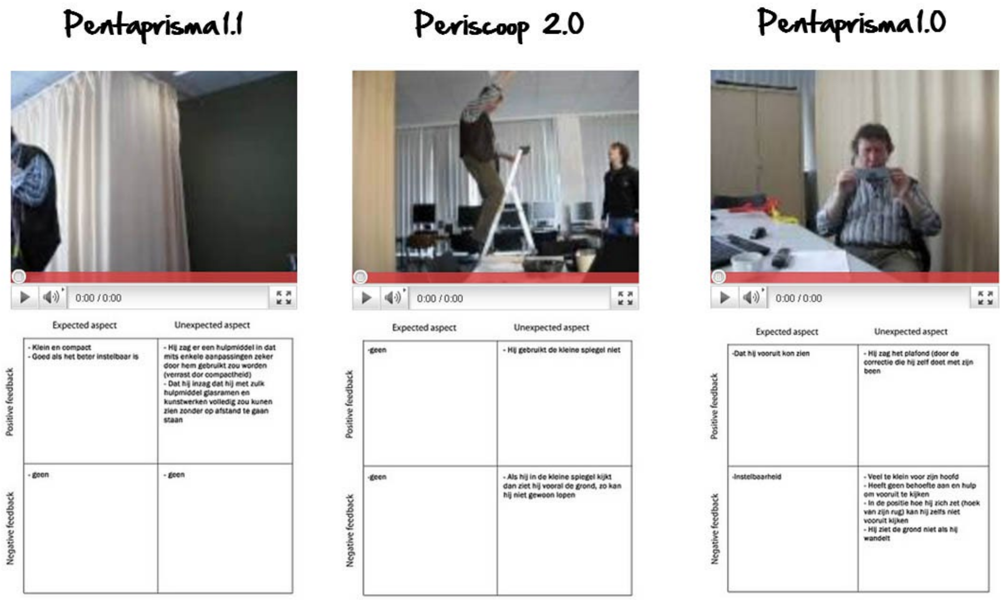

Figure 7. Use time report 1 (Bellens & Stubbe, 2011).

to different odd jobs related to his ceiling at home, which lies within the scope of the original problem.

As mentioned in the Schön matrix, another latent goal emerged from the interaction with the *pentaprisma 1.1*. From the moment Fred used the prototype, he perceived a whole new range of vision, which exceeded his current physiological limits. In response, Fred mentioned emotionally that he is passionate about photography. In his free-time, he takes pictures of large paintings by the Flemish Primitives and stained glass windows of old churches. His disability makes it increasingly harder to engage in this activity. This 'double-loop' reaction changes Fred's assumptions; he suddenly experiences the possibility of engaging in his meaningful activity through the use of an assistive device, and the reaction can be interpreted as an important cue.

The compact shape of the artifact evoked another unexpected positive reaction. The nature of this response was co-experienced as a rightfulness appraisal and focused on Fred's self-image. Fred is a very proud man with a high degree of self-reliance; the non-intrusive character of the *pentaprisma 1.1* embodies his attitude and standards towards assistive devices. The latter is a 'single-loop' adaptation, which explicates a governable variable which was awoken through the situation.

Of course, a lot of unexpected negative aspects were raised too: the view size of the *pentaglass 1.0* was too small, the artifact blocked the view of the ground, the size of the prototype was too small and so on. But the effort to overcome them was perceived as manageable by the students. The intensity of the

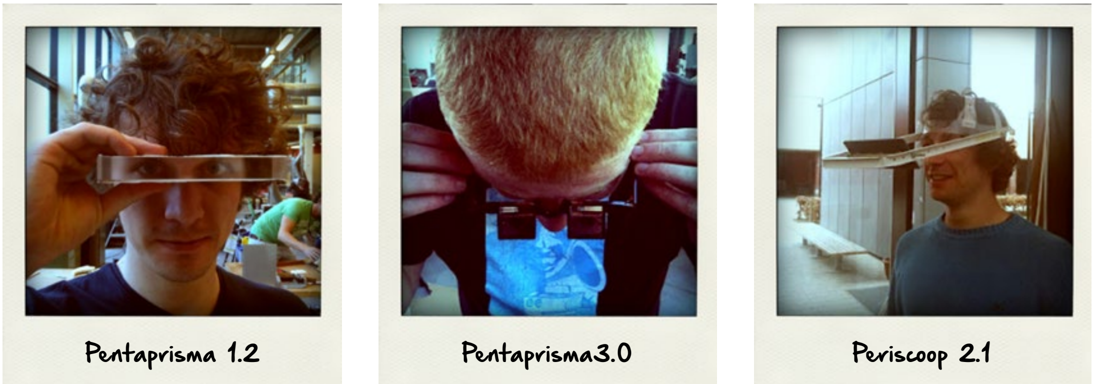

Figure 8. Design time report 2 prototypes (Bellens & Stubbe, 2011).

positive co-experience prompted them to plan new actions that would integrate these new areas of focus. Both agents experienced a sense of accomplishment, which nurtures the relationship.

FABRICATION LAB REPORT 2

In this phase, the students try to counter the unexpected negative aspects through creative prototyping and make new variations on the *pentaglass 1.1* and *periscoop 2.0* (figure 8). They still work on both main design strategies as they still have the time, interest and resources to do so. Although both prototypes have evoked several cues, the students want to repeat the same behaviour and see if they can observe coherent patterns in Fred's appraisals and behaviour.

The occupational therapists had noticed that Fred spontaneously corrects his vision through a flexion of his hip joint. This behaviour makes him capable of self-adjusting his field of vision and eliminates the technical requirement on the level of the product by integrating this skill. As the distance and angle between both reflective mirrors is so crucial, the designers decided to make their own prism glasses out of PMMA or Plexi glass. Although they managed to calculate the exact angles and size, the students did not manage to reach the same optical performance. This clearly is an unexpected negative co-experience which disturbs the flow within their creative process. Somehow they have reached the physical limits although mentally they understand all the principles for designing the PMMA glasses. The group decides to alter their action strategy and change their position towards the value and pleasantness of making the prototypes by themselves. With the help of the occupational therapist, they manage to buy standard prism glasses for 34 euros. This object turns out to be *pentaglass 3.0.*

The *periscope 2.1* consists of a mirror attached by means of a curved profile on the inside of a helmet suspension. The students expect that this hacked artifact will allow Fred to carry out tasks located above his head that demand a certain precision, such as turning a screw or replacing a lamp. The artifact makes it possible for Fred to keep both hands operational during a repair activity and therefore enables him to contribute within his domestic living environment.

WORKSPACE HOSPITAL REPORT 2

While testing the *periscoop 2.1*, Fred looks and behaves reasonably satisfied. He confirms the advantage of the hands-free aspects and considers the prototype to be useful when climbing a ladder as well. The space between the mirror and his eyes gives him the opportunity to look at his steps. He also repeats the spontaneous tendency to move the mirror closer to his eyes and emphasizes the compactness.

The purchased *pentaglass 3.0.* is tested by flipping it 180° and placing it in front of Fred's current glasses. He still manages to self-adjust his vision and is able to perform activities while looking ahead more and examining the ceiling. Fred again expresses a lot of positive emotions. Nevertheless, his global vision is distorted because the lenses do not align correctly to the position of Fred's eyes. Measuring and aligning both aspects are set as subsequent actions in Fablab time 3. After comparing both prototypes within this participatory design session it is clear that *pentaglass 3.0* evoked the strongest co-experiences, which highlighted several meaningful ingredients. The group is happy and confirms its accomplishments within this iteration. As well as the excitement of the unexpected event the designers perceive the next iteration as challenging too. There were no fundamental changes regarding the focus of the variables. The reciprocation of the co-experience characterizes a typical 'single-loop' iteration for all stakeholders

FABRICATION LAB REPORT 3

The group has found an area of focus that strengthens the group's relationship and increases expectations. The design activities follow in quick succession, which illustrates the reciprocating tendency within the process (see figure 4). As previously mentioned, the designers concentrate on several performance-related aspects within a 'single-loop' iterative process. Their action strategies focus on optimizing by making variations of the same aspects within their potential prototyping limits. In the first place, they want to investigate the distance between both prism glasses in relation to the position of Fred's eyes. Simultaneously, they are exploring the connection with the temples and the top bar. The resulting prototypes are all designed from an open and adaptive perspective. By using low-tech materials such as brass wires and double-sided tape, the prototypes can be easily transformed during the next encounter. These actions illustrate the willingness of the students to engage with Fred and the occupational therapist as equal participants in the participatory design process.

WORKSPACE HOSPITAL REPORT 3

All three prototypes were brought into the context of Fred's working environment. Together the group adapt the prototypes and they set up a real-life situation where Fred had to climb a ladder (see figure

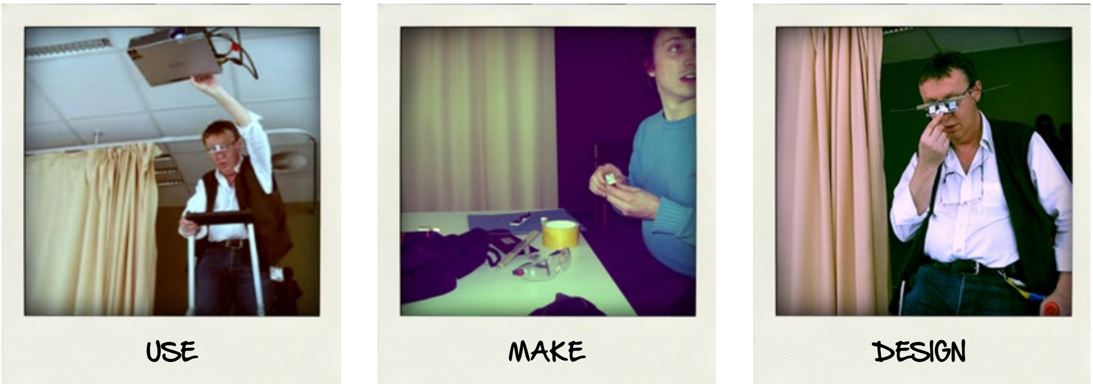

Figure 9. Hospital report 3, several prototype interactions within one context (Bellens & Stubbe, 2011).

9). The adaptive prototypes have a positive effect on Fred's co-design behaviour. Immediately, he starts adapting, using and suggesting new ideas. The students ask him to read the user interface of a projector that is mounted to the ceiling. By doing this they also find out by chance that Fred uses two types of glasses, one pair for close vision and the other for distances. Both frames are slightly different in shape and size. This unexpected 'single-loop' aspect creates some new challenges regarding the final connection of the prism glasses. The students perceive it as rightful and useful that the prism glasses should fit both pairs of glasses. Only this will enable Fred to use the assistive devices properly within his working environment as well as during his photography activities. The students integrate the aspect, but do not change their design strategy, perceiving the challenge to be manageable.

An unexpected positive aspect is the pleasantness appraisal on the weight of the prototype which Fred immediately shares with the group when he puts the *pentaprisma 3.1* on. The pressure on his nose is experienced as very light and makes the prototype look elegant. But as soon as he starts climbing the ladder the construction tilts backwards and forwards. Apparently, the connection that is established by the brass wires is not rigid enough to deal with these types of movement. Once he stands on top of the ladder he proudly shouts: "Yes!" and raises his thumbs to the students, which embodies a sense of accomplishment. From this iteration, the team gained the exact distances of the lenses. They express the fact that both prism lenses should be fixed parallel to Fred's glasses within a rigid structure to avoid distortion of his vision. All of these unexpected co-experiences have a 'single-loop' character as they only relate to the optimization of the current design solution. Again, the positive reaction of Fred and the experience of literally making together prototypes brings the team closer to each other, which results in the development of an open and shared language on relevant aspects for all agents.

Figure 10. Hospital time report 3, prototypes (Bellens & Stubbe, 2011).

FABRICATION LAB REPORT 4

The proposed goals of "Fablab-time 3" have been achieved and as a result of the previous co-experience, the designers are focusing on the stability of structure in addition to efficiently connecting to the temples of the glasses. The designers use another prototyping technique from their skillset and make three variants from thick rigid cardboard (see figure 10) with dual lock Velcro. This enables the group to compare and discuss the impact of some design distinctions. For all of the prototypes, they use the measurements they gained from the previous participatory design session. While making the prototypes, they explore the concepts themselves and share some experiences they found relevant. The design students co-experience the support bridge of *pentaprism 4.2* as useful while mounting the artifact onto the glasses. At the same time, they assume that the length of the bridge itself will be too big and will make contact with Fred's nose. They appropriate the auditory feedback of the Velcro as a useful aspect. The *pentaprism 4.3*, without a support bridge, takes much longer to align and position.

WORKSPACE HOSPITAL REPORT 4

The *pentaprisma 4.1* evokes, as expected, the most promising co-experiences within the team. Thisemphasizes the 'single-loop' character of this iteration. The support bridge surprisingly does not touch or bother the Fred's nose; it is widened by another 5 mm. Together, they concluded that the prism lenses should be aligned with the top of the eye lenses. Fred feels more and more confident in his role as co-designer. He suggests a lot of practical solutions and has noticed that the model fits perfectly in his spectacle case. The horizontal alignment of the lenses should be explored more thoroughly. The group's first impression is to make use of the top bar. These events show the openness and transparency of the decision-making process.

FABRICATION LAB REPORT 5

The design team felt confident enough to integrate all their current knowledge into more high fidelity prototyping techniques. They chose 3D printing and laser cutting. The designers are looking forward to the result as it is the first time they are using the techniques. They express positive emotions as they know that the result will look professional, coupled with the fact that they expect Fred to be impressed as well. They explore both manufacturing processes and provide all prototypes with the Velcro connection. By chance, the structure of the 3D print made it possible to fix the prism lenses through the friction generated by the ribbed surface. This was another unexpected win-win constructed within a 'single-loop' iteration.

WORKSPACE HOSPITAL REPORT 5 & 6

The printed model fits the reading glasses perfectly but still shows some problems with Fred's glasses for distant vision. The Velcro works perfectly but is not acceptable for the design students' finishing standards. They challenge themselves to explore more esthetical solutions. These events illustrate a nice example of a 'single-loop' correction based on the current belief system of both students.

FABRICATION LAB REPORT 6

They explore the use of small magnets and heat shrink tubes to attach the whole onto the temples of the glasses. The esthetical effect looks promising and from a behavioural point of view they will guide Fred even more intuitively during the position activity.

The designers still need to cut out some material at the level of the nose bar. 6 mm seemed to be sufficient. This action illustrates a typical 'single-loop' iteration which ends with quantitative measurements. Also the small legs can be shortened to print less material. While wearing the assistive device, Fred noticed that two small screws from his glasses scratched the printed part. He was afraid of damaging his glasses. Technically this could not happen, but the designers respected Fred's concern and immediately made two small cuts. This again illustrated the mutual relationship between both agents. Although there were a few practical concerns, the team felt in control.

FABRICATION LAB REPORT 7

The latest model was printed with an FDM printing technique. The students felt confident enough to send their file to Shapeways.com and print their frame with an SLS printer. This technique produced a much more detailed finish without losing its rigidity. The connection of the magnets onto the frame was solved with a small leather strip. With the help of an orange wire, they emphasised the aesthetic character of the connection. As the icing on the cake, they engraved Fred's name in the leather strip (figure 11). Fred trusts the students, as they do not have to come over to the hospital the show their

Figure 11. Reversed prism glasses - final result.

end-result. The actual product adaptations stop here: the students do not see any more challenges from their perspective. The product itself has reached a reliable stage of performance and reflects a nice balance between hedonic and pragmatic qualities. Fred, too, is not experiencing any problems that are serious enough to trigger a new iteration. As a result, they all are satisfied and proud of their achievement.

Results

In this case study, we already recognize some patterns (Table 1) between the unexpected co-experiences and subsequent adaptive design actions. Co-experiences of user-prototype interactions steer both 'single' and 'double-loop' adaptations and nudge engaging stakeholders into meaning-making. The prototyping actions act as a mobilization medium (Heylighen, Kostov, & Kiemen, 2013) which (a) coordinates and (b) motivates design actions towards new collaborative solutions. From a practical perspective, coordinated adaptations lead the group to "make the right things" and motivational adaptations stimulate the team to "make the things right". Both adaptations have an impact on the subjective well-being of the participants.

'Double-loop' adaptations coordinate the process in a compulsive way by integrating change at the level of be-goals, attitudes and standards. They literally transform the opinion and self-image of the engaging stakeholders. As a result, they start focusing on new activities, skills, engagements, and relationships. These co-experiences have a compulsory character; once physiological aspects exceed their limits when operationalizing a certain goal, forcing the co-design team to intervene. This does not always have to be in a negative way. We would like to refer to the moment where Fred puts on the pentaprisma 1.1 and experiences a whole new field of vision. With this experience, his current physiological aspects exceed their upper limits. 'Double-loop' patterns are sometimes hard to describe from a first-person perspective. From the experience of the changing agent, they are manifested through a type of passive reciprocation or rejection. This stresses the importance of designing with multiple agents who can mutually observe behaviour and interact with each other from a first and third-person perspective.

	Unexpected within limits	*Unexpected outside limits*
Positivily evaluated	• Adaptation through ‘single-loop’ learning. • Active reciprocation • Affects motivation	• Adaptation through ‘double-loop’ learning. • Passive reciprocation • Affects coordination
Negatively evaluated	• Adaptation through ‘single-loop’ learning. • Active rejection • Affects motivation	• Adaptation through ‘double-loop’ learning. • Passive rejection • Affects coordination

Table 1. Dynamics within co-experience driven design.

‘Single-loop’ adaptations instigate motivation to explore and challenge certain elements within the boundaries of the group’s current assumptions. Their starting point is the current set of activities, skills, engagements, relationships and contributions. Through a creative process, new combinations are made without questioning the initial scope. They compare a current state to a desired state, act to achieve the desired state with the resources at hand and measure progress toward the goal. ‘Single-loop’ prototype activities are strongly related to the concept of flow (Csíkszentmihályi, 1990), which puts the emphasis on the balance between skills and challenges. Participants who undergo these activities experience a type of active reciprocation or rejection. They have a sense of autonomy and control towards the actions within a certain environment. These design activities strengthen emotions towards relationships, accomplishments and contributions.

8.5 DISCUSSION

We believe that based on our experiences with several participatory design cases, making together is a powerful method that provides pleasure and respects meaningful goals, leading engaging agents to new sources of profound happiness. Its incremental and experiential approach allows them to adapt their assumptions through the engagement with design activities within their own local environment. The case study illustrates some necessary and sufficient conditions, which make this regeneration process possible. In all of these conditions, the co-experiences of prototyping actions play an essential role and have both social and technical aspects that we will discuss in greater depth.

(1) The process of reflective co-design serves as a common language between all stakeholders, which identifies meaningful goals and our personal limits in achieving them.

While using, designing and making artifacts, we are reminded by the environment of our physical, cognitive and emotional limits. All of these are a function of time and force ourselves to adapt one way or another. We need to explore these edges while undertaking action and simultaneously creating a shared understanding of the common goal. Some disabled people do not realize what they really are capable of or what truly makes them happy. Others seek unrealistic challenges or are fixated on one particular way of reaching their goal. This process might take some time, typically a few weeks at least, depending the nature and relationship of the participants. 'Double-loop' adaptations in particular need a certain time span due to their passive character. If certain elements are not clear, the best thing the team can do is to re-iterate with several new variations, consisting of other prototypes, activities or environments. Make sure that at the start of the process especially that each concept is clearly distinctive from the others. Work preferably with extremes and use these as a spectrum for the participants to engage with. By sequentially asking 'why' one prototype is better than another triggers the participants to examine their responses. Once the shared goal is clear, the process usually speeds up, driven by 'single-loop' co-experiences. The begin status should be clearly described in the start document to enable the group to compare its progress later on. For practically every iteration, the activities can be executed with both the initial and the adapted prototype. This method helps to highlight the accomplishments and lets the participants co-experience the progress or deterioration.

(2) The process of reflective co-design serves as an exploratory process to create new possibilities for achieving new goals.

From a 'single-loop' perspective, the most prominent question can be formulated as follows: "How many ways are there to accomplish a specific goal through well-balanced occupations?" We cannot stress the importance of this creative action as the strength of the method is based on repeat with variation. Designers are normally trained in this skill, but often focus too hard on product-oriented variations. A well-balanced occupation consists of three factors: the individual himself, his activity capital and the surrounding habitat which encloses both social and physical capital aspects. Morphological matrices, which underline these factors, force participants to explore in a much wider perspective and increase the number of ideas by making new combinations (for examples, see Desmet, 2011 & Pohlmeyer, 2012). Non-designers often have problems with the notion of creativity. We invite them to suggest new ideas through the process of copying, transforming and combining elements from the several user-prototype interactions. These activities increase the sense of engagement and slowly move the participant to the position of "expert of his/her experience" (Visser, Stappers, Van Der Lugt & Sanders, 2005). From a 'double-loop' perspective, each creative process within a "design for well-being" context has the tendency to shift from a problem-driven approach to a possibility-driven approach. The instigators are often perceived as unexpected positive events. The Schön matrix is a useful tool for creating openness and joint attention towards these types of event. As mentioned in the results, critical co-experiences have a compulsory character and demand the group's attention through a creative reaction. Denying them will, in the end, stop the self-organization and split the participatory design collective.

(3) The process of reflective co-design nudges people to take action to progress the co-design activity.

The ability to bring ideas into practice is a third essential condition. Before the group can make errors and learn, they have to take experiential action within a certain environment. Despite the accessibility of digital manufacturing processes, we emphasise the importance of underdesigned artifacts (Fischer & Giaccardi, 2006). What makes these primitive prototypes so exceptionally useful is that some properties are explicitly given up in order to augment the engagement process and leave space for spontaneous behaviour. By framing prototyping actions as meaningful activities, we aim to make this process from a 'single-loop' perspective more fluent and self-organizing. The team should honour the fact that participants have different capabilities. Design for engagement has to resonate with the level of skills and interest, using just enough technology to get the prototyping activity going. Everyone is creative at a certain level. The work of Liz Sanders (2006) distinguishes four levels of experiencing creativity: doing, adapting, making and creating. Each level requires more interest and a higher skill set. From a pragmatic point of view, we always start at the level of doing and adapting. The use of a prototype by a disabled person can be considered as the lowest level, that is, doing. The case study illustrates a nice example of adaptive prototyping. At a certain stage, the students made adaptive prototypes that enabled Fred to adjust the location of the prism glasses so that they better fit his functional needs. These actions require a more facilitating role, but lead to positive emotions and a sense of accomplishment when properly tuned. A good adaptive prototype medium is robust to small technical details, making it easy to leave out details, and does not require detailed skills, which makes it possible to focus on what you are doing rather than how you do it (Gedenryd, 1998). Materials such as Velcro, double-sided tape, brass wire and Plasticine are often used to give prototypes a more adaptive character.

4) The process of reflective co-design stimulates habituation of new options in the design process, such as new technology and new human skills.

This fourth condition refers mainly to the process of flow within 'single-loop' adaptations. Csíkszentmihályi (1990) describes occupational emotions as the relationship between the perceived challenges of the task at hand and someone's perceived skills. Practically, when a co-experience of prototyping action leads to anxiety, the co-creation team can undertake two types of action. The first action could be to vary the characteristics of the challenge. Occupational therapists can break down activities into achievable components or they can teach new ways of approaching tasks. Within this approach, activity analysis is an often-applied technique. It is defined as a process of dissecting an activity into its component parts and a task sequence. It allows people to identify inherent properties and skills required for its performance. A second type of action can be found on the horizontal axis. It rests on augmenting the skills and ability of the patient through product and environmental adaptations. Factors like people can also be taken into account through the guidance of family members and caregivers. In the first approach, we admit that much of human behaviour can be thought of as an adaptation to the powers and limitations of technology (Norman, 2005). The second approach asserts, as a tenet, that technology adapts to human agents. Adapting technology to users increases prototyping effort. Adapting users to technology takes time. In reality there is no ideal standard approach. Design for well-being switches constantly from meaning to technology and vice versa.

8.6 CONCLUSION

In many more cases, disabled actors cannot act physically as designers but somehow trigger caregivers from their direct environment into taking action and give birth to self-organizing design activities. This paper suggests a process-oriented approach that respects the subjective experiences of all participating stakeholders and highlights the meaningful aspects of the process itself. Prototyping activities (making, using and designing) are framed as sources of happiness, which lead to engagement, new challenges, fruitful relationships and sense of accomplishment. Product adaptations and stakeholders co-evolve towards balanced well-being equilibria. The notion of single and double-loop helps us to explain the underlying transformation processes driven by the physical, cognitive and emotional potential of each stakeholder. Double-loop adaptations have a compulsive character and steer the creative process to new and disruptive possibilities that keep the participatory design team together. Single-loop adaptations strengthen emotions towards relationships, accomplishments and contributions. The process itself tries not to be prescriptive; rather, it attempts to build on the use of local knowledge and works with the situation that emerges from unexpected user-prototype interaction. Mismatches will lead to new understandings and identify challenging opportunities for new solutions. By balancing empathy and systematic observation, it tries to detect and make use of relevant skills and experiential knowledge. The participatory design method allows participants to understand the experience domain of the patient in relation to the product ecology. Design for adaptive capacity through participative systems is an optimistic and sustainable way of turning disabilities into new possibilities. Ideally, these structures help people to find out for themselves what the most effective way to act in a meaningful and challenging manner is.

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9. UNCONSCIOUS TOOL

IMPLICIT VIDEOLOGGING
OF ADAPTIVE PROTOTYPING

"The secret of change is to focus all of your energy, not on fighting the old, but on building the new."

(Plato)

In this chapter we explore the implicit use of physiological technology to tag the orienting response of design agents while performing hacking activities. Our goal is to tag adaptive behaviour by synchronizing electrodermal activity with a video stream of prototyping activities. Unlike all the other case studies, the studies comprised in this chapter were conducted within a semi-controlled laboratory setting. The development of the tool was mainly triggered as a digital optimisation of the conscious analogue tool descripted in chapter 8.

ABSTRACT

Hacking behaviour principally builds on the patterns of reflection-in-action and the remarkable ability of humans to recognize change in the consequences of their design actions that they anticipated ahead of time. In this case study we propose the use of physiological technology as a tool for capturing situation awareness within tangible prototyping activities by measuring the orienting response (OR). The user's OR is captured by electro dermal activity (EDA) sensor in order to generate real time tags in a video stream. Our aim is to explore the appropriateness of the proposed technology within the context of participatory hacking. Within this case study we describe a clear theoretical rationale and a practical design process of an open-design capture system. To validate our approach we conducted two preliminary studies in which we compare the efficiency and relevance of the technique with third person protocol analyses (case study 1) and first person self-reports (case study 2).

Out the first study and design we could conclude that the explicit sensor data coming from the event-mark button on the capture system is negligible. As both buttons were hardly used and only positive experiences were explicitly tagged. On the contrary the implicit sensor data coming from the EDA sensor captured a variety of prototyping events which encloses all type unexpected physical, cognitive and emotional interactions on events. By tuning the threshold of the EDA sensor designers can literally zoom in or out on personal prototyping experiences.

The second study focused on cross-referencing data streams of multiple agents, which resulted in a thorough sample relevant co-experienced events within a common design activity. The results are a prelimanry proof that the technology is also able to capture "*tacit knowing*". This partially confirmed through the observed fact that *non-verbal actions* and *re-appropriations*, *unexpected consequences* (both positive as negative), *emotions* and *action tendencies*, *nuances in optimizations* of action strategies and *physical effort* coming from both agents, are indicated in an unaware manner through their common physiological responses on shared prototyping-interactions. A second conclusion is the need of a post processing information dashboard to do distinguish the personal relationships of specific OR patterns with physical, mental, and emotional components.

9.1 INTRODUCTION

Today the playground of industrial designers consists of dynamic social-technical environments with hidden interdependencies and fast changing requirements. Problems involving the relationship between human meaning and technology have a certain *"wicked component"* (also see Rittel & Webber, 1973; Buchanan, 1992), which demands an opportunity-driven approach, requiring decision making, doing experiments, launching pilot programs and testing prototypes on the spot. Co-design methodologies involving embodied prototyping activities are a powerful engine for handling wicked aspects through engagement with stakeholders and their local environment (see chapter 5). Situated prototyping puts stakeholders at its heart, working from their spontaneous behavior, engaging latent perceptions and emotional responses. Problem understanding and decision-making that deal with uncertainty arise from experiencing meaningful events around situated possibilities. The most important competence of designers is to create experiential artifacts and learn through situated prototype-interactions involving other stakeholders within their local ecology. Each stakeholder experiences a prototype in his own way and context. Doing so he interacts spontaneously using all his knowing, even if this is tacit (Polanyi, 1966). Doing and thinking are complementary and make it hard to document key incidents that steer decision-making and the inquiry process of relevant design aspects. Therefor the focus of this publication lays on the application of interaction capture and retrieval within the context of adaptive prototyping behavior.

There are several motivations for constructing documentation of the reasons behind local decisions made while creating an artifact (Caroll & Moran, 1991): (a) first of all to support the reflective reasoning processes within a co-design process, (b) secondly to facilitate communication among the various direct and indirect stakeholders within the design projects and detect human biases (designers, implementers, maintainers, users, etc.) and (c) finally to further the accumulation and overall development of design knowledge across a diversity of design projects. An approach towards minimum system participation has led to reconstruction (Lee, 1997). A technique that is used to capture the design rationale from raw video data. In contrast with systemizing techniques, this "second-generation" design method (Rittel, 1984) aims to capture the non-linear reasoning processes behind the design and specifications of artifacts. Reconstruction allows more careful reflection on the representation of the rationales with a clear focus on decision making without disrupting the activities of the design agents. On the down side, the technique still heavily relies on the weakness of human memory and the effort/cost of reconstructing activities is considerable high. Most capture systems focus on recording activities during meetings, lectures, or other forms of work related conversation (Whittaker, Tucker, Swampillai,| & Laban, 2008) and use smart pens (Li, Cao, Paolantonio, & Tian, 2012), whiteboards (Oehlberg, Simm, Jones, Agogino, & Hartmann, 2012) notebooks (Lee, 2008) or smart tables (Hunter, Maes, Scott, & Kaufman, 2011) as interaction recording techniques. New life logging technologies involving wearable sensor triggered video and audio systems, can partly solve this paradox through implicit human computer interaction (Schmidt, 2000). The technological advances within this field create new opportunities to design situation-specific capture and access systems that are intuitive and unobtrusive.

Within this case study we generally focus on capturing changes within situated awareness or in other words capturing new information coming from the interaction with the environment. Doing so we aim to retain the relationship with embodied prototyping-interactions such as making, exploring and testing of artifacts. The context of prototyping-interactions brings in some new challenges on the process of capturing situated design behavior: (1) In the first place co-design sessions have a spontaneous character (cycles of action on re-action) which makes it hard to reconstruct or even document meaningful events without losing the flow (see Kunz & Rittel, 1970; Jones, 1991 ; Conklin, 2005; Cross, 2006). (2) At the same time each stakeholder experiences designs in their own way and in their own contexts and interacts spontaneously with the designs using all his personal knowing, even if this is tacit (Polanyi, 1966; Rust, 2004; Wood, Rust, & Horne, 2009). (3) One cannot predict in which sequence the actions will happen or when emergent knowledge will pop-up during embodied prototyping interactions (Flach, Dekker, & Stappers 2008). Although video is a powerful medium to capture all observations the post processing analyses takes a lot of time when one wants to filter out all the key-incidents. While doing so there is often a big discrepancy between the remembering self and the experiencing self (for an elaboration see Kahneman, 2000). Furthermore, every interaction or insight changes its observer and makes it impossible to return unbiased to previous states of awareness (Kounios & Beeman, 2009). (4) In most co-design projects agents need both hands or their entire body to handle the physical artifacts while interaction with the environment. In this case study we use the theory of embodied interactions as a perspective to frame the above prototyping interactions as a phenomenological approach (Dourish, 2004).

With these requirements in minds we discuss the role human orientation reactions coupled with video glasses as a possible solution. The aim of this capture system is to filter and share online video reports from on-the-spot relevant prototyping interactions from the first person perspective of the engaging stakeholder. Our goal is to log cues in a non-intrusive and spontaneous way. Through explicit and implicit event-based tagging we document the orienting response around embodied prototyping interactions. For this purpose we have combined conscious and unconscious sensorial data with a first person view video stream and conducted a first study to evaluate the video data with the actual key events.

9.2 SITUATED AWARENESS

Over the past twenty years the construct of situated awareness (SA) has received considerable attention from psychology and human factors communities. Generally speaking the field of study is concerned with perception of the environment critical to decision-makers in complex and dynamic real-life situations. Its theories and assessments have been applied within applications areas such as aviation (Craig, 2012), air traffic control (Kraut, 2011), large system operations (Parashar et al., 2012), tactical and strategic systems within fire fight (Toups & Kerne, 2007), police and military units (Van den Broek, Neef, Hanckmann, Gosliga, & Halsema, 2011). In essence SA involves being aware of what is happening around you to understand how information, events, and the expected consequences of your own actions will impact your goals and objectives, both now and in the near future. Still there is no universally accepted definition of the concept in the human factors literature or among the practitioner communities that apply the construct. The literature on SA is generally speaking divided into two main approaches to define the construct. The main amount of SA research originated from static information processing and typically follows the cartesian tradition that sets the mind against the world and that maintains that it is meaningful to examine a mind independently of that world (e.g. Endsley, 1995). In contrast stands the dynamic view of Neisser's (1976) perception/action cycle which advocates that consciousness exists and gets its shape as a process of the flow of events by interacting with the environment (Adams, Tenney & Pew, 1995; Chiappe, Strybel & Vu, 2012)

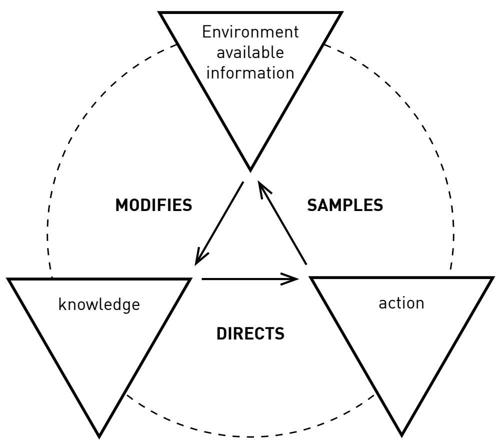

Figure 1. The perception/action cycle (Neisser's, 1976)

For this case study we adopted the view of the latest approach as it harmonizes with the reflective practice in design activities (Schön, 1983) and has strong ties with the ecological perception theory (Gibson, 1979) that created the foundations of affordances within prototype-interactions (Norman, 1988). While prototyping, a designer perceives the world in terms of what he can do with it, i.e. in terms of the action possibilities of our bodies; the functionality of the world reveals itself through manipulating the world, in interaction.

figure 1 shows that the perception/action cycle (Neisser's, 1976) consists of three elements (a) the actual present environment which contains all available information, (b) schema of present environment (i.e internal knowledge that is theoretically structured, developed through training/experience) and (c) perceptual exploration through action. The cycle is hypothesized to work as follows: the environment informs the agent, modifying its knowledge. Knowledge directs the agent's activity in the environment. That activity samples and perhaps anticipates or alters the environment, which in turn informs the agent. The informed, directed sampling and/or anticipation capture the essence of the behavioral characteristic of SA. (Smith & Hancock, 1995).

As a rule we define SA as adaptive, externally directed consciousness (Smith & Hancock, 1995). In essence a crucial construct which can explain goal-directed behavior within practice-led design environments. We will use it as a descriptive label that embraces adaptive prototyping behavior by capturing the change of directed consciousness that generates a new action given a particular prototyping situation as it unfolds. First we characterize the dynamics of SA within adaptive prototyping behavior and secondly we discuss the experience of SA in terms of the perception-action cycle.

The Dynamics of Situated Awareness within Embodied Prototyping-interactions

We define prototyping as the embodiment of new knowledge in the practical outcomes of making, using and exploring prototypes. Embodied prototyping presupposes that you anticipate a problem or issue through tangible solutions, e.g., a product, a device or an environment. SA generates knowledge and action on prototyping, giving the structure of its environment. Situated prototyping behavior principally builds on the same patterns of reflection-in-action and the remarkable ability of humans to recognize change in the consequences of their moves that they have expected or described ahead of time (Schön, 1983). For this reason embodied prototyping epistemology within design practice is in essence constructivist (Koskinen, Zimmerman, Binder, Redstorm & Wensveen, 2011). Knowledge cannot be passively absorbed from the environment; it must be dynamically constructed through dialogue with the engaging design agent itself (Gedenryd, 1998). The act of developing a prototype within an environment, observing expected and unexpected behavior, functions as a generative algorithm of knowledge.

Within this iterative process the design problem and potential solutions "co-evolve" over time (Maher & Poon, 1995). This form of adaptation is a process in which an agent channels his knowledge and behavior to attain goals as tempered by the conditions and constraints imposed by the environment (Holland, 1975). The validity of the problem-solution co-evolution model of design behavior has been argued as a cognitive model within design research literature (Dorst & Cross, 2001; Maher & Tang, 2003). Even outside laboratory contexts the same patterns seem to arise in naturally occurring collaborative design activities. (Wiltsching, Christensena & Ball, 2013). As a rule adaptive prototyping

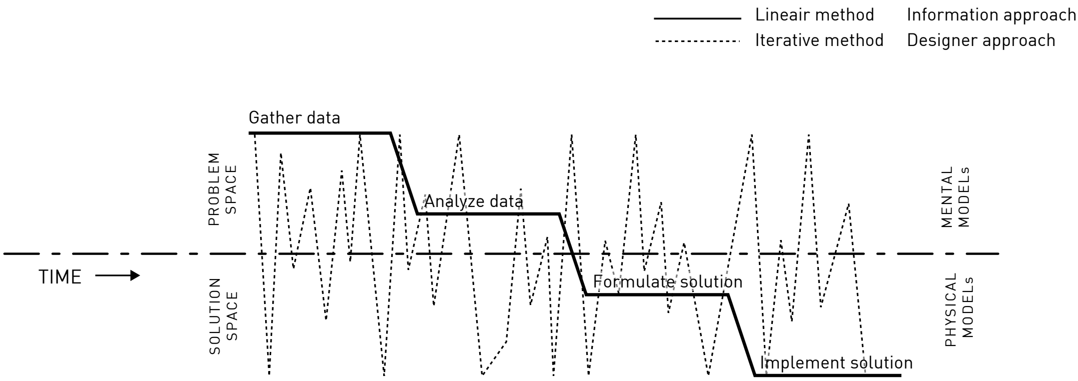

Figure 2. Pattern of cognitive activity of one designer – jagged line (adapted from Concklin, 2005)

participants aim to reduce uncertainties by experiencing constraints on practical possibilities (Ashby, 1960; Krippendroff, 2007). Figure 2 illustrates the pattern of cognitive activity of one designer in contrast with the waterfall process applied within traditional information processing. Designers show the tendency to understand problems by formulating potential solutions. Each solution unfolds new information and redefines the understanding of the problem. As a result the agent modifies its knowledge in a manner that affords appropriate action (Gibson, 1979). In this case study we state the hypothesis that if we want to log new information gained through adaptive prototyping behavior we need to capture the relevant tipping points between changes of prototyping-interactions from the perspective of the involving stakeholders. These events capture the changing states of an agent that perceives, feels, or is suddenly conscious of changing environmental events, objects, or sensory patterns.

The Experience of Situation Awareness within Embodied Prototyping-interactions

As discussed within the above section the mind is not an observer at all, but rather the central creator of a perceptual cycle (e.g. Neisser 1976). The perception of the environment is continually being created by cycles of expectation and action, by the questions asked of it (Smith & Hancock 1995). The ontology of this view holds that it is the dynamic transaction or conversation between the situation and the agent's awareness that is the only relevant reality (Flach, Dekker & Stappers, 2008).

We distinguish therefor three ways to frame prototype experiences and discuss how they are dynamically related to SA based on an interactionist perspective (Forlizzi & Ford, 2000). (1) The first layer of experience is the constant stream of stimuli that happen during moments of consciousness. For instance, when riding a bike one only focuses on certain aspects of the road, and meanwhile you experience all kinds of default aspects which are perceived as naturally and processed intuitively: wind blowing through your hair, feeling of balance, the precision in which you have to take a corner, and so on. We perceive these sub-conscious experiences as "thoughtlessly". (2) Another way to talk about experience is having an experience, suddenly an aberrant behavior occurs and the interacting agent senses a change. For example, during the bike trip one suddenly hears a strange noise coupled with experiencing high friction when pedaling. All of a sudden tacit experiences that were unconsciously sleeping, wake up and draw our attention (Polanyi, 1966). This type of experience entails the interaction of low-level cognitive, perceptual, and motor operations. It has typically a beginning and an end and is sensed as "unfamiliar" or "confusing" or "surprising". (3) Immediately after the surprise comes a positive or negative emotional appraisal. The third way is to talk about experience as a story on a meaningful event. This can be a form of internal self-talk or a communicative transaction to one or more participants within the co-design context. Agents try to communicate and explain what happened and judge the effect of the event on their current activity and their goals. In the case of the biking trip one can stop biking and think about getting a bus to reach its destination, or phone a friend which lives nearby and ask some help to repair the tire.

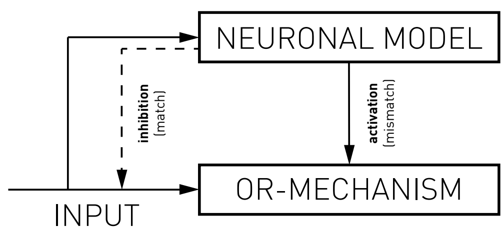

Figure 3. Model of OR-mechanism adapted from Sokolov (1960).

With these three components we aim to illustrate the spectrum of SA when interacting with prototypes. From this theoretical perspective it is clear that we have to capture meaningful prototyping events (or the tipping points within figure 2) not only when they are verbalized, but also when they are perceived and "grab" our attention. Designers or stakeholders always have default implicit or explicit expectations that can differ from each other but also raise conflicts with perceived experiences build around prototype interactions. These events are key incidents (Suwa, Gero & Purcell, 2000) within the inquiry process steered by adaptive prototyping. To measure consequences in relation to intention, we decided to focus on the act of surprise. Surprise is right there on the fuzzy border between two related cognitive phenomena, emotion and attention (Ludden, Hekkert & Schifferstein, 2006). A surprise reaction has its origin in encountering an unexpected event, and illustrates when the theory-in-use is congruent with the espoused theory of the co-design team (Schön, 1983). Or in other words when a tangible solution changes the perspective on a problem (Dorst & Cross; 2001).

This basic emotion characterized by a state of arousal indicates new reality constructions for all participating stakeholders and helps them focus on new possibly significant design variables within the environment. In biological psychology, awareness is defined as a human's or an animal's perception and cognitive reaction to a condition or event. The human reaction to experiences on novel or significant stimuli is called the orienting response (OR) and was first described by Ivan Pavlov in 1927. The most effective orienting stimuli are loud sounds, suddenly-appearing bright lights, changes in contours, or movements in the peripheral visual field that are not regular, predictable occurrences (Sokolov, 1960). It is as though we had an internal 'model' of the immediate world of stimuli around us (see figure 3) and the violation of an expectation elicits an OR. When we perceive a departure of stimulus input from that model, we reflexively orient to that stimulus in order to update that model as quickly as possible (Sokolov, 1975). ORs are often examined to gather insights on human attention and information processing. (Pan et al., 2011a). It has sometimes been suggested that the facilitation of learning is one of the functions of the OR (Kahneman, 1973). From an evolutionary perspective, this mechanism is useful in reacting quickly to events that call for immediate action. The brain focuses its attention on gathering more information while the rest of the body is quiet.

9.3 OPERATIONALIZATION

Measuring SA within Embodied Prototyping-interactions

Our aim with this project is to design a more intuitively and non-intrusive logging tool which fits within the cognitive dynamics of a prototyping process. The capturing process should not interrupt nor interfere with the diversity of local prototyping-interactions (e.g. making, using, exploring). These requirements impinges with the fast majority of SA measurement techniques (for an extensive overview see Salmon, Stanton, Walker & Green, 2006 ; Uhlarik & Comerford; 2002) which are derived from the information processing perspective and mainly focus on SA as a state of knowledge and changing mental models. Generally speaking we can make a distinction between three categories. (1) Most techniques assess the participants only verbally on certain predefined variables through think-a-loud protocols, freezing simulations or retrospective interviews. (2) A second approach focusses indirectly on task performances to infer SA. In the case of adaptive prototyping this is almost not possible due to the high degree of uncertainty. We don't know at the start of the design process what the exact end-goal will be and what the most optimal approach is. (3) A third category consists of subjective measurements techniques which focus on self-rating, either by the participant or an observer. At a later stage physiological techniques, such as EEG and Eye-tracking (Smolensky, 1993), have been shown useful for exploring the processes agents use in achieving SA but received less attention due to their inability of using them outside the laboratory setting (Endsley, 1995).

Within this case study we choose to further explore the potential of physiological techniques through wearable biosensors as our aim is to capture the behavior of goal-directed actions within situated

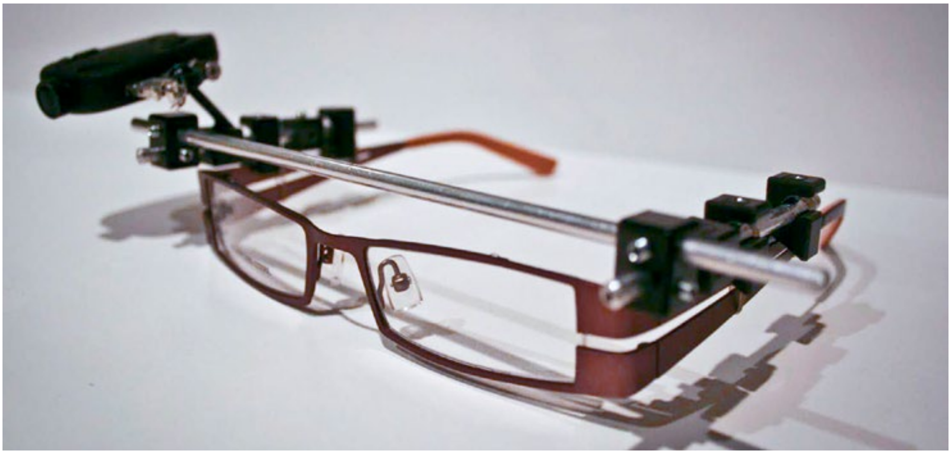

Figure 4. Headcam setup

environments. As stated within the above section on human experience of SA we aim to capture both conscious and unconscious reactions on prototyping-interaction. It is clear that embodied prototyping is a typical multitasking scenario and could benefit from implicit human computer interaction (Wickens & Holland, 1999). By using a system that can recognize a user's actions (Schmidt, 2000) we aim to capture also low-level cognitive, perceptual, and motor operations through interaction with the design context. Within the next section we describe the operationalization of the chosen measurement approach.

Capturing SA within Embodied Prototyping-interactions

By taking the above theory into account we blended following aspects within one multimodal capture system: (1) a device which records audio and videos from a first person view as we want to log personal events, (2) apply a biometric sensor that is capable of measuring a user's voluntary and involuntary physiological responses to a situation, (3) allow conscious user input to document meaning-making and new anticipations on prototyping events. As a rule we strived to produce a setup with open hardware by using technology designed and offered by the open design community.

VIDEO TECHNOLOGY FOR IMAGERY AND SOUND OF ORIENTING RESPONSES

For building the video glasses we were inspired by the groundbreaking work of Steve Mann (2001) on the Eyetap technology and the rise of the google glasses. However, for our premier purposes we wanted to create a one-way system, which means a small camera mounted on a wearable frame and no display that superimposes computer-generated imagery. This setup made us capable to log a participant's fixations during prototyping-interactions. We used a small 808 camera that has its roots in spy cameras, but evolved to a multipurpose device. It is a popular video-logging tool for remote controlled devices.

The head mounted unit of the capture system started out as a camera taped on some glasses, went through numerous upgrades based on user tests with the design researchers, and ended up with a modular open hardware frame. This frame can be used on glasses (see figure 4) or as standalone unit and consists of aluminum bars with 3D printed plastic connectors. That frame suits the needs of the enabling them to add features. The functions of the final prototype were: (1) External battery, (2) a battery guard which indicates low power level of the external battery, (3) Boost convertor to charge the camera, (4) Wireless video module.

PHYSIOLOGICAL TECHNOLOGY FOR SENSING AND FILTERING ORIENTING RESPONSES

Several researchers within the HCI field have recognized the potential of implicit human-centered tagging and have developed interactions based around user physiological sensing (for an extensive overview see Soleymani & Pantic, 2012). Out of the variety of physiological sensors we selected electrodermal activity (EDA) as it is one of the physiological mechanisms associated with OR (Bradley, 2009). Previous research has shown that within normal ranges of ambient room temperature and controlled subject state and motion there is a high correlation between OR and EDA (Frith & Allen, 1983). Another advantage is the fact that EDA can be detected quickly and has no need for complex analysis.

An EDA sensor measures electrical conductance of the skin, which varies with its moisture level. This is of interest because sweat glands are controlled by the sympathetic nervous system (Sato, 1989), so skin conductance is used as an indication of physiological arousal, such as surprise. Technically, this process measures the electrical conductance between two points by sending a small current through the skin. The density of sweat glands is more concentrated at the hands and the soles of the feet (Mendes, 2009; Poh, 2010; Bouscein, 2012;). The hands will be used to attach the electrodes, because they are easily accessible. Specifically, the electrodes will be put on the adjacent fingers because they are innervated by the same spinal nerve.

There have been initial successful attempts to use EDA-based classification to tag context-aware interactions within several applications. For example: Healey and Picard's pioneered with the Startlecam (1998), a wearable video camera which captures take digital images when a user is startled, Other more recent applications are EDA-driven bookmark system for audiostreams (Pan et al., 2011b) and highlight detection in movie scenes (Chenes, 2013).

Practically we made use of the EDA sensor open-design manual by Wang and McCreary (2006). The sensor consists of a circuit that measures conductance, an LCD menu and pushbuttons for user input. Aside from software possibilities, they also made a simple biofeedback game. Some important remarks during their process are noted and considered in this project. The EDA sensor proved to be

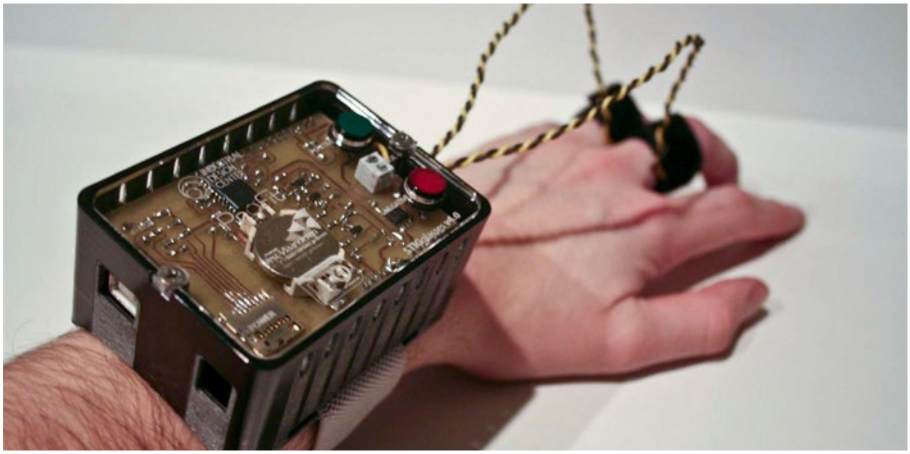

Figure 5. Arduino setup with EDA and valence event-mark buttons

a good guideline to construct a reliable open-hardware Galvanic Skin Sensor. The final prototype (See figure 5) is an Arduino UNO shield with these functions: (1) Ambient temperature sensor, (2) Real-time clock to enable the sensor to work independently. (3) Wheatstone bridge to calculate the skin resistance with a frequency of 30 milliseconds. (4) Differential amplifiers to raise the measurement value. (5) Low pass filter that filters out interference peaks. (6) Voltage divider with microSD module to log the measurements

NARRATIVE TECHNOLOGY FOR INTERPRETATION AND ANTICIPATION OF ORIENTING RESPONSES

The last requirement is to allow users' input for documenting meaning-making and new anticipations on prototyping events. This has been implemented by adding two user input buttons that represent a positive (green) or negative (red) valuation (event-mark buttons). Valence, as used in psychology, especially in the context of emotions, means the intrinsic attractiveness (positive valence) or averseness (negative valence) to an event, object, or situation. Together with the data from the implicit EDA sensor (which represents the dimension of arousal, ranging from calming to exciting or agitating) we can construct the nature of an affective experience (Russel, 1980). These buttons (see figure 5) enable the participant to consciously tag certain events. Additionally, the participant can capture his interpretation of that event through a think-a-loud speech that is recorded via the microphone.

9.4 CASE STUDY 1

The goal of this study was to compare synchrony of a single user capture system with a third-person protocol analyses within a hacking activity. Or in other words, how well does the automatic capture system corresponds with a traditional reconstruction process.

Procedure and Setup.

As a primary validation of the capture system we created a setting in which a co-design team had to solve a practical challenge through participatory prototyping. Both participants had a graduate degree in industrial design and were recruited from the industrial design engineering technology educational program. We examined the co-design behavior of the participants while they interacted with various prototyping materials and each other. By putting the designers into pairs we aim to evoke more think-aloud dialogues that give us a better perspective on cognitive reasoning within the prototyping activities. The room of the setup was deliberately kept open to create a naturalistic session and stimulate spontaneous social interactions with other passing agents.

For the procedure we chose the egg drop test where participants design a vessel from everyday materials to protect a raw egg from a fall. They received limited materials (see figure 6) and a strict time scheme of 20 minutes to find from their perspective a solution through participatory prototyping. One participant was tooled with the capture system described within the above section and was briefed about the red and the green button; representing the capture of positive or negative prototyping interactions. According with the standard practice (Bouscein, 2012) the capture system was positioned on the left wrist, which corresponded to the non-dominant hand of the participant. The logged designer created his own video and sensor data from a first-person perspective. From the latter, there were two data variants, (1) one constructed with the EDA data and (2) one constructed through the two reflective event-mark buttons (i.e. green=positive and red=negative). The session took place in an open environment so randomly other agents could interfere with the design process and drag the attention of the co-design team. Our main goal was to evaluate the use and performance of the capture system within a situated context of adaptive prototyping. To achieve this objective we observed the tipping points within the embodied prototyping behaviour and looked for similarities and discrepancies with the conscious and unconscious sensor data.

CODING PROCESS AND DATA ANALYSIS

For the protocol analyses of the video data we took a strong behavioural perspective. We assume that the goal of the behaviour that directs SA resides in the prototyping behaviour rather than in the agents head. Table 1 shows a snapshot of how the raw data was categorized and analyzed. The protocol analyses method was chosen, as it is a technique that takes a qualitative stance on the interaction between

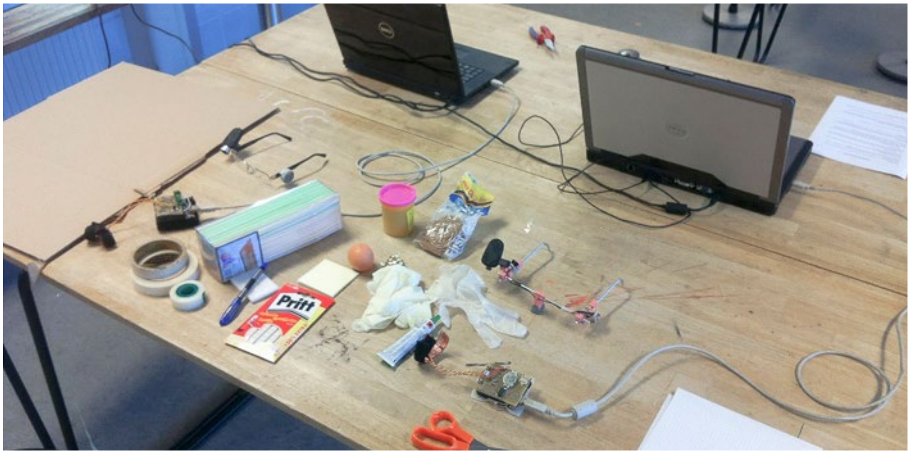

Figure 6. Set up study 1

cognitive and behavioural design activities. The recordings were transcribed in time and segmented to units of complete though. Later on each verbal extract was combined with the observed prototyping-interaction. Through thematic analysis, we identified a limited number of design strategies that adequately reflected the verbal data of the transcripts. All prototyping-interactions within each design strategy were interpreted and abstracted to several design objectives. A design objective is defined as an operationalization of certain design strategy by coupling a function with one or more prototyping means. Each time a design objective switches a tipping point it is marked and considered as a co-evolution pattern. This can happen within the current design strategy or at the beginning of a different strategy.

Line	*User*	*Time*	*Verbal Protocol*	*Verbal Protocol*	*Design Strategy*	*Means*	*Tipping Point*	*Prototyping-Behavior*
1	U1	0:00:04	*"Lets first surround the egg with this...".*	Protection egg	M1	Protecting the egg by covering with plasticizer		Pointing the plasticizer in its packaging.
2	U2	0:00:10	*"Why don't we put the egg in the little pot..."*	Protection egg	M1	Protecting the egg by covering with plasticizer		Grabbing the plasticizer in its packaging.
3	U2	0:00:14	*"We just take that little pot and stab that egg in it".*	Protection egg	M2	Protecting the egg by covering with plasticizer and the packaging	T1	Grabbing the packaging of the plasticizer .
4	U1	0:00:16	*"Oh yes!!!"*	Protection egg	M2	Protecting the egg by covering with plasticizer and the packaging		Opening the packaging of the plasticizer .

5	U2	0:00:19	*We pick out the plasticizer and make a hole for egg".*	Protection egg	M2	Protecting the egg by covering with plasticizer and the packaging		Opening the packaging of the plasticizer .
6	U1	0:00:22	*"Yes, chill, write it down, write it down..."*	Protection egg	M2	Protecting the egg by covering with plasticizer and the packaging		Opening the packaging of the plasticizer .

Table 1. Showing the reconstruction procedure of the video data.

CAPTURING THE DATA OF THE EVENT-MARK BUTTONS

The explicit sensor data generated by the event-mark buttons were captured with MegunoLink (Blue Leaf Software, 2013).

PREPROCESSING THE EDA DATA

The raw data of the EDA sensor was preprocessed through a discrete decomposition analysis from Ledalab, an open source MATLAB function for the analysis of skin conductance data (Benedek & Kaernbach, 2012). The aim of Ledalab is to provide a decomposition of skin conductance (SC) data into its tonic and phasic components. The method captures and explores all intra-individual deviations of the general response shape and computes a detailed full model of all components in the entire data set (Benedek & Kaernbach, 2010). The decomposition results in the extraction of unsuperposed response components and thus allows for an unbiased quantification of SCR characteristics (e.g. SCR amplitude).

ANALYSING THE SYNCHRONITY OF SENSOR DATA WITH THE VIDEO DATA

The phasic component derived from the discrete decomposition analysis was used to make a synchrony analyses with the thematic analyses of the video data, corresponding with the changes within spontaneous prototyping activities. Three different analyses were conducted to give us a better view on the behavior of the designed capture system within the context of adaptive prototyping.

(1) The first method compared the capture rate of the sensor data, both passive and active, with the thematic analyses of the video data. We counted how many of the overall design strategies and objectives were captured and what the effect was on the sample rate of the video. For the EDA data we created a threshold based on the average of the total amplitude. We hypothesized that this method could address some of the individual differences between the active and passive functionalities of the capture system and give us more insights on the type of events that were captured.

(2) The second analyses focused more specifically on the relationship between passive data and the video data. The same procedure was followed for several thresholds starting from amplitude 5 to 20.

We hypothesized that this method would help us in illustrating the impact on the sample

(3) The third analyses focused only on proximity of the EDA peaks with the tipping points marked within the protocol analyses. Therefor we counted how many of the peaks occurred within the detected means and compared the overall amount of peaks relatively with those within a proximity of 10 seconds before and after each tipping point (see figure 7). To define the corresponding threshold we select the lowest EDA amplitude which still captures all the design strategies. We hypothesized that this method could show us where and how the behavior of the capture system corresponds or differs with the protocol analyses.

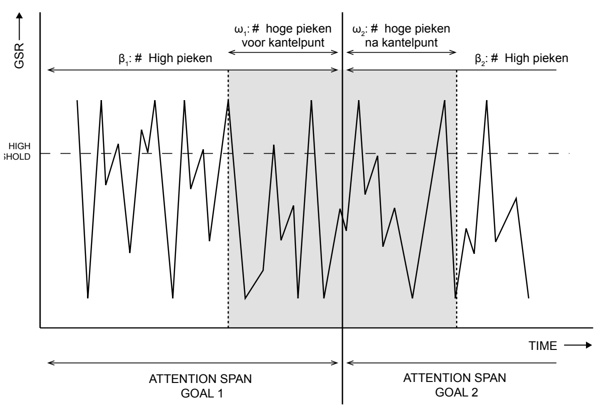

Figure 7. Relative proximity of peaks around tipping points

RESULTS

The team started with brainstorming and jotting sketches down, but this process stopped when the team members started to discuss possible solutions through physical prototyping. The reports they made with the traditional sketching tools were very loose and even the conversations were cut off through the intense and rapid reflective interaction with the prototyping means. This behaviour expressed itself in the snipped dialogues. Verbs and nouns were replaced by embodied gestures with the actual prototyping objects. In total eight design strategies emerged each with several reciprocal co-evolution sessions, randomly spread over the co-design session of approximate 20 minutes and influencing each other.

COMPARISON IMPLICIT SENSOR DATA VS EXPLICIT SENSOR DATA

Only four conscious user inputs were given during the participatory prototyping session (see figure 10). All of them capture only positive events such as; successful ideas while brainstorming, finished

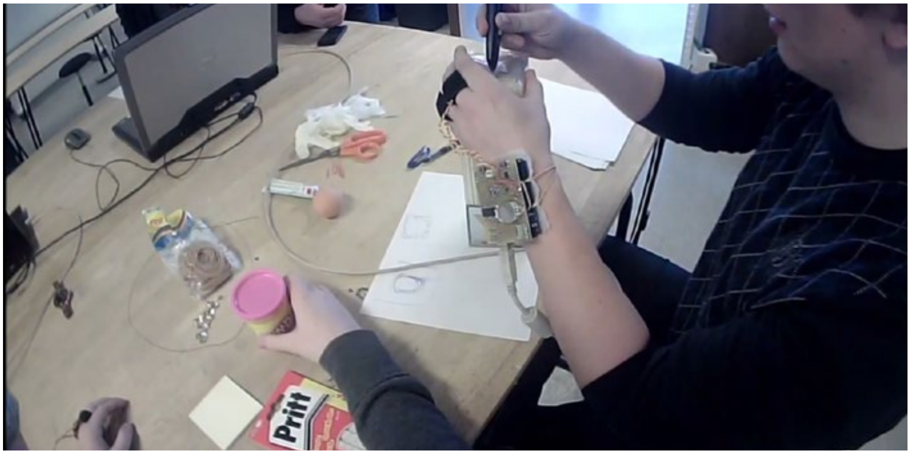

Figure 8. User physically struggles to open the box

sub assembly of the prototype, finished prototype and a successful test.

The unconscious EDA sensor detected a wider range of prototyping events that corresponded with both frustration (See figure 8) and happiness on consequences of actions related to the chosen design strategy (Table 2).

	# Peaks	Sample time	% vs total	# Design strategy	# Means	% Total
Explicit sensor	4	0:00:40	3%	4	4	13%
*Implicit sensor**	60	0:10:00	48%	7	19	59%

* a EDA mean value 10

Table 2. Capture efficiency active vs passive sensor data

COMPARISON THRESHOLD OF THE IMPLICIT EDA DATA VS PROTOCOL ANALYSES

When incrementally increasing the EDA threshold the number of peaks decreases exponentially, resulting in smaller sample times. At a EDA threshold of 10 still 7 overall design strategies where captured with a sample of 48% from the total video stream (Table 3).

Threshold	# Peaks	Sample time	% vs total	# Desig strategy	# Means	% Total
5	342	0:57:00	272%	8	32	100%
10	60	0:10:00	48%	7	19	59%
15	15	0:02:30	12%	5	6	19%
20	1	0:00:10	1%	1	1	3%

Table 3. Impact of threshold on EDA amplitude

COMPARISON RELATIVE PROXIMITY EDA PEAKS VS PROTOCOL ANALYSES

To define the corresponding threshold we select the lowest EDA amplitude which still captures all design strategies. When setting the EDA threshold on amplitude 8 all design strategies were still included. The relative proximity of peaks could be applied on 72% of the tipping points within the protocol analyses. Generally speaking 68% of the EDA peaks within a span of 10 seconds, were located after the tipping points marked within the protocol analyses (Table 4).

Threshold 8	*Mean*	*SD*	*Proximity*
Pre-peaks	1,11	1,03	40%
Post-peaks	1,37	0,96	68%

Table 4. Proximity of peaks near tipping points

DISCUSSION

In this section we discuss the behaviour of the capture system within a naturalistic participatory prototyping setting.

COMPARISON PASSIVE SENSOR DATA VS ACTIVE SENSOR DATA

A striking first observation is that the event-mark buttons have been hardly used. Both participants were consciously so merged in the co-design activity that they neglected the active input channel. Most of the time they physically also used both hands to manipulate the artifacts and communicated through gestures with the prototyping materials. From a naturalistic perspective the event-mark buttons are blocking the mental and physical flow of spontaneous prototyping behaviour.

A second observation is the fact that the unconscious tagging from the EDA sensor did tag both unexpected negative and positive events more reliably than either the notes made in the traditional design report and through the conscious tagging with event-mark buttons. Apparently the participants show a tendency to over-report positive events with the green (positive) event-mark button and avoid the capture of negative experiences with the red button. This phenomenon is also known as the "*self-serving bias*" (Pal, 2007). The participants show a the tendency to claim more responsibility for successes than failures. Practically they favor to communicate positive over negative information in the capture process of their memories on the design process. In contrast the role of failure is just as important within the process problem-solution co-evolution. Design strategies that lead to negative consequences force the participatory prototyping (PP) team to think of creative alternatives and question their design strategy (see Argyris & Schön, 1978; De Couvreur et al., 2012).

Although the EDA does a great job tagging both type of events, the sensor focuses purely on the arousal of the participant without any contextual link to the design task. Personal feelings or encounters that do not relate to the design task will also be captured and can be open for ethical discussions about the privacy of the participants. On the other hand external and/or personal distractions can also be detected with this approach. Therefore we propose this system to be used as a personal documenting system which entitles the user to filter out random none-practice related events which had no effect on the accomplishment design task. Within this case study the PP team was frequently interrupted by passers which gave their opinions on certain aspects. Some of these captured opinions were relevant others were not.

PROXIMITY EDA PEAKS VS PROTOCOL ANALYSES

Overall 24% of the tipping points between prototyping-interactions were not captured through the system. If we analyse these situations, we clearly see that most of the events act on common appropriation actions of the prototyping means (for examples using tape to close a box or using straws as a shock absorbing filler within their own packaging box). The main consequences of these prototyping-interactions are in line with the neuronal model of the participant and do not evoke any discrepancies. On the contrary the detected tipping points encloses all type unexpected *physical* (the struggling of opening a box without damage), *cognitive* (re-approriating the packaging of clay to cover the egg) and *emotional interactions* on events (being ashamed towards a reaction from a bystander on the esthetic look of the artifact). Some design strategies re-appear more than once during the overall inquiry process but do not evoke the same amplitudes. We attribute this behaviour to a form of habituation that appears when the same stimulus emerges repeatedly during prototyping-activities. The habituation of the OR does not imply that the stimulus is no longer registered or analyzed. Rather, the subject has learned to expect the stimulus, and the OR is only released when the characteristics of the stimulus violate expectations. Within design practice this happens often when partial solutions are integrated into a whole (e.g. some straws did not fit within the box due to other elements, the design team decides to cut them into smaller pieces). These moments elite new interdependencies and forces the PD team to shift its attention and prototyping effort. A new neuronal model is constructed which entails new set points within the expectancies towards plans and goals.

The analyses on the proximity of the EDA peaks around the tipping points, shows us a tendency that more peaks are detected after the coded tipping point. This phenomenon strokes with other general EDA research which shows that EDA responses may appear 1 to 5 seconds after a specific stimulus. Only 40% of the pre-peaks and 68% of the post-peaks fall within sample width around the majority of tipping points. The latency within the synchrony of physiology during participatory prototyping actions can be attributed to the difference in process time of thinking and making. Within a lot of situations peaks are detected in the middle of a prototyping-interaction but no immediate changes within the overall behaviour are observed. Within this situation the participant forces himself to complete his previous task or is waiting for his fellow co-operator to discuss the new insight. Another typical design behaviour is the capacity of buffering experienced stimuli during a certain timespan. The goal of this behaviour is to let the prototype interact within time and see if the same pattern emerges over and over.

The above mentioned discussion obliges us to reconsider all the elements of the capture system and add an extra feature which leaves room for human interpretation. In the first place, subjoining an information dashboard that provides an overview/summary enables the user of the capture system to filter, synchronize and add extra meaning to EDA peaks within prototyping-interactions. Secondly this post-processing feature can also facilitate the creation of a common language between the carrier and the third person perspectives of other stakeholders within the design projects.

Cross-referencing multiple devices should result in a thorough journal of an activity. Those journals can be shared with other stakeholders or used as report. The information stored in those journals provides a brief summary of how the user experienced the detected events from a first person perspective. The video stream set the starting threshold for external agents at an easily accessible level. The simplicity of the sensor keeps the user's actions during the process limited, while the software gives the opportunity to adjust sensorial thresholds, events and tags. Simultaneously we have to explore how the capture systems can be designed in a way that does not impede spontaneous interactions with prototypes. Finding the right trade-off between sensor tightness and awareness as well as finding the best location of the sensor are still critical.

9.5 CASE STUDY 2

The goal of this study was to compare the synchrony of a multi-user capture system with a first- person protocol analysis. Or, in other words, how well does physiological technology captures the subjective co-experiences of participating agents within hacking activities and vice versa? Simultaneously, we have explored how the capture systems can be redesigned in a way that does not impede spontaneous interactions with prototypes. For the analyses, we study the data from two perspectives : (1) which type of events are captured through the system and are not within the self-report of both participants? (2) In addition, we also wish to compare which types of events are only captured by the self-reporting process and do not appear in the reconstruction of a capture system.

Procedure and Setup

As a secondary validation of the capture system, we created a similar setting with nine co-design teams, each consisting of two members (in all n=18). The second goal of this proof of concept was to explore synchrony of co-experiences of a multi-user capture system with the self-reported protocol analyses of the engaging participants. Again all the participants (10 males, 8 females) had a graduate degree in industrial design (mean age: 21.2; age range: 21-23) and were recruited from the industrial

Figure 6. Setup study 2

design engineering educational programme. Within each group, both participants were wired with an EDA Arduino sensor. Several small features were improved and adapted. Audio and video were recorded from a third-person perspective as the main goal of this study was to capture individual and collaborative prototype interactions.

For the procedure we chose the same egg drop test in which participants design a vessel from everyday materials to protect a raw egg from a fall. All the groups received the same amount of limited materials (see figure 6) and a strict time scheme of 5 minutes to find a solution through participatory prototyping. At the end of the prototyping activity, both participants were asked to write down individually the relevant prototyping steps that had led to their solution.

OPTIMIZATION HARDWARE EDA SENSOR

In this second research cycle, we also adapted the capture system on the basis of the observations made on the occasion of the first explorative study. The main adaptations were triggered because of the following key incidents.

1. The conscious event-marking buttons located on the sensor unit were removed. The participants were so much immersed in the prototyping activity that they neglected the input channel.
2. When pre-analysing the logged EDA data, some parts were filled with small noise, caused by the movement of the sensor strips while the person was performing a prototype-based action. The corresponding product adaptation removed the sensor strips and integrated two gel electrodes located at the inside lower arm. Location and Sensor type provide a much more

Figure 7. Second version of the open design EDA sensor unit.

reliable measuring result within prototyping activities.

3. Throughout the test, it was already noticeable that the black data cable leading up to the computer, the size of the casing, and the sensor strips strapped around the fingers, limited and even prevented the participants from performing certain prototyping tasks because they affected their mobility. These events impelled us to redesign the casing into a more compact module with a chargeable battery integrated into the circuit. To be able to make the sensor unit really mobile, the data needed to be logged directly in the product itself. To that end, we integrated a MICRO SD card.
4. In order to satisfy the criteria on compactness, we were looking for smaller-sized electrical components to fit in a relatively small casing and make the whole sensor unit portable while maintaining its functions and some necessary add-ons. For the main processing unit we chose the Adafruit pro trinket 5V ready 16MHz processor. It uses the same ATmega328 chip as the Arduino UNO which allowed us to keep the programmable language used in Arduino, while reducing the chip size and keeping the necessary analogue and digital inputs and outputs.
5. The participants and researchers had no feedback on whether the sensor unit was actually measuring data in a correct way. We incorporated a subtle feedback mechanism in the form of a green LED that informs the user that data is being logged correctly on to the SD card. An on/off switch allows the user to turn off the power of the circuit, thus extending the battery life. An extra start/stop button allows the user to pause the measurement at will. This feature is highly coveted by the users themselves and can save a lot of time during the post-processing of the data.

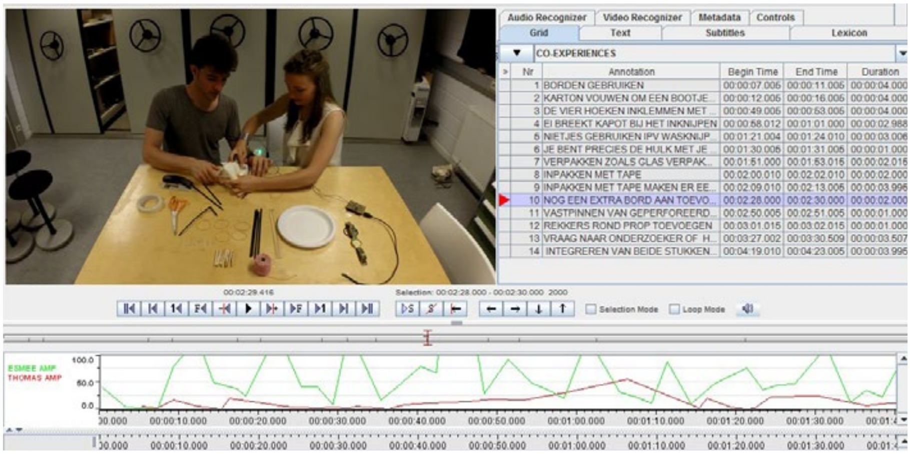

Figure 8. Screenshot of open source ELAN software (Lausberg & Sloetjes, 2009) to annotate co-experiences according to synchronizing skin-conductivity of both participants

PRE-PROCESSING THE CO-EXPERIENCES FROM EDA DATA

Within each team the EDA datasets of the two participants were pre-processed with the discrete decomposition analysis from Ledalab. To create the right subjective threshold, each dataset was filtered with his own third quartile value (the middle value between the median and the highest value of the dataset) as lower limit. After this step, the co-experiences were extracted by marking the coinciding events in time. There is a delay between stimulus and EDA response, usually considered to be a minimum of 0.8 seconds. Therefore, the extraction of co-experiences was effected with a margin of 4 seconds after each tipping point. Each co-experience event was annotated within the corresponding video data and abstracted in a prototyping-interaction according to the observed design behaviour of the participants (Lausberg & Sloetjes, 2009). (See figure 7). A total of 122 co-experiences was collected. These were submitted to a conventional qualitative Content Analysis (CA) (Hsieh & Shannon, 2005). Conventional CA is appropriate when prior theory exists, but the researcher wishes to be open for unexpected themes and will only at a later stage relate his findings to the existing theory. Co-experiences which had no direct relation to the prototyping activity were excluded. For example, jokes and remarks on the capture system itself, questions addressed to the researcher regarding the time span of the activity, and so on.

PRE-PROCESSING THE SELF-REPORTED DATA

The total amount of 120 self-reported prototyping actions was collected. The corresponding reported events were chronologically merged into two lists for each group and submitted to a qualitative content analysis. Self-reported steps which were too abstract and had no direct link to a prototyping-interaction were excluded. For example: “we discussed”, “we choose a final idea”, “finished the artefact”, etc.…

RESULTS

Due to the limited amount of time, the majority of the teams immediately started sharing their thoughts and experiences through physical prototyping. A small quantitative analysis resulted in the following insights: on an average level, the teams (n=18) self-reported 6 action strategies that were relevant (SD =2,06) within the co-construction of their shared solution. During the same time span of 5 minutes, the self-reports captured an average of 4 co-experienced events (SD=1,49), the EDA sensors captured a medium of 10 co-experienced events (SD =2,70). Given the small sample size, we used the non-parametric Wilcoxon signed-rank test to analyse whether there were statistically significant differences in the amount of both self-reported actions and the co-experiences. The two-tailed test indicated that the co-experiences were significantly higher than the self-reported actions (Z=-3,234, p = 0,001). After the qualitative content analysis, we could conclude that an average of 76% from the self-reported action strategies from both members was captured through co-experiences derived from synchronizing EDA data. As a surplus, each team unconsciously tagged 35% additional non-reported events.

The qualitative content analysis of the non-captured and non-reported events resulted in the following axial codes & frequencies:

non-captured events from self-report	*frequency*	*non-reported events from Eda Sensor*	*frequency*
Initial plan	10	Changing action	7
Standard use of means	9	Consequences	12
Repitition of action	1	Action tendency	5
Distinction creation	3	Physical effort	5
		Attunement/nuance	13

Table 5. Overview of axial codes & frequencies of non-captured and non-reported events

DISCUSSION

IN GENERAL

All participants reconstructed their design process with less steps than their joint co-experiences. We notice a spontaneous form of distinction destruction, a phenomenon better known as chunking, which illustrates the limitation of our human memory and information processing. The average amount of self-reported actions leans close to “the Magical Number Seven, Plus or Minus Two” (Miller, 1956). From a cognitive perspective, a chunk can be defined as “a collection of elements having strong as-

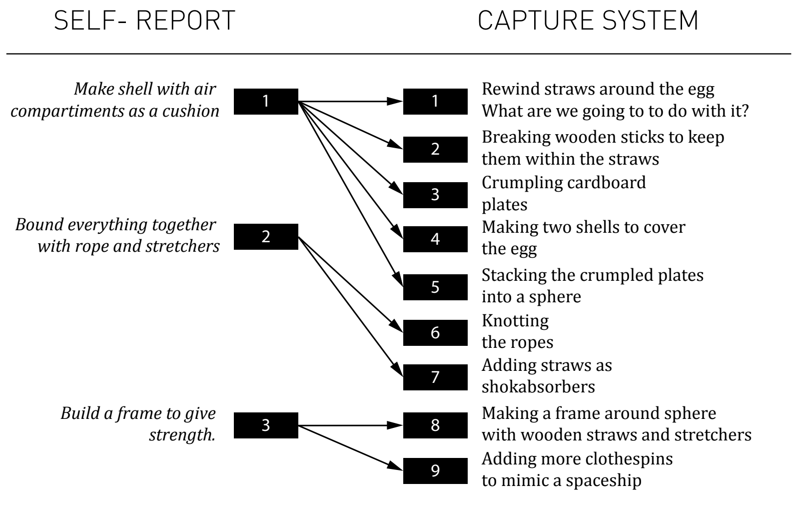

Figure 9. Example of the chunking behaviour. Comparing one the self-report with the corresponding capture events through the EDA sensor.

sociations with one another, but weak associations with elements within other chunks" (Gobet et al., 2001, p. 236). Although the associations were co-experienced while interacting with prototypes most times the participating designers were not able to document these underlying phenomena. On the contrary, the implicit co-experiences coming from the EDA sensors captured very specific interactions, often even more than one event (distinction creation) within a corresponding self-report chunk from a specific participant. It would be interesting to observe this phenomenon while stretching the time span of the total prototyping activities. This observation also illustrates the complementary relationship between the human agent and the capture system. Both can be used to demystify the associations and relationships between prototyping-interactions and changing-action strategies. It is hard to find a comprehensive structure within the implicit co-experiences of the capture system, but in a same way it is hard to unravel the experiential key aspects that triggered and created a specific chunk.

The level of detail in which the participants describe their actions was contingent for each individual participant and mostly retained during each individual self-reporting process. Goals were rarely explicitly mentioned.

Although most self-reported action strategies respect the chronology of consecutive prototyping events, the participants have a strong tendency to only report their protocol from the unilateral perspective of their end result. Side ideas, failures or any other unexpected associations which led to new action strategies were not reported. Both the self-reports and the implicit co-experiences variate from detailed experiences to general design strategies.

COMPARISON NON-CAPTURED REPORTED ACTIONS FROM THE SELF-REPORT

During the qualitative analyses we found a lot of non-captured events that were located at the start of each self-report list. If we reflect deeper on this phenomenon, we could conclude that this is rather logical. The first step the designers take is often based on their current common ground which is based on their past experiences and attitudes. As soon as these initial plans are actually tested through prototyping-interactions, the situation awareness changes by emergent unexpected consequences. Taking notice of this phenomenon we should also look differently at the average capture rate. If we systematically leave out the first self-reported actions from the analyses, the final capture rate will even be much higher. In addition, the need is expressed to capture these type of events in an alternative manner within a dashboard.

A second reoccurring "non-capture" phenomenon consists of actions in which the design participants use resources or materials for their original already appropriated purposes. For example, a lot "non-captured events" were dealing with the conventional use of tape or elastics. Both were used to connect and attach new parts in a traditional manner. The use of these materials is also based on the common knowledge of both participants and if the consequences of these action do not cause any new unexpected events these steps do not result in a new OR.

A third category of "non-capture" phenoma are related to repetitive prototyping actions. On the basis of the observation, we see a sense habituation that forms the basis of a third type of non-capture events. Again, if no unexpected consequences pop-up repeated actions are not captured through the EDA sensor.

The last category deals with optimization. When certain wicked consequences become tame by changing the action strategies the further implementation of small details, which are perceived as achievable, are often not captured. Agents often divide the prototyping work and consequently there attention is on their individual prototyping activity. As a result, no true co-experiences can come about.

COMPARISON NON-REPORTED CAPTURED ACTIONS WITHIN THE CO-EXPERIENCES

Within the co-experiences that were captured through capture systems, we also found a lot of events which were not self-reported. The qualitative content analysis resulted in five categories: new actions, consequences, nuances, action tendencies and physical effort.

The first category of "changing actions" illustrates extra non-reported events of new prototyping actions. These events are characterized by their non-verbal, but nevertheless executive character. Often the reflection process is so fast because the participating agents are completely absorped in the process of the prototyping activity. The only way to document the actions is by capturing non-verbal expressions and actual prototyping behaviour from a third- person perspective. Some captured events were focussed on the making of parts and on the integration of different parts to an assembly.

A second category encompasses all types of unexpected consequences. These events are all related to small tests and verifications of action tendency through prototyping interactions. We can make a distinction between unexpected consequences that bring the participating agents closer to their goal (quick-wins) and a type of events that are experienced as a diversion from a particular goal-directed behaviour. (small failure, mistakes)

A third category of non-reported events deals with attuning action strategies to an acceptable level. It captures ordinal nuances between the implementation of resources and plans. For example, more or less tape, adding extra plates or making an incision even wider.

A fourth category shows events in which the prototyping effort was experienced as intense. For example, cutting a wooden barbeque stick with a scissor or gluing a piece of tape on a hard-to-reach location. These peaks have a repetitive character within one action strategy.

As last, the collaborative capture system also captures mental action tendencies. These events can be recognised by verbal questions and dilemmas that the participating agents share with each other while interacting with the prototype. Some of these expressions explicitly mention mental models or expectations. For example : “We need a scissor to cut the cardboard” or “ Should we use a straw or some rope to attach this component?”

9.6 CONCLUSION

This initial work extends the possibility of capturing meaningful prototyping-interactions within a naturalistic co-design environment. The observed prototyping behaviour within the study was, completely spontaneous, partly “unconscious” and constructed in a creative setting. Designers learn by changing work in environments that are constantly changing. These changes are independently initiated by our own activities/knowledge and other external self-organizing events and are therefore always a combination of both. There is no learning without interaction and observation. Physical prototypes in their context are the only available “measuring instruments” to share tacit knowledge.

We do not claim that our experiments are validated techniques. Further analysis is necessary to improve their robustness and reliability. However, these preliminary studies show a potential, viz. that biosensor technology can be used to capture unobtrusively co-design processes and overcome the limitations of human memory and its incapacity to verbalize tacit knowledge. The aim of the OR capture system is not the perfect design rationale as such, but to focus on an agent’s change of the situated awareness from a first-person perspective and to link these events to embodied prototyping-interactions. When a design agent experiences such a meaningful event, it is often impossible to return to the previous state of the neuronal model (or awareness) of the perceived reality, as shown in the self-report analysis.

The second study focused on cross-referencing data streams of multiple agents, which resulted in a thorough sample relevant co-experienced events within a single design activity. A first proof that the technology is also able to capture "tacit knowing" is partially confirmed through the observed fact that non-verbal actions and re-appropriations, unexpected consequences (both positive and negative), emotions and action tendencies, nuances in optimizations of action strategies and physical effort coming from the agent are indicated in an unconscious manner. A second conclusion is the need of a post-processing information dashboard to distinguish the relationship of specific OR patterns with physical, mental, and emotional components within events.

Our goal is to further investigate the relevance of automatic physiological video tagging within design practice and to develop a capture system that works in synergy with the human memory, creativity and perception, rather than as its replacement.

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APPENDIX

This case study has been conducted from an open-design perspective. Multimedia files, such as 3-dimensional computer models for 3D printing , Electronics circuits schemes for arduino & software for the analysis of skin conductance data; can be published online - licensed under a Creative Commons Attribution - as an extra to the manuscript.

http://stigbril.blogspot.be/

Part V

FINALISATION

10. DISCUSSION
FUTURE RESEARCH

DISCUSSION

The craftsmanship of design hacking

In chapter 2 we discussed the potential of horizontal user innovation networks to solve wicked problems in the context of universal design. This paradigm shift is slowly being acknowledged by the design community, too (Cottam & Leadbeater 2004; Burns et al., 2006; Brand & Rocchi, 2011; Gardien et al., 2014). Topics such as wellbeing, sustainability, education and open welfare express the need for collaboration among local and cross-disciplinary stakeholders.

We see the same paradox in each context. Although the problems often manifest themselves on a large and very diverse scale, effective solutions cannot be generated on a global level. Universal solutions need to be appropriated from the environmental, ethical, cultural, social, political and economic contexts. Vice versa, quick fixes from stakeholders who work on local issues can inspire others to adapt their approach and create universal patterns. By working on related problems in different locations, institutes can build an overarching understanding of these local problems.

In both scenarios we can benefit from hacking activities as a way to interact and foster appropriate adaptation. Reon Brand and Simona Rocchi (2011) see this kind of collaboration as being at the core of a new emerging economy, namely the transformation economy. Hummels and Frens (2008) also stress that the collaboration in this transformation economy requires engagement, empathy and respect based on a horizontal collaboration in which all stakeholders are equal, but not identical, and valuable in their own way.

But empathy alone is not enough to foster change that creates valuable offerings for all local stakeholders. We need real-life actions in the field that make these changes experiential and allow open-endedness. Hacking design can be used as an iterative technique that puts users at its heart, working from their perspectives, and engaging latent perceptions and emotional responses. In the transformation economy, the role of professional designers will transmute into two new roles.

The first role will still be a top-down approach. Professional designers will transform themselves into meta-designers (Fischer & Giaccardi, 2006; Stappers, 2009) and create platforms with tools that hacking practitioners can shape to fit their needs. This basic approach focusses on creating a design environment for unskilled users, or creating design blueprints, allowing practitioners to design their own products. Besides fostering design activities, these platforms also entail sharing the results of finished or unfinished projects and facilitating collaboration on innovation development, production and consumption.

The second role will cultivate a more bottom-up approach in which professional designers transform themselves into real hacking craftsmen. Sennett (2008) draws a comparison between these users-as-producers and traditional craftsmen, who are intrinsically motivated to deliver quality work for its own sake and to further hone their skills. Similarly, in open source communities, the reward system is based on the quality of the outcome, the social appraisal within the group and the participants' personal development. In this role they are part of a community, living lab or institute fulfilling their main objective to combine creative skills with local insights and to efficiently embody one-to-one empathy in qualitative hacks.

In my opinion, future professional designers should also work in hospitals, schools, home care and local rehabilitation centres, sheltered workshops, and so on, catalysing and facilitating open-innovation by customizing and/or building their unique products with the help of production facilities such as fab labs. Although these production facilities are promoted as being open, they often still create a high threshold for non-technical agents. All DIY approaches require a particular skillset. For instance, most existing digital platforms are tailored to specific types of end-users, mostly people with a substantial background in or affinity with technology. Although theoretically everybody can access and use tools in a fab lab workshop or makerspace, on a practical level the learning curve is still very steep for non-designers. If non-designers finally manage to handle a certain production technique, they often become very fixated on it. This works counterproductively from an economic and engineering perspective, as the strength of a fab lab lies in the combination (or again the variety) of all the production techniques. The hacking craftsmen will think in terms of functions and properties, and then look for alternative methods to achieve the same functions with standard components, recycled parts or specially designed components. Design thinking and crafting are both competencies that require many years of education and practice, like any other profession. The task of professional hacking designers should be to close this gap as facilitators in these social design processes. They are specialists in design thinking and have empathy for people and for other subject areas. Through making together, hacking craftsmen indirectly catalyse collaboration by creating new realities for stakeholders while sharing physical, intellectual and tacit resources. The strength of hacking design lies in the ability to get more from less, to continually experiment, and to creatively engage people who are typically left out of the innovation process.

The hack prototype as agent

As demonstrated by several key incidents, the emergence of general meaning occurs during embodied prototype interactions (chapter 4), more specifically through co-experiences between the participating agents in several hacking spaces in which they explore, make and use hack prototypes. The uniqueness of hacking design is that despite the hacking space, one combines the four hacking attitudes in a parallel and circular manner while being engaged with hack prototypes. The activities around hack prototypes act as main coordination mechanism and organize the hacking entity to enable its constituents to 'make together' a solution in an efficient manner. 'Efficient' means that they achieve their goal with economical use of resources, and 'make together' means that the actions are perceived as harmonious and synergetic, the one helping rather than hindering the other. Both aspects are critical for the resulting experience of the hacking activities and to guarantee an optimal use of the workforce.

The idea of designing for re-appropriation almost seems like an oxymoron: 'plan for the unexpected' (Dix, 2007). However, although we know we cannot design for the unexpected, can we design such that people are more likely to be able to use what we produce for the unexpected? We believe that the real environment and the randomness of human creativity play substantial roles in the flow of each project. From this perspective, the role of hacking practitioners emphasizes support rather than control. How easily can we create variations on the same actions? And how can we create a rich environment to evoke a variation of consequences? The strength of hacking design as reflective prototyping technique lies in its low-fidelity character. Re-appropriating other local artifacts or environments is a very economical and open-ended way of expressing one's goals and ideas. It invites non-designers to immediately engage with realistic interactions and have an impact on the design process. The hack prototypes are fun to work with and their unfinished character invites the participants to modify them and give critique. A pitfall might be that the notion of the critique is always very detailed. But if unexpected consequences trigger essential variables, the hacking practitioners should be able to abstract these events through double-loop learning and find new possibilities by changing their perspective on the hack prototype.

Compared to traditional methods of organization in product design, hacking design makes absolutely minimal demands on the agents. In particular, in this type of self-regulating collaboration (Heylighen, 2011a; Heylighen, Kostov & Kiemen, 2013), which is built on experiential prototyping activities, the hack prototype removes the need for:

- Planning – participating agents only need to experience the present state of the hacking activity, embodied by interactions with the hack prototype.
- There is also no need for memory. Agents do not need to remember their previous activity, as the state of their work is stored in the hack prototype and its interaction in its current environment.
- No explicit information needs to be transferred between the agents except implicitly via the work done and the changes between the different states of the hack prototype.
- There is in general no need for all the agents to be present at the same time or at the same place. The hack prototype affords tasks that can be picked up by agents whenever and wherever available.
- The hack prototype imposes the sequences of actions. The workflow emerges spontaneously as the completion of one task triggers the initiation of the next task.

- The hack prototype also imposes the division of labour. Each agent will only perform the actions for which it has the required competencies and confidence.
- Finally, the hack prototype creates a type of centralized supervision of interdependencies. Errors are automatically compensated for by stimulating new corrective actions focusing the attention of the hacking entity on the relevant aspects.
- Hacking prototypes create a certain spontaneous commitment between all engaged stakeholders. There is no need for obligatory or legal contracts. All agents engage themselves towards their own subjective conditions. If an agents quits or otherwise becomes unavailable, he or she is automatically replaced by another agent in order to maintain the viability of the hacking entity.

Wicked aspects and requisite variety

This thesis proposes a framework (chapter 5) for hacking design that supports personal and social transformation. Problems involving disabled people have a certain 'wicked component' that demands an opportunity-driven approach, requiring decision making, doing experiments, launching pilot programs and testing prototypes. A certain amount of trial and error is necessary to untangle the physical, emotional and cognitive interactions between human beings and their environment. By looking at product hacking activities through the lens of cybernetics, we can understand adaptation from a completely new perspective.

The main rule that bonds all insights is the law of requisite variety coined by Ross Ashby (1960): *"Only variety can absorb variety."* That is, in order to deal properly with the diversity of multifaceted problems the world throws at you, you need to have a repertoire of responses that are at least as nuanced as the problems you face. Hacking teams with a wide repertoire according to their changing environment always feel in control and actively adapt their environment by combining variables from their common repertoire.

The repertoire discussed in this dissertation consists of design variables in terms of technology, activity and human skills. If this repertoire is too narrow, the hacking team is forced by its environment to adapt. This compulsory adaptation manifests itself through the awakening of essential variables that trigger the hacking design team to adapt its adaptation process. Only by introducing new parameters into their repertoire can they transform their design space and create new variety to maintain their goals and thus their identity.

In other words, the hacking design team has adapted to the unexpected consequences in a way that is meaningful to them. In hacking activities, this results in new action tendencies driven by situated co-experiences that lead to new re-appropriations of local technologies, activities and human skills. Acknowledging the role of re-appropriations is a fundamental condition for using product adaptation in the process of solving wicked aspects. The language of hacking design is well suited to fostering this condition. We see hacking design as a specific approach to open design, in which groups of intrinsically motivated people from various backgrounds develop new adaptations together in an open community. The most obvious re-appropriation in hacking design is that of technology. Production techniques, products, parts or components are repurposed to create new attempts to attain meaningful goals. In addition to physical objects, activities and human skills also play an important role in creating the right amount of requisite variety. The hacking design team can break down or merge product-related activities into new components, or they can apply new ways of approaching tasks from other meaningful perspectives.

Finally, the variety in human skills is also an important determinant to enlarge the group's repertoire. During hacking activities, agents need to use and develop their local skills in the process of attaining their goal. In extreme situations, new skills have to be trained or new agents have to join the hacking team to broaden the skillset. We believe that both categories – activity and skill development – are still unexplored as sources by hacking designers to create more variety.

First-person emotion as the seed of co-experience

Hacking design is not about problem solving, as is often thought. Problem solving implies that the solution space is already determined by the problem definition. In contrast, hacking activities open up and explore new territories, reframe and imagine new ways of doing things in a specific socio-cultural context. The process asks people to put themselves – their points of view, their value systems, their experiences and their skills – into the shared design space. This step is not self-evident, because meaningful goals that are aimed at, or the anti-goals that should be avoided, are always emotionally loaded (chapter 7).

The circularity in hacking activities plays an important role in establishing trust and empathizing with all engaged agents. Learning how to deal with matches and mismatches creates a common language among all engaged participants. Especially the mismatches play an important role in opening up or leaving a current design space. They stimulate hacking practitioners to be creative and seek opportunity in adversity, while respecting the concerns of all participants. Rather than try to limit the possibility of different understandings, we use these limitations constructively to explore new ways of achieving goals. Each hacking practitioner is initially designing from a first-person perspective while intermittently taking a third-person perspective through sharing prototype interactions with other participating agents, and vice versa. Co-experiences based on first-person prototype interactions form the basis of self-coordination in hacking design activities.

To establish this connection, the participants should be able to resonate with each other. To create emotional resonance, the participants must be able to recognize emotions both verbally and behaviourally, the latter through body language. We therefore see emotional intelligence as a key competency in any experience-driven design activity. In the context of co-design, emotions are useful sources of information that help one to make sense of and navigate the social design process. Hacking practitioners can help participating agents to perceive, use, understand and manage their emotions in hacking activities.

From a cybernetics perspective, emotions (considered a by-product of our hormone system) are an essential part of the human entity and are closely intertwined with our nervous system, which is responsible for regulating our cognitive and sensorial actions. Everything you think or perceive affects your emotions, and all of your emotions affect the way you think or perceive. As discussed in chapter 6, we argue that each co-experience is context dependent and is phenomenologically related to the reality of each participant in that context. Respecting those realities forms the basis of transformations and new creative insights.

This aspect has been clearly illustrated through the collaboration with disabled people. We sense and perceive the world through our unique minds and bodies. How does it feel to play a guitar with one arm? Or how does it feel to ride a bike with a motoric disability? To disentangle the nuance that each participant brings to the design process, we need to construct a language based on tangible experiences. The only reliable measuring instruments are physical prototyping interactions that can be observed and shared in a real-life environment. In those moments, all participants trust their senses and intuition becomes more valuable than rationality. Some of these insights into prototyping interactions are easy to describe, whereas others are difficult to transfer to another person through verbalization. Although it is difficult to articulate, this dimension of tacit knowledge also shapes the way we perceive the world and also embeds crucial information on relevant design variables. This also urges us to respect the subjective experiences of each participant and to use physical prototypes as vehicles to unleash spontaneous emotions (related to standards, beliefs and values) that are attached to these intuitions.

We can conclude from the case studies that we need these emotions, as co-experiences of these events shape the first action tendencies at the beginning of each adaptation strategy. They nudge the action strategies in the fuzzy start of hacking activities. Later on, reality will show whether the hacking activities based on certain intuitions are also helpful in achieving a common goal. We also want to nuance the term ‘co-experience’. Although emotions are universally recognizable, the underlying concerns, values or aspirations of emotions cannot possibly be the same for each participant. But this is not an issue in the context of co-experiences. If certain events trigger two or more agents, the underlying reasons can still have a different nature for each of the agents. As long as the subsequent actions stay within the first-person limits of each agent, the synergy is sensed as meaningful.

Tools for removing hacking redundancy.

The sharing and reusing of ideas is an important aspect of social creativity (Fischer, 2000). In chapters 8 and 9, we explored two meta-design tools to capture adaptation in hacking activities. In this section we discuss the future role and applications of capturing adaptation behaviour in prototyping activities.

In contemporary hacking communities such as instructables, only information on the finished product is captured. However, as illustrated in chapters 8 and 9, the work in progress of such hacking activities can embody many other valuable ideas and experiences that are worth recollecting by the participating agents or sharing with other hacking practitioners. Although total capture systems are technically feasible, the subtlety and emerging character of reflective practice through physical prototyping asks for more appropriate capturing processes that can support local design thinking and creativity. The main challenge of these systems is to actively remove redundancy, a lot of which is usually created by the live logging of design practice.

Redundancy is a concept that has emerged from information and communication theory (Shannon & Weavers, 1949). Redundancy is the opposite of information. Something that is redundant or repetitive adds little, if any, information to a message. Redundancy is important because it helps combat noise in communicating systems, especially when messages are repeated or copied. By focusing only on unexpected changes, from the first-person perspective of hacking practitioners, we can reduce the redundancy in digital archives of hacking activities.

In general, this principle is applied within our own visual, tactile and auditory perception. For example, the process of lateral inhibition increases the contrast and sharpness in perceptual responses by exciting certain neurons which in their turn reduce the activity of their neighbours. A simple example is the processing of a visual image in a digital photo camera or the retina of the eye. A lot of pixels will be very similar to their neighbours, except those lying on the contours. Through lateral inhibition, only the changes that make a difference (from the perspective of the observer) are transmitted and processed; the other ones are filled in as equably. This research shows us new ways of looking at capturing design rationale in real-life environments.

FUTURE RESEARCH

Context

To fully understand the dynamics in hacking activities, we chose the context of assistive technology. This rich context allowed us to clearly observe changing prototyping behaviour from the limitations and capabilities of all the engaged participants, designers and disabled clients. The living lab mainly worked around a variety of physical impairments. In the context of occupational therapy, some cognitive impairments such as dementia, amnesia, asperger syndrome and other developmental disorders were deliberately not covered within the living lab. We assumed that our students did not have the expertise to deal properly with these clients and that , for example, the role of long-term memory, self-identity and empathy would be an essential condition to participate in iterative hacking activities. Nevertheless, some case studies involving clients with multiple disabilities were very successful and stressed the role of prototypes as agents that trigger spontaneous behaviour.

In the co-design community, there is a growing need for and interest in techniques that can be used with people who are living with cognitive or sensory impairment (Slegers, Duysburgh & Hendriks, 2015). It would therefore be interesting to see how we have to adapt the hacking design method to suit clients with cognitive and/or sensory impairments. What happens when such phenomena as habituation or emotion interpretation are not occurring? Recent research still suggests that the role of direct encounters with prototypes and caretakers are important to design the right triggers and learn from the perceived behaviour (Van Rijn et al., 2011; Van Rijn, 2012). Following the model of Ashby (1960), we can research the role of prototypes as sensory stimuli and explore the use of physiological technology for sensing the emotional states of participants who have speech and language disabilities.

A second, broader perspective is to frame hacking design as a method in social innovation. Humanity is slowly beginning to come to terms with the limits of the planet. Social innovation is a new discipline that works towards meeting social goals (Mulgan, 2006) and strengthening civil society with sustainable practices focused on working conditions, education, community development and health. At the core of social innovation is openness and the creation of new relations from creative re-combinations of existing assets (social capital, cultural capital, technological capital) (Manzini, 2014). Social innovations can lead to both new products and new services. In both outcomes, prototyping plays a crucial role (Hillgren, Seravalli & Emilson, 2011; Blomkvist, 2014): (1) to collaborate more closely with a variety of stakeholders, (2) to reveal dilemmas and opportunities and (3) to cultivate trust. Just like hacking design, the process of social innovation is characterized by building relations with diverse actors and allotting time and resources flexibly. A network of local living labs that use hacking design techniques facilitates the emergence of possibilities along the way, and new design opportunities could evolve through a continuous local and global matchmaking process (Bjorgvinsson et al., 2010). Manzini (2011) refers to it as the SLOC scenario (Manzini & Rizzo, 2011), where SLOC stands for small, local, open and connected. These four adjectives, in fact, synthesize very well the socio-technical system on which this scenario is based: a distributed production and consumption system where the global is a 'network of locals'.

Technology

From a practice–based perspective, the hacking community could benefit from a pattern language on real-life product adaptations. Generally speaking, patterns are essentially recurring problem-solution instances, described in a referenceable way that enables practitioners to recognize the situation. This method of describing good design practices within a field of expertise stems from a "*Pattern Language* " (Alexander et al., 1977), which covers the design and layout of buildings, towns and communities. By describing them as a sort of generative grammar design, a pattern bridges functionalities to real-life attributes or properties. The pattern form can help a hacking practitioner to recognize that a 'new' problem situation is similar or analogous to one encountered (and solved) elsewhere, perhaps even in a different context. This technique makes it very useful for a transdisciplinary transfer. The general pattern language has the structure of an open-ended network that consists of a variety of interconnect seeds (Fischer, 2006) that can grow evolutionarily through interaction with different local environments.

It will be important to also thoroughly research how these design patterns should be documented and communicated. We have noticed that overdetailing the descriptions of hacking designs (cf. instuctables.com) leads to discouragement, as some external reproducers are too fixated on copying the exact same artifact and get blocked when one or two parts are not available in their local environment. When we lower the level of detail (Werner, 1998), building plans or design patterns are more abstract and leave more space for open-endedness and social creativity. In future research, the limitations on open-endedness could be further explored by teaching hacking practitioners to document only those design variables that are essential to the functionality, and to leave all the others open to the conditions of the reproducers (Ostuzzi et al., 2015). From another perspective, we can also observe reproducers to see which disturbances they encounter when they copy DIY assistive technology. According to the level of creativity and the available skills, the same hacking design could be translated or appropriated into different types of manuals.

We also noted that this generative design approach can also be used to upscale individual assistive devices to small series or low-cost mass-manufactured assistive devices. In this design strategy, the manufacturing system could be designed to suit the product and not the other way round. Many DIY assistive devices have a disruptive character as they are often simple solutions that deliver more value at less cost. Therefore, good redesigned product hacks can be targeted at the bottom of the pyramid, including the largest but poorest socioeconomic groups. Conversely, low-volume products are defined as products that are manufactured in batches of fewer than 50. In this design strategy, personal assistive products have to be redesigned to suit local manufacturing systems. Especially for niche markets in assistive technology, this approach is mainly cost-driven. How do we make the right trade-off between parts or components that can be assembled with bought-in standard components or manufactured in small batches with local resources? This approach enables communities to provide local and adapted versions of their products if they do not have the resources to tempt commercial developers.

Activities

A fundamental principle of human-centred design (HCD) has always been that technology should adapt to people, and not vice versa. But if we look at the majority of DIY products, they are not so human-centred. Why are they so successful? Donald Norman (2005) argues that by taking a more activity-centred approach (ACD), we can not only understand people but also gain a deeper understanding of the way that technology is appropriated, which skills are needed, and what the underlying reasons or needs are for the activities. "*Learn the activity, and the tools are understood. That is the mantra of the Human-Centered Design community. But this is actually a misleading statement, because for many activities, the tools define the activity. Maybe the reality is just the converse: Learn the tools, and the activity is understood.*" (Norman, 2005)

The history of design contains numerous examples of successful devices (such as writing systems, music instruments and the automobile) that people had to adapt to and learn to use. In ACD, we admit that much of human behaviour can be thought of as an adaptation to the powers and limitations of technology (Norman, 2005). Adapting technology to users increases the costs and somehow deskills the actual users. Adapting users to technology takes time and the active development of new skills, both of which are rich resources in most DIY contexts. In reality, there is no ideal standard approach; instead, hacking design switches constantly from ACD to HCD and vice versa. Although both strategies can evoke rich experiences, ACD takes a more positive perspective by focusing on new possibilities arising from the skills and talents of interacting agents.

Many people may be able to identify occupations that make them feel good and those that make them feel bad. A deeper understanding of how and why occupations impact on wellbeing will enable designers and occupational therapists to design more affective products and provide more efficient services. Our various case studies have shown the heterogeneity of needs in certain activities. Of course we cannot produce all our products through a DIY approach for all the activities in which we engage. Many hacks are still built around intentional activities (e.g. nurturing relations, committing to one's goals, taking care of one's body). In her book "*The How of Happiness*", positive psychologist Sonya Lyubomirsky (2008) argues that by engaging in these intentional activities we can foster our own subjective wellbeing or happiness. For example, a consequence of the personal adaptation process (Mugge et al., 2007) in co-design is a sense of ownership and pride. This may simply be an intrinsic feeling of control. The participating agents feel that they are doing things their own way with respect to their personal concerns. In the living lab, participants often proudly showed their product hacks to their own community. They suddenly became ambassadors for new assistive devices that they can share, and this enabled them not only to help themselves but also to contribute to something bigger, that is, a community of people who can benefit from their ideas. These positive feelings can be as important as the things that are achieved.

The recently arisen positive design movement (Desmet, Pohlmeyer & Forlizzi, 2013) in the design community is promoting the role of design in enhancing and sustaining subjective wellbeing in human development. We believe that these insights and models (for an extensive overview, see Jimenez, Pohlmeyer & Desmet, 2015) could enrich hacking designers in two ways. First, these techniques can be used to create more variety in the ingredients for designing meaningful activities (Desmet, 2011). The models can help us to achieve a good person–activity fit. More research in this context could help hacking practitioners to better anticipate the overall impact of a certain product hack, so that we can invest our hacking time wisely and efficiently. Despite the low threshold, hacking design activities still require effort and willingness on the part of all the participating agents. From a practical perspective, we cannot hack all the products in our environment. Some projects in the living lab stopped abruptly because in the end the initial selection of the activity was not sufficiently meaningful to the participating agent or had been imposed by other agents.

The second perspective that would be worth investigating is the role of subjective wellbeing in sustaining participatory design activities. Can we as designers shape the creative design process an experience that is meaningful in itself? How can we design meaningful activities for a group of stakeholders in such a manner that they all voluntarily take part and flourish in small local networks? The hacking design projects in the living lab often succeed in creating new products that are attuned to the people affected. But how can such results be sustained after a project ends? One way could be to focus on human flourishment and deliberately design co-design processes that increase the wellbeing of individuals and communities. This approach requires agents to develop their skills, and enables them not only to help themselves but also to contribute to something bigger. Both elements contribute independently to wellbeing (Seligman, 2012). But perhaps there are many more to be explored and translated into the concept of meta-design applied in end-user development programs. Can we deliberately design co-design processes that increase the wellbeing of individuals and communities?

Agents

We can also derive some new research themes from the observed roles of agents in hacking design activities. First, the average team size in the case studies was rather small, namely only as many as 5–6 people? What would happen when we add more agents to the projects? The law of requisite variety suggests that only more variety (in the bigger group) can absorb variety (the bigger the problem or challenge). Still, small groups can think together effectively, but only have the capacity to deal with simple challenges. In the past, large design groups had the capacity to deal with complexity, but often did not work together well enough to realize their full potential. With the advent of networked computers, social networks, tagging and collaborative filtering, new many-to-many methodologies to let large groups work in a synergetic and self-organizing manner have arisen. The 'global brain' is a metaphor for this emerging, collectively intelligent network that is formed by the people of this planet together with the computers, knowledge bases and communication links that connect them (Mayer-Kress & Barczys, 1995). It can be defined as the distributed intelligence emerging from the worldwide network of people and communication machines (Heylighen, 2011b). Nevertheless, this network only contains explicit knowledge that can be readily articulated, codified, accessed and verbalized. As discussed, the nature of knowledge in hacking design activities is much richer and also entails a lot of tacit aspects related to real-life prototype interactions. We therefore investigated how the worldwide network of manufacturing machines could extend this vision towards the ‘global body’. In other words, how distributed action emerges from the network of people and their interactions with digital fabrication machines. A nice example is the Fab Academy (2015), an international rapid prototyping course that originated at MIT but is now connected to a number of fab labs around the world. The program provides students with advanced digital fabrication instruction through a unique, hands-on curriculum and access to technological tools and resources. Each lab that participates in the program is part of the global Fab Academy network. The local branches of the Fab Academy work with other experts from around the world via a distributed educational model in which they pool their knowledge, production facilities and prototypes to provide a unique educational experience. Sharing prototypes through digital fabrication networks can create global co-experiences of both explicit and tacit design aspects, steering communities towards shared design solutions.

A second research theme could deal with the appropriation of prototyping means. Each agent has his or her own level of prototyping skills. Finding the right prototyping means to engage with is an important aspect of participatory design (Sanders et al., 2013). Professional designers could observe hacking practitioners during hacking activities with the purpose of gaining insight into how to lower the threshold of prototyping effort. A good low-tech example is Sugru (2015), a self-curing silicone rubber that resembles modelling clay. Its play-dough characteristics make it easy and intuitive to use. It bonds to almost any other material and cures just by exposing it to air. This prototyping technology illustrates how low-tech and more easily handled tools open a whole new perspective on the democratization of innovation. One of the most influential views on user-driven innovation, in this tradition, is Eric von Hippel’s (2005) notion of lead-user innovation. Although Von Hippel acknowledges that users are active creators, he states that is only plausible for a small elite of lead-users who have access to technological production means and use it at the most advanced level of creativity. However, Sugru shows us that there is still great potential among those users who do not reach that level of professionalism but can still contribute to an innovation process by re-appropriating technology with a new meaning (Norman & Verganti, 2014). Following this line of thought leads us to another potential research question: is it possible to turn anybody into a potential lead-user through the attunement of the right prototyping means? Can meta-designers create the right infrastructure and encourage everyday people to play with technology and turn them into bottom-up frugal innovators? We believe there is still great potential. The strength of frugal innovators lies in their ability to get more from less, to continually experiment and to creatively engage people who are typically left out of the innovation process. These types of horizontal user innovation networks can be very responsive and rapidly change course when needed.

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11. CONCLUSION

ADAPTATION BY
PRODUCT HACKING

ADAPTATION BY PRODUCT HACKING

The aim of this dissertation was to gain more insight into adaptation by participatory hacking. Little had been known about the dynamic processes that take place when hacking practitioners learn from situated encounters through prototyping interactions. The primary research question was: How do specific prototyping interactions influence general adaptation in participatory hacking behaviour? In order to answer this question, the dissertation was split into three parts, namely 'infrastructure', 'framework' and 'capture tools'.

INFRASTRUCTURE

Because it was not yet known what variables are relevant, a quasi-experimental approach was unsuitable, and a case study approach was chosen. The first step in the infrastructure process was the selection of a relevant context to observe product hacking, namely DIY assistive technology (chapter 3). This context was chosen because the phenomenon of product hacking is trending on both a local and the global level. In addition, the distinct differences between the abilities of impaired people and their interaction with their immediate environment made it possible to observe product adaptation in its purest sense.

The next step was the facilitation of random case studies. For this we created a living lab on DIY assistive technology to embrace a variety of contexts and embed the role of situatedness through practice-based design research (chapter 2). The collaboration and management cycle was described in detail, giving an overview of the management process of finding partners, defining the project, running it, and then taking the next steps. This approach led to a rich dataset originating from 110 co-design case studies.

We also described the theoretical underpinnings from which we observed and analysed the case studies. The literature review has been a continuous effort, but one of the contributions of this work is that it has brought the field of cybernetics to the attention of designers. Although the process of product adaptation has not been addressed in depth in design research, we found many parallels between the fields of design research and cybernetics (chapter 4). As a premise or a starting point for our reasoning, we formulated the following axiom: '"Acting in the real world implies that something different from what was expected will always happen." We accept that experienceable prototyping interactions are the changing mediators in this spontaneous process and made a basic distinction between four mutually exclusive attitudes in these interactions, that is, constructing, creating, realizing and behaving.

FRAMEWORK

The main conclusion of this thesis is based on the fact that the process of product adaptation is based on the dynamics of self-regulation. A cybernetics design approach was chosen to develop a framework to explain the circular causality and relationships in local hacking activities. This approach allowed us to investigate both detailed and general hacking behaviour from a holistic perspective – putting brain, body and world together. Instead of reinventing yet another framework, we decided to position our product adaptation model as a partner to complete and validated models from cybernetics and design research. Our product hacking insights were fitted in to the work of Ross Ashby (1952) and his original notion of 'requisite variety'. We used key incidents to describe very formally the elements (anticipation and feedback) and steering conditions (or essential variables) needed to keep autonomous hacking entities viable when they pursue their goals in an ever-changing environment (chapter 5). Whether a specific prototyping interaction has an impact or influence on general adaptation behaviour depends partly on how the hacking entity assesses the situation (Is this harmful/beneficial to the achievement of our goal and therefore our belief system?) and on the variety of resources or repertoire (skills, technology and activities) that entity has to deal with that situation. The dynamics of this self-regulating process are characterized by two types of feedback, namely single-loop adaptation (adapting the environment; in other words, the activity of product hacking) and double-loop adaptation(being adapted by the environment; in other words, changing the goal and therefore the belief system of the entity).

In the sub-research questions, we focused on each type of regulation. RQ1 was: How do adapting prototyping interactions influence general adaptation in participatory hacking behaviour? To answer this question we analysed all the prototyping interactions and their self-reported assessments in the dynamics of a single case study (chapter 6). From this study we concluded that the observed hacking behaviour shows great similarities with the principles of self-organizing systems. From the random prototyping interactions, some kind of focus emerged, based on educated guesses. In the very action of product hacking both feedback loops continuously change and interact. Only unexpected prototyping interactions change the course of general adaptation behaviour and embody double-loop adaptations. Design actions that led to intended or manageable consequences created a single feedback loop by reducing deviations from the already chosen action strategy. In these single-loop learning situations, we observed a tendency to increase the level of measurement, from nominal to ordinal. Design actions that led to unexpected consequences forced the team to adapt its design strategy or priorities. These events induced new nominal measurements and were integrated through double-loop learning.

The act of hack prototyping consists of making lifelike models in a frugal manner with local resources and the skills at hand. The situated interactions with each hack prototype focus on relevant relationships between indispensable design variables, and others are explicitly given up or randomly filled in by the prototyping means and skills in the environment. To create a comprehensive overview, the hacking entity cognitively and physically breaks down the prototyping task into comprehensive subsystems or chunks. Through unexpected events, new relationships draw the attention and result in the creation of distinctions and the destruction of design variables. The respective properties are adapted to their specific inquiring purposes and partial successes are conserved and accumulated. This is done by integrating prototypes with the intention to retain certain functions and co-experiences. In this design practice, we distinguished between three types of prototype integrations: explorations, optimizations and interrelations.

To answer RQ2 – How do adaptive prototyping interactions influence general adaptation in participatory hacking behaviour? – we conducted a cross-case analyses to show the variety of double-loop adaptations in several contexts (chapter 7). Double-loop adaptations have a more transubstantiate character. Hacking entities are forced to change their internal structure, goals and belief system when their changing prototyping interactions in an environment make existing goals no longer viable. Changing variables that evoke the most significant change in meaning or objectives are called 'essential variables'. These variables are highly contextual and closely linked to survival or wellbeing. For the human species, both physiological variables (e.g. body temperature, level of sugar in the blood, nervous and muscular system) and psychological ones (e.g. feeling of safety, of belongingness, of esteem) are among its essential variables. The general rule is simple: if through a certain prototyping interaction an essential variable exceeds its limits (upper or lower), the viability of the entire system is in danger and the hacking entity is forced to adapt its design behaviour by changing its objective and therefore also its prototyping approach. From a practice-based perspective, we used the concept of 'emotion-as-affordance' to frame second-order understanding and to disentangle relevant essential variables of all engaged agents in a certain environment. Drawing on product appraisal theory (Desmet, 2002, 2007), we illustrated several sources of product adaptation arising from the distinction between three types of concerns (rightfulness, pleasantness, usefulness) shaping the belief system and three types of product stimuli (self-focus, activity focus and product focus) describing the variety of experienced consequences.

As a rule, the starting point of every hacking project is always triggered by a double-loop process. A physiological or psychological variable that exceeds its limits is co-experienced and creates an action tendency towards a new type of product adaptation. The counteractions always create alternatives on the level of how the hacking entity assesses the situation (changing standards, beliefs or values) or the way resources are used (make new variations between the available skills, technology and activities) to deal with a particular situation and keep the hacking entity in the right flow.

CAPTURE TOOLS

Capturing the appraisals process on prototype interactions was key to studying adaptation in participatory hacking behaviour. For this, we developed a self-conscious and an unconscious capture technique, namely the low-end 'self-report Schön matrix' and the high-end 'physiological video logging'. Both techniques grew out of the practice-based research and were explored in naturalistic design practice settings.

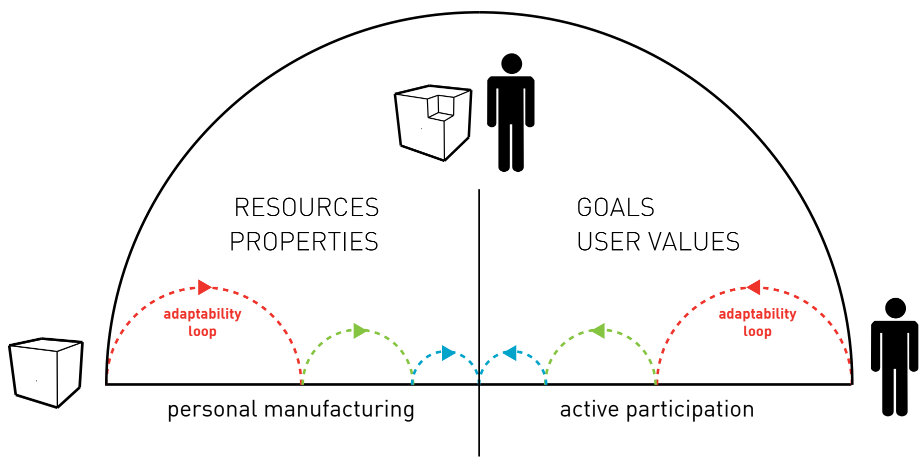
From a first-person perspective, the Schön matrix (chapter 8) served as an explicit self-report tool that helped hacking practitioners to document their momentary co-experiences together with their prototyping interactions. By explicitly mentioning unexpected positive events (quick wins) and negative events (failures) for every prototyping interaction, the hacking agents made their experience-driven design process more explicit for each other. In addition, the tool helps design agents to reconstruct with less bias the entire prototyping story from one co-experience to another. The semi-structured tool facilitates self-regulation on several levels. First, the technique creates a common language between all stakeholders – a language on new design variables based on real prototype interactions that identify meaningful experiences and personal limits. The act of sharing unexpected co-experiences also functions as a collaborative distinction-creation process that orientates the attention towards new possibilities for achieving goals. Combined with product hacking, the technique encourages people to take small but concrete actions and therefore progresses the co-design activity with more realistic plans; after all, this type of iterative learning stimulates habituation and reappraisals of new options in the design process, such as new technology or new unexplored human skills. This allows people to switch from a fixed mind-set (entity theory) on the possibilities of their own abilities towards a more growth mind-set (incremental theory). From a third-person perspective, the combination of the changing prototypes (input) with the self-report matrix (output) makes it more feasible to reconstruct the co-evolution dynamics (black box) in prototyping interactions.

A second technique focused on the implicit use of physiological technology to tag the orienting response of design agents while performing hacking activities. Our goal was to tag adaptive behaviour by synchronising electro dermal activity with a video stream of prototyping activities (chapter 9). The aim of this open design capture system was not to create an overall perfect design rationale as such, but to focus on an agent's change of the situated awareness from a first-person perspective and link these events with embodied prototyping interactions. When a design agent experiences such a meaningful event, it is often impossible to return to the previous state of his neuronal model (or awareness) of the perceived reality, as shown in the self-report analyses The first study showed that the unconscious tagging from the EDA sensor tagged unexpected negative events more reliably than either the notes made in the traditional design report or through the conscious tagging with buttons. Finding the right threshold for each participant's stress level is personal and crucial. The second study focused on cross-referencing data streams of multiple agents, which resulted in a sample of relevant co-experienced events in a single design activity. A first proof that the technology is also able to capture 'tacit knowing' is partially confirmed by the observation that non-verbal actions and re-appropriations, unexpected consequences (both positive and negative), emotions and action tendencies, nuances in optimizations of action strategies and physical effort by the agent are indicated in an unaware manner. A second conclusion is the need for a post-processing information dashboard to distinguish the relationship of specific OR patterns with physical, mental and emotional components within events. We do not claim that our experiments are validated techniques. Further analyses are needed to improve their robustness and reliability. However, these preliminary studies show that biosensor technology has the potential to unobtrusively capture co-design processes and overcome the limitations of human memory and the human's incapacity to verbalize tacit knowledge.

SIDE BY SIDE OVERVIEW

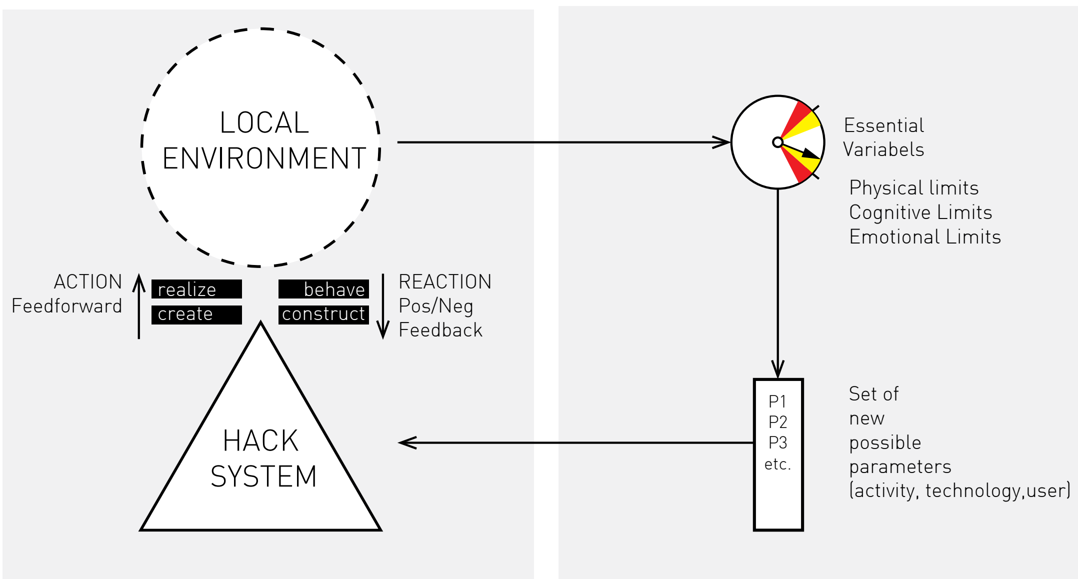
Main Research Question
'How do specific prototyping interactions influence general adaptation in participatory hacking behaviour?

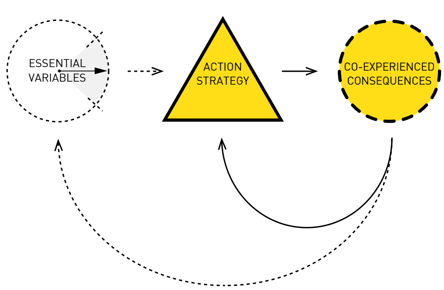
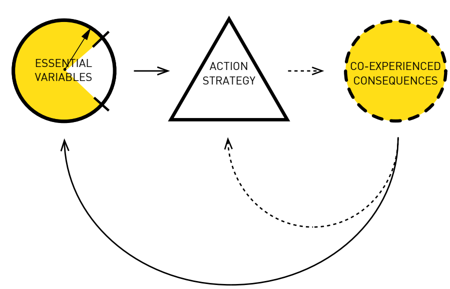
Axiom
"Acting in the real world implies that something different from what was expected will always happen."

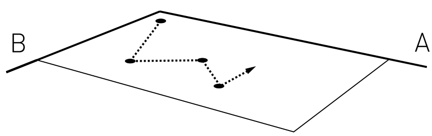
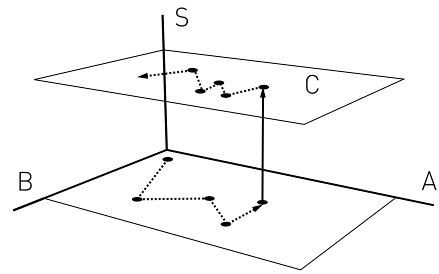


Focus 1: Adapting	Focus 2: Adaptive
TECHNOLOGY MAKING THE THINGS RIGHT (skills, activities, technologies)	MEANING MAKING THE RIGHT THINGS (standards, attitudes, goals)

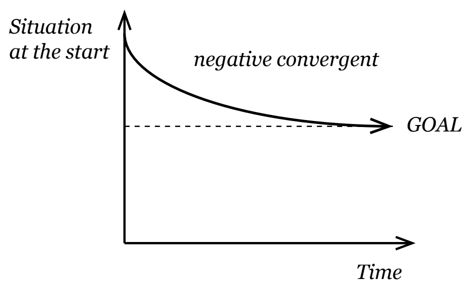
FRAMEWORK ON PRODUCT HACKING



Feedback 1	Feedback 2
(RQ1) 'How do *adapting* prototyping interactions influence general adaptation in participatory hacking behaviour?'	(RQ2) 'How do *adaptive* prototyping interactions influence general adaptation in participatory hacking behaviour?'
	

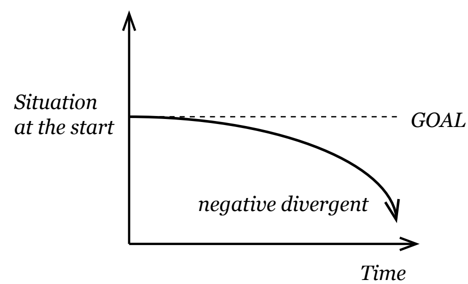
Focus 1: Adapting	Focus 2: Adaptive
Single-loop Adaptation	**Double-loop Adaptation**
	
• The hacking agents produce a sequence of deliberately controlled chosen actions to increase the level of predictability in the pursuit of their goal. • Based on their common repertoire and belief system, they actively perform adapting prototyping interactions and change their external world, combining their skills, technology and activities. • The sequence of spontaneous eliciting events resulting from the consequences of these actions takes no essential variable outside their limits.	• A sequence of eliciting events resulting from the consequences of these prototyping actions takes one or more essential variable outside their limits. • The agents are passively forced to change their co-design strategy and perform adaptive prototyping interactions by changing their attention and internal belief system (standards, attitudes and goals). • By doing so, they enrich their repertoire with new possibilities through a distinction creation process, introducing new parameters into the hacking system. • As a result, they enter a new problem solution space that will be responsible for a new sequence of deliberately chosen actions.

Focus 1: Adapting	Focus 2: Adaptive
Self-Regulating First-order Pattern	**Self-Regulating Second-order Pattern**



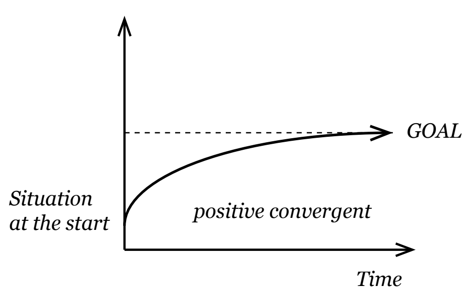
1. NEGATIVE FEEDBACK & NEGATIVE CONVERGENCE.

The hacking feels the need to approach a common set point or goal. Positive expected aspects are further integrated and optimized.



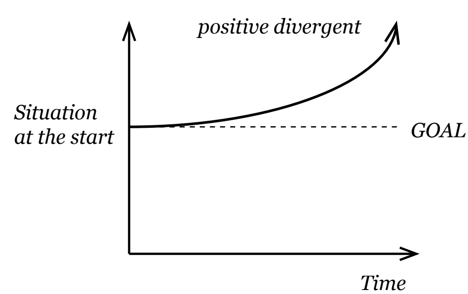
2. POSITIVE FEEDBACK & NEGATIVE DIVERGENCE.

The hacking entity deviates from current expectations to find a new set point that creates relevance. The team's attention is drawn to unexpected negative events.



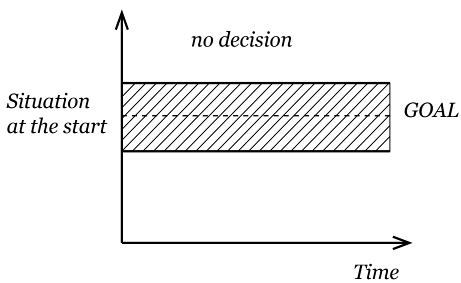
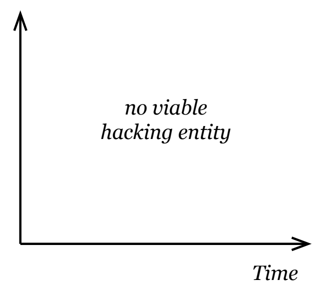
3. NEGATIVE FEEDBACK & POSITIVE CONVERGENCE.

The hacking entity feels the need to approach a common set point or goal. Negative expected aspects are further integrated and optimized.



4. POSITIVE FEEDBACK & POSITIVE DIVERGENCE

The hacking entity deviates from current expectations to find a new set point that creates relevance. The team's attention is drawn to unexpected positive events.

<table>
<tr><th>Focus 1: Adapting</th><th>Focus 2: Adaptive</th></tr>
<tr><th>When do first-order prototyping actions stop?</th><th>When do second-order prototyping actions stop?</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>BUFFERING

The relationship between the investigated design aspects is assessed as predictable and desirable for all participating agents. No further actions are carried out.

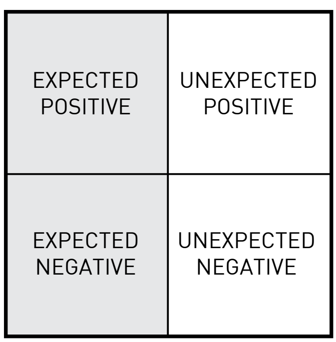
Unexpected events do not arise from the noise /limits. The hacking entity has adjusted itself to its environment and assesses this state as desirable.</td><td>1. NO VIABILITY

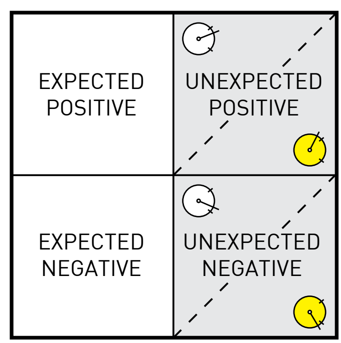
No hacking entity is able to survive through a synergy with its environment. The variety of its common repertoire and belief system is not big enough to cope with variety of interactions that its environment imposes. When essential variables are exceeded for a long time, the hacking entity stops to exists.

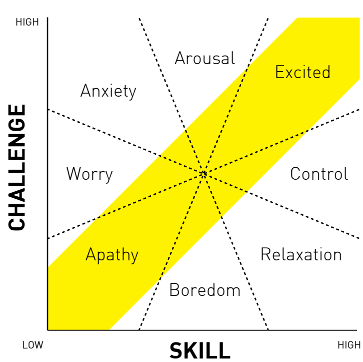
2. NEW IDENTITY.

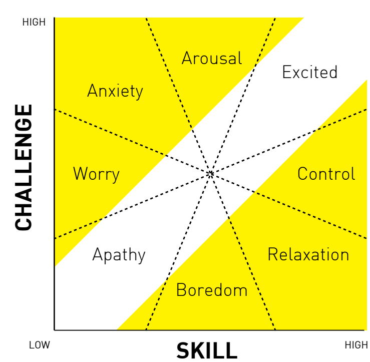
A distinction creation on the level of resources (skills, technology or activities) or challenges (standards, goals, attitudes) leads to a new and stable hacking entity.</td></tr>
</table>

Focus 1: Adapting	Focus 2: Adaptive
Level of measurement	**Level of measurement**
1. Copy/explore, reference (Nominal, YES/NO) *2. Combine/interrelation* (Ordinal, BETTER/WORSE) *3. Transform/fine-tune, optimisation* (interval/ratio, HOW MUCH BETTER/ HOW MUCH WORSE)	*1. copy/reference* (Nominal, YES/NO)
Emotional self-regulation	**Emotional self-regulation**









12. SUMMARY

ADAPTATION BY
PRODUCT HACKING

ADAPTATION BY PRODUCT HACKING

Whatever you may have heard about product hackers, the truth is they do something really, really well. In short: "*hackers build things, crackers break them.*" Through their experiential and social approach product hackers discover new possibilities in a frugal manner with the local resources and skills at hand. The human race has built up a rich history in adapting and designing his living environment and surrounding artifacts. In fact, this human tendency is even one of the rudiments of professional product design. Although the phenomenon of product hacking has been around for a long time, it's manifestation has drastically changed through several paradigm shifts within the DIY culture which lead to open-design (chapter 1). These shifts imply that professional designers are no longer placed above users when determining what is right or wrong for them. This dissertation explores the role of professional designers within this new and open-ended context. In general the research focus is on the epistemic dynamics of hacking behavior within the pursuit of making a tailored product adaptation for a single user.

Most famous product hacks are well documented but the situated design processes leading to these insightful hacks are often neglected and not discussed. If we want to support this movement and fully want to use its potential we need to understand which conditions enable learning and co-ordination. As the phenomenon of open design is relative new we conducted research through a practice-based design approach and explored the phenomenon in a holistic and situated manner. For that reason, we created a living lab environment (chapter 2) to facilitate product adaptation case studies and observe hacking behavior within real-life environments. Over the last 7 years, 110 participatory design case studies have been set up in local contexts built around meaningful activities of individual people. We used both quantitative and qualitative research methods to keep track of the designers' prototyping-interactions and the matching thoughts, feelings and experiences.

Simultaneously we also selected a general relevant context where the phenomenon of product hacking is naturally occurring (chapter 3). The advent of networked computers and digital fabrication make it feasible that individuals which mainly fall out of the mainstream can produce or adapt their own unique tools. More often these hacks can even compete with the qualitative standards of mass-production coming from large factories. Within the context of design for disability this perspective opens-up a complementary alternative to universal design. Today there are a lot of people with disabilities whose assistive devices have not yet come about, due to unique needs and challenges. A new generation of makers and occupational therapists are seizing this opportunity by producing one of a kind product adaptations in people's homes, sheltered workshops and rehabilitation centers. Although future healthcare policies are encouraging to effectively engaged people in the collaborative maintenance of their own health there is little known on the dynamics of these self-organizing processes and how professional designers can take part of them. With this research we tend to open the discussion on the use of product hacking methodologies within self-care.

Within this experiential design process, the creative process directs the resulting user experience and engaging users in turn direct this creative process. Other than in professional product development, we do not recognize consecutive stages of gradual refinement. The design behavior principally builds on the patterns of reflection-in-action. This process of continuous learning generally involves the detection and correction of errors through feedback loops on prototyping-interactions. To create a deeper understanding we made a connection between the basics of organizational learning in design practices and self-regulating learning systems within the field of cybernetics (chapter 4). The main shared propositions between both fields are forming the fundamentals of the framework : the acknowledgement of the environment as an completing agent, the role of agents as subjective observers, the role of failure to stimulate problem-solution co-evolution and the resonance between several agents through co-experiences on prototyping interactions consequences. An evolutionary epistemology which assumes that knowledge is constructed by the subject or group of subjects in order to adapt to their environment in the broad sense. That construction is an on-going process at different levels, physical as well as psychological or social.

Generally speaking collaborative hacking activities are a form of self-organizing co-design activities driven by participatory prototyping-interactions. For this reason, the starting point of this thesis was the question : "*How do specific prototyping-interactions influence general adaptation within participatory hacking behavior?*" To answer this question we propose a framework which illustrates hacking entities as a self-regulating learning systems. A cybernetic design approach was chosen to develop a framework to explain the circular causality and relationships within local hacking ecologies. Building further on the work of Ashby (1952) we list the minimum conditions and elements of an autonomous hacking entity in order for it to be able to adapt to changing circumstances and '*to get what it wants'.* With his holistic thinking, it integrates the surroundings as part of the a self-regulating system by means of two adaptation types, namely single and double-loop adaptation. Both loops enact respectively as an (1) active (agents actively change their environments through external adaptation) and (2) passive (agents compulsory change their internal construction of the environment through internal adaptation) component of adaptation. Although both type of adaptations are strongly intertwined we tried to illustrated them through the variety of data from the practices and illustrate how the self-organize the hacking process.

Within chapter 6 we illustrate the dynamics of adaptation from a single loop perspective. Within one entire case study we try to clarify the principles of self-organizing systems within hacking activities. Out of the varying prototyping-interactions we clearly observe a self-organizing design pattern which reduces variety or uncertainty, and at the same time increases information or more constraints on social-technical design aspects. Changes on causal relationships are triggered by unexpected events induced by co-experiences on embodied prototyping-interactions. Co-evolution is often viewed as a biologic process that is general slow. But the power of human exploration & exploitation, which are both inherently driven by spontaneous creativity , can also been seen as a type of self-organizing design process. Single loop hacking behavior is characterized by negative feedback, or reducing deviations from the already known action strategy. Theoretically this results in hierarchical climbing up in the level of measurements (from nominal to ratio). Within practice we noticed that at the beginning of each practice climbing up is very hard as so many unexpected consequences overrule chosen action strategies through double loop adaptations.

Within chapter 7 we discuss more in-depth the unexpected consequences which lead to double loop adaptation and thus change action strategies. Human actions are governed by a set of essential variables. These governing variables are the '*shared truths*' of the design collective constructed out of attitudes, be-goals and standards. As a rule for maintaining the viability of the social system, human agents steer their actions to keep these variables within acceptable limits. The general rule is simple, if an unexpected prototyping-interaction exceeds the limits of an essential variable (physically or mentally) the viability of the system is perceived as in danger and the system is forced in a compulsive manner to adapt his behavior. The human process of signaling the personal (and therefor also through co-experience social) relevancy of an event has been conceptualized as process of product appraisals. The appraisal model is a theory which emphasis the role of emotions as feedback and control towards physical and mental consequences of actions in the pursuit of human goals. Although the nature of these variables is very divers and tacit, emotional reactions on them can be easily picked up and become related to the changes within prototyping-interactions. These re-actions typically create a positive feedback, they increases deviations from the actual plan or sense of urgency and stimulate double loop learning which change the internal belief system of the hacking entity. Similar like product appraisal research we combined the several concerns and stimulus types to create a nine-source matrix of product emotions which trigger adaptive behavior As it is hard to predict the nature and emergence of certain essential variables several sources of product adaptation are discussed throughout key incidents of multiple case studies.

In this view if we want to learn the origin of adaptations we need to capture the tipping points caused by unexpected consequences coming from events. Therefore, we development discontinue and continue logging techniques, namely the low-end "*Schön matrix*" (chapter 8) and high-end "*OR glasses*" (chapter 9) using electro dermal activity to sense the physiological arousal. Both techniques grow out of the research and were explored in practical settings driven by prototyping-interactions to investigated both detailed and general hacking behavior.

In the general discussion (chapter 10), the application possibilities are discussed. We argue why open-ended hacking is powerful engine to design solutions for wicked problems. The idea of designing for appropriation almost seems like an oxymoron: "*plan for the unexpected*". However , can we design that people are more likely to be able to use what you produce for the unexpected? The role and implications for professional designers are also considered as changing, ranging from tool-designers to hacking design craftsmen. Co-experiences on first person prototype-interactions form the basis of self-coordination in hacking design activities. This implies that we need our emotions as they are very beginning of each adaptation strategy, and furthermore for valuating each side-effect that emerges through unexpected prototype-interactions. The work in progress of such hacking activities can enclose many other valuable idea's and experiences which are worth to recollect by the participating agents or to share with other hacking practitioners. We discuss the application possibilities of both logging techniques as t tools for removing hacking redundancy. Finally some future research is proposed on the elements of the hacking entity namely: context, technology, activity and the human agent as maker.

12. SAMENVATTING

ADAPTATIE DOOR PRODUCT HACKING

ADAPTATIE DOOR PRODUCT HACKING

Het negatieve beeld dat men in de media creëert rond product hacking strookt niet altijd met de realiteit. In werkelijkheid zijn product hackers heel goed in een, misschien zelfs vergeten, fundamenteel menselijke kwaliteit. Om even de nuance te schetsen : "*hackers bouwen op een inventieve manier aan nieuwe mogelijkheden binnen bepaalde beperkingen, crackers hebben als hoofddoel vooral schade aan te richten en mogelijkheden te beperken*." Door hun ervaringsgerichte en sociale aanpak ontwikkelen product hackers vaak op een heel sobere wijze nieuwe opportuniteiten die op een synergetische wijze gebruik maken van lokale middelen en vaardigheden. Het mensdom heeft een rijke geschiedenis opgebouwd van specifieke adaptaties binnen bepaalde omgevingen, situaties of product-mens interacties. In feite is deze fundamentele menselijke neiging zelfs één van de eerste drijfveren die tot op vandaag tot professioneel product design heeft geleid. Hoewel het fenomeen product hacken al sinds mensheugenis bestaat, is zijn manifestatie drastisch veranderd door verschillende paradigmaverschuivingen binnen de DIY cultuur, met als recent hoogtepunt "open design" (hoofdstuk 1). Deze verschuivingen brengen als gevolg met zich mee dat professionele ontwerpers en fabrikanten in het maakproces niet langer boven de eigenlijke productgebruikers worden geplaatst. Het zijn de productgebruikers die hun eigen unieke product creëren en lokaal afwegen welke product-interactie zowel in de maak- als gebruikerscontext een toegevoegde waarde creëert. Dit proefschrift onderzoekt de algemene dialoog tussen professionele ontwerpers als product hackers en andere lokale stakeholders binnen open en spontane ontwerpprocessen. In het algemeen onderzoeken we de epistemische dynamiek binnen collaboratief hackgedrag van op maat gesneden productaanpassingen voor individuele gebruikers.

Vanuit de open design cultuur zijn heel wat product hacks goed gedocumenteerd als eindresultaat, maar de ontwerpprocessen die leiden tot deze pientere hacks worden vaak verwaarloosd en niet besproken. In dit proefschrift willen we de achterliggende dynamiek rond product hacks beter begrijpen en een totaalbeeld schetsen van de randvoorwaarden die het gezamenlijke leer- en coördinatieproces mogelijk maken. Omdat "open design" een relatief nieuw onderzoeksgebied is, werd er gekozen voor een praktijkgerichte onderzoeksaanpak die het fenomeen op een holistische wijze benadert en focust op ontwerpgedrag. Vanuit dit perspectief werd er een living lab-omgeving (hoofdstuk 2) gecreëerd om enerzijds een breed spectrum aan spontane processen binnen diverse omgevingen toe te laten en de dynamiek rond ontwerpgedrag goed op te volgen. In de afgelopen 7 jaar werden er 110 participatieve lokale design case studies opgezet rond zinvolle activiteiten van individuele personen. Binnen het proefschrift gebruikten we zowel kwantitatieve als kwalitatieve onderzoeksmethoden om een beter beeld te krijgen van het soort prototype-interacties van de ontwerpers en hun bijbehorende gedachten, gevoelens en ervaringen.

Bij de opstart van het living lab werd er tegelijkertijd gekozen voor een algemene relevante context van hulpmiddelen waarin het fenomeen van het product hacken spontaan en frequent voorkomt (hoofdstuk 3). Geen twee personen of beperkingen zijn dezelfde en toch kunnen deze unieke gebruikers slechts kiezen uit een klein aanbod van universele hulpmiddelen die geproduceerd worden volgens massaproductiestandaarden. Geholpen door de opkomst van digitale fabricage en de ongelimiteerde hoeveelheid kennis die via het internet toegankelijk is, kan in principe elke gebruiker buiten de mainstream zijn eigen productadaptatie maken. Door de recente technologische vooruitgang binnen de digitale fabricage kunnen deze unieke producten voor het eerst zelfs concurreren met de kwalitatieve normen van gestandaardiseerde massaproductie. Binnen het kader van "*design for disability*" is product hacking dan ook een complementair alternatief t.o.v. het reeds gehanteerde "*universal design*" of "*design for all*". Vandaag zijn er een heleboel mensen met een functiebeperking voor wie nog geen specifieke hulpmiddelen bestaan, als gevolg van hun unieke behoeften en uitdagingen. Een nieuwe generatie ergotherapeuten en makers neemt het heft in eigen handen en innoveert en produceert bij mensen thuis, in beschutte werkplaatsen en in lokale revalidatiecentra. Hoewel het toekomstige beleid binnen de gezondheidszorg meer zelfmanagement en betrokkenheid van mantelzorgers nastreeft, is er weinig bekend over de dynamiek van deze zelforganiserende processen en hoe professionele ontwerpers hieraan kunnen deelnemen. Met dit proefschrift willen we alvast het gebruik van de hacking methodologie binnen de zelfzorg verkennen en de discussie op gang trekken.

Dit ervaringsgericht ontwerpproces wordt gestuurd door creatieve prototype-interacties. De consequenties en ervaringen rond deze prototype-interacties sturen op hun beurt het creatieve proces verder aan. Anders dan in de professionele productontwikkeling herkennen we geen opeenvolgende stadia waarbij men de focus bewust verfijnt of heroriënteert maar een cyclisch reflectie-in-actie proces. Het ontwerpgedrag binnen hacking activiteiten bouwt voornamelijk voort op het waarnemen van verandering binnen diverse patronen uit de reflectie-in-actie. Dit continue leerproces komt tot stand door het gezamenlijk detecteren van afwijkingen (fouten of quick-wins) via feedback loops over ervaringen rond prototyping-interacties. Om de dynamiek binnen lerende ontwerporganisaties beter te begrijpen, werd er in dit proefschrift een verbinding gemaakt met de cybernetica (hoofdstuk 4), de basiswetenschap die zich bezighoudt met de besturing van biologische en mechanische systemen met behulp van terugkoppeling (feedback). Zowel de cybernetica als de ontwerpwetenschap delen een aantal fundamentele proposities die de basis vormen van het ontwikkelde raamwerk in dit proefschrift: beide erkennen de rol van een dynamische omgeving als een complementaire agent, de rol van de deelnemende agentia als subjectieve waarnemers, de rol van afwijkingen die co-evolutie stimuleren tussen problemen en oplossingen, de resonantie tussen verschillende agenten door middel van gemeenschappelijke ervaringen rond consequenties van prototyping interacties. Deze stellingen creëren de basis voor een evolutionair epistemologisch wereldbeeld waarin nieuwe kennis wordt verworven door een zelfregulerend proces waarin een steeds veranderende hacking entiteit zich wil aanpassen aan een steeds veranderende omgeving. Vanuit dit perspectief bekijken we de co-constructie tussen de deelnemende leden als een continu proces dat zich uit in verschillende aspecten, zowel fysiek, als psychisch of sociaal.

Collaboratieve hacking activiteiten zijn in het algemeen een vorm van zelforganiserende co-design activiteiten gedreven door gemeenschappelijke ervaringen rond prototyping-interacties. Het uitgangspunt van dit proefschrift was de vraag: “Hoe beïnvloeden specifieke prototyping-interacties het algemene aanpassingsgedrag binnen participatieve hacking activiteiten?” Om deze vraag te beantwoorden gebruiken we een raamwerk dat hacking entiteiten als een zelfregulerend leersysteem illustreert. Vanuit een cybernetisch designperspectief wordt circulaire causaliteit binnen ontwerpacties en het ontstaan van nieuwe patronen binnen de lokale hacking ecologieën verklaard. Bouwend op het werk van Ashby (1952) geven we een overzicht van de minimale randvoorwaarden en basiselementen om een autonome hacking entiteit te vormen zodat zij in staat zijn zich aan te passen aan veranderende omstandigheden “*om te bereiken wat hij of zij wil*”. Met zijn systemisch holistische benadering integreert het raamwerk interacties met de omgeving, als onderdeel van een zelfregulerend systeem, door middel van twee soorten aanpassingen, namelijk “*single*” en “*double-loop*” adaptaties. Beide lussen belichamen respectievelijk een (1) actieve (agenten veranderen hun omgeving actief door middel van externe aanpassing) en (2) passieve (agenten veranderen verplicht hun interne constructie van het milieu door middel van interne aanpassing) vorm van aanpassing. Hoewel beide soorten aanpassingen sterk verweven zijn, proberen we in dit proefschrift het nuanceverschil te illustreren aan de hand van een gevarieerde set case studies om zo een praktisch beeld te schetsen van zelforganisatie binnen product hacking.

In hoofdstuk 6 illustreren we de dynamiek van adaptaties binnen het perspectief van “single-loop learning”. Dit doen we in de diepte doorheen één hele case studie. We proberen het basisprincipe van zelforganiserende systemen binnen hacking activiteiten te meten, nl. de afname van entropie of chaos. Uit de wisselende events rond prototyping-interacties herkennen we duidelijk het basisprincipe dat zich vertaalt in een dalende onzekerheid (of het aantal keuzemogelijkheden van een co-design team vermindert) en de nieuwe kennis die tegelijkertijd toeneemt. De hacking entiteit co-creëert op deze wijze hun unieke beeld op hun eigen beperkingen als team en de relevante sociaal-technische aspecten komende uit de interactie met de omgeving. Veranderingen op causale relaties rond productproblemen of oplossingen worden veroorzaakt door gezamenlijke ervaringen met onverwachte gebeurtenissen veroorzaakt door prototyping-interacties. Co-evolutie wordt vaak gezien als een biologisch traag proces. Maar de kracht van menselijke exploratie en exploitatie, aangedreven door creativiteit, kan ook aanzien worden als een soort zelf organiserend ontwerpproces. “*Single-loop*” gedrag wordt gekenmerkt door negatieve feedback of het verminderen van de afwijkingen ten opzichte van de reeds gekende actiestrategie. Theoretisch resulteert dit in een stijging van meetniveaus (van nominaal tot rationaal) rond bepaalde ontwerpaspecten. Binnen de praktijk merken we op dat aan het begin van elke ontwerpactiviteit het stijgen in meetniveau rond design aspecten erg moeilijk is. De teams vallen heel snel terug op nominale metingen omdat er zoveel onverwachte gevolgen zijn die hun gekozen actiestrategieën overrulen door middel van "*double-loop*" aanpassingen.

In hoofdstuk 7 gaan we dieper in op de onverwachte gevolgen die leiden tot het wijzigen van adaptatiestrategieën en dus "*double loop learning*" veroorzaken. Menselijke handelingen of actiestrategieën worden beheerst door een reeks van variabelen die belangrijk zijn voor het voortbestaan van het totale systeem. Deze 'essentiële variabelen' zijn opgebouwd uit complexe relaties tussen directe fysiologische (bvb. bloeddruk, lichaamstemperatuur, suikerspiegel, enz.…) en indirecte psychologische aspecten (attitudes, doelen en normen). Als regel voor het handhaven van de levensvatbaarheid binnen het sociale systeem sturen de menselijke agenten hun acties steeds bij om deze essentiële variabelen binnen aanvaardbare normgrenzen te houden. De algemene regel is eenvoudig: als een onverwachte prototyping-interactie een essentiële variabele overschrijdt (fysiek of mentaal), wordt dit ervaren als een gevaar voor de levensvatbaarheid van dit systeem. Het systeem wordt gedwongen om zijn gedrag aan te passen wil het verder zijn doel bereiken in een bepaalde omgeving. Om de relatie tussen de relevantie van een evenement en een product-interactie te meten binnen hacking activiteiten, werd in dit proefschrift gebruik gemaakt van de emotietheorie. Emoties fungeren als '*bekrachtigers*' en vormen de motor van double loop ontwerpgedrag. Het cybernetisch model van de cognitieve beoordelingstheorie legt de nadruk op emoties als feedbackmechanisme komende van fysieke, mentale of sociale consequenties uit tastbare product-interacties. Essentiële variabelen zijn heel divers en contextafhankelijk. Hoewel sommige variabelen zelfs moeilijk te verwoorden zijn, kunnen de emotionele reacties rond bepaalde prototyping-interacties wel gedeeld worden en met elkaar in verband worden gebracht. "*Double loop learning*" reacties veroorzaken vaak een positieve feedback. Ze verhogen afwijkingen van de feitelijke plannen en verplichten het team zijn mentale model en daaropvolgende actie-strategie aan te passen. Om de diversiteit aan double loop productadaptaties te illustreren, hanteren we de product-emotiematrix die de verschillende beoordelingstypes met allerlei product-interacties in kaart brengt. Aangezien het onmogelijk is te voorspellen welke emoties er zullen opduiken, proberen we het landschap te schetsen dat de verschillende bronnen van productadaptaties in kaart brengt. De verschillende gebieden werden besproken vanuit sleutelmomenten komende uit de zelfrapporteringsdagboeken van diverse case studies.

Als we meer willen te weten komen over het ontstaan van productadaptaties en de dynamiek die ze veroorzaken binnen hacking activiteiten, moeten we in staat zijn de kantelpunten die sommige onverwachte prototyping-interacties veroorzaken te capteren. Binnen dit proefschrift hebben we daarom geëxploreerd met twee nieuwe captatie technieken, namelijk de low-end "*Schön matrix*" voor zelfrapportage (hoofdstuk 8) en de high-end "*OR glasses*" (hoofdstuk 9) die gebruik maken van de huidweerstand om opwinding bij ontwerpers te detecteren. Beide technieken zijn gegroeid vanuit het onderzoek naar spontaan ontwerpgedrag en werden kritisch toegepast binnen de praktische setting van hacking activiteiten om zowel gedetailleerd als generiek hacken gedrag te kunnen observeren.

In de algemene discussie (Hoofdstuk 10) worden de toepassingsmogelijkheden van product hacking besproken. We argumenteren waarom product hacken een krachtige motor is om lokale oplossingen voor "*wicked problems*" zichzelf te laten genereren. Het idee om productinteracties te ontwerpen die gaandeweg toch een ander doel of bestemming zullen krijgen, lijkt bijna een contradictie: een "*plan voor het onverwachte*". Hoe kunnen we als professionele designers mensen meer mogelijkheden bieden door wat we produceren ook voor onverwachte doeleinden open te stellen? Binnen het product hacking verhaal verandert de rol van professionele ontwerpers, variërend van tool ontwerpers tot en met echte hacking ambachtslieden. Het gezamenlijk erkennen van afwijkende productervaringen vormt de basis van zelf-coördinatie in hacking activiteiten. Dit houdt in dat we onze emoties nodig hebben als drijfveer van elke nieuwe adaptatiestrategie en daarenboven gevoelig moeten zijn voor nieuwe neveneffecten die op de voorgrond schuiven door onverwachte prototype-interacties. Het is van cruciaal belang om niet alleen het eindresultaat maar alle sporen of kantelpunten binnen het ontwerpproces te documenteren zodat externe hacking agentia ook hierop kunnen inpikken. Om nieuwe variaties te maken, bespreken we kritisch de toepassingsmogelijkheden van de beide logging technieken als hulpmiddelen om de redundantie van hacking ervaringen op peil te houden. Als laatste onderdeel worden een aantal nieuwe onderzoeksdomeinen blootgelegd die verband houden met diverse elementen van het raamwerk rond product hacking, namelijk context, technologie, activiteiten en de mens als maker.

Part VI

APPENDIX

13. VALORISATION

ADAPTATION BY PRODUCT HACKING

SCIENTIFIC PUBLICATIONS

Journal Papers

-De Couvreur, L., Vanhoucke, M., Dejonghe, W., Saldien, J., Detand, J., & Goossens R. H. M. (2016). Capturing Situational Awareness within Embodied Prototyping -Interactions : An Open -Design Case Study on Physiologically-Triggered Videologging. (SUBMITTED).

-De Couvreur, L., Dejonghe, W., Detand, J., & Goossens R. H. M. (2013). The role of subjective well-being in co-designing open-design assistive devices. International Journal of Design, 7(3), 57-70.

-De Couvreur, L., & Goossens, R. (2011). Design for (every) one: co-creation as a bridge between universal design and rehabilitation engineering. CoDesign, 7(2), 107-121.

Book Chapter

- De Couvreur, L., Dejonghe ,W., De Munck, K., Detand, J. & Goossens,R. (2016). Faal samen, faal snel, faal beter! Een cybernetische benadering van participatie door ervaringsgerichte co-design. In G. Van Hove, M. Cardol & A. Schippers (Eds.), Disability Studies in de Lage Landen. Antwerpen: Garant .

-De Couvreur, L. Vollens,E. (2012). Thea schommelt. Ed/s. Beysen, A. De Lameillieure, A. Lenstra, R. Oskamp, J. ,Cecilia 's keuze - Ontwerpen met meerwaarde op basis van gebruikersinzichten (pp.82-86). Lannoo Campus.

Conference Papers

-De Couvreur, L., Detand, J., Dejonghe W. and Goossens R. (2012). Expect the unexpected, the co-construction of assistive artifacts. In Proceedings of the 8th International Conference on Design & Emotion. London.

-De Couvreur, L., Detand, J. and Goossens, R., 2011. The role of flow experience in co-designing open-design assistive devices. In: Proceedings of the Include 2011 Conference. 18-20 April 2011 London

-De Couvreur, L., Goossens, R., 2010. Design for (every)one: Co-creation as a bridge between universal design and rehabilitation engineering. Codesign In Proceedings of the 8th International Conference on Design & Emotion. Chicago.

-De Couvreur, L., Detand, J., Grimonprez, B., Mistiaen, B. (2009). Design for (every)one, Proceedings of designing pleasurable products and interfaces 2009 Conference, (pp. 340-348). Compiègne

AWARDS

- NOMINATED SENIOR CERA AWARD 2014

- 14TH FEA PHD SYMPOSIUM UGENT 2013
  Laureate best poster awards

- INCLUDE CONFERENCE AWARD 2011
  The award for best paper at Include 2011

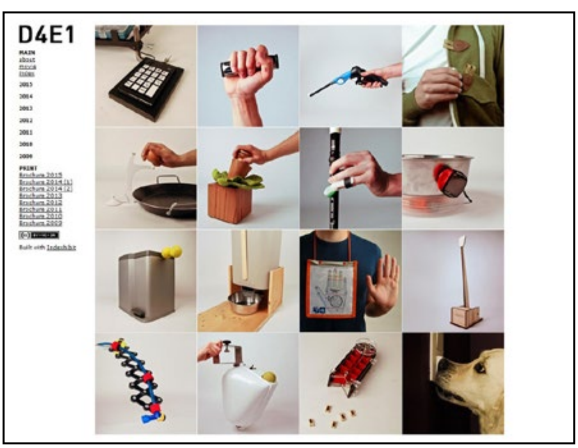
- DESIGN MANAGEMENT EUROPE AWARD 2010
  Category 'Best management of design in a public or non-profit organization'

- HANDICAP INTERNATIONAL 2010-2011-2012-2013-2014-2015
  Winner "design with a heart"-competition category student-work

EDUCATION PROGRAM

The practice based research and the activities within the living lab have led to the foundation of a new minor called "adaptation & design" within the professional bachelor education program on occupational therapy within the University College West Flanders (Howest)

REPOSITORY WEBSITE CASE STUDIES



website: http://designforeveryone.howest.be/

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DONDERDAG 10 JUNI 2010

HULP DIE HET VERSCHIL MAAKT

Nagels knippen of schommelen zijn vanzelfsprekende handelingen. Maar voor mensen met een fysieke beperking kunnen het onoverkomelijke problemen zijn. Studenten uit het laatste jaar ergotherapie en industrieel ontwerp van de Hogeschool West-Vlaanderen staken de koppen bij elkaar om handige hulpmiddeltjes te ontwerpen. Samen met de hulpbehoevenden gingen ze op zoek naar een oplossing voor hun alledaagse problemen. De hogeschool stelde de resultaten voor op haar jaarlijkse ontwerpbeurs. Vier opvallende ontwerpen.

NICOLAS WALSCHAERT

1. Honddraagzak

Dit ontwerp werd gemaakt op vraag van een leraar met een motorische beperking. De leraar had al een draagzak voor zijn hulphond, maar die was te klein voor de cursussen en niet gemakkelijk te openen voor iemand met een motorische handicap.

De studenten ontwierpen een harnas voor de hond waar een draagtas aan bevestigd kan worden. Voor de vorm van de tas haalden ze hun inspiratie bij een fietszak. De tas is groot genoeg om cursussen of wat boodschappen in te vervoeren. Je kan de draagtas gemakkelijk losmaken van het harnas en als gewone tas gebruiken. De zak wordt gesloten met magneten, wat het openen makkelijk maakt. Om zeker te zijn dat hun honddraagtas niet schadelijk is voor de hond, gingen de ontwerpers langs bij een dierenarts voor enkele tips.

2. Wandelstoel

De wandelstoel is gemaakt voor mensen die niet lang kunnen blijven rechtstaan. De ontwerpers kregen hun opdracht van een man met het postpoliosyndroom. Dat zorgt ervoor dat hij stilaan spierkracht verliest en dus moeite heeft met lang rechtstaan. De studenten wilden een concept ontwerpen dat op een bestaand product gemonteerd kan worden. Het resultaat zijn drie aan elkaar vastgemaakte buizen die je met een riem aan een rolkoffer kan bevestigen. Het zijn pvc-buizen met twee soorten schuim rond, waardoor je zacht zit. Je kan op twee manieren op de wandelstoel zitten. Met de trolley tussen je benen, een beetje zoals op een paard, of je kan er gewoon op zitten met het handvat als rugsteun. Als je op de wandelstoel zit, blijf je op ooghoogte met de mensen rondom je, ideaal dus voor op recepties.

3. Nagelknipper

Deze nagelknipper is ontworpen voor een vrouw die na een hersenbloeding haar rechterarm niet goed meer kon gebruiken. Met haar goede linkerhand kan ze perfect nagels knippen, maar de nagels van die linkerhand knippen was onmogelijk. Er bestaan al hulpmiddelen om met één hand nagels te knippen, maar die bleken helemaal niet praktisch en gebruiksvriendelijk voor de vrouw. De studenten ontwierpen een nagelknipper die je met het voorhoofd moet bedienen. In de voet past een gewone nagelknipper waar een grote buis over is geschoven. In die buis past een kleinere buis waar je met je voorhoofd op moet duwen om de nagelknipper in te drukken. Omdat de vrouw tijdens haar revalidatie haar arm steeds beter kon gebruiken, maakten de ontwerpers een buis waar ze met haar arm op kan duwen *(zie foto)*.

4. Schommelkuip

De schommelkuip werd ontworpen voor een meisje met het syndroom van Rett. Ze heeft een beperkte motoriek waardoor ze moeilijk touwen kan vastgrijpen of haar benen kan strekken. Hierdoor is het voor haar onmogelijk om te schommelen. De schommelkuip is een soort zitzak die je aan elke gewone schommel kan hangen. Het ontwerp is een alternatief voor al bestaande zitschommels, maar die waren te duur, lelijk of onpraktisch. De ontwerpers kwamen op dit idee door een gewone rugzak aan een schommel vast te maken. De schommelkuip is handig en veilig. Doordat je er achterover in ligt, kan je er niet gemakkelijk uitvallen. Je kunt de schommelkuip oprollen tot een rugzak en overal mee naartoe nemen. De schommelkuip won de publieksprijs op de ontwerpbeurs van de Hogeschool West-Vlaanderen.

Handicap International beloont viertal dat Simeon Vanquaillie (36) laat musiceren

Met één arm toveren met de trombone

Trombone spelen met één arm. Simeon Vanquaillie (36) kan het dankzij het technisch vernuft van vier jonge studenten uit Kortrijk. 'Ik hoop dat die mensen beseffen hoeveel plezier ze, ons 'gehandicapten' geven'.

Sara Vandekerckhove

Een fuga van Johann Sebastian Bach of een concerto van Felix Mendelssohn: mits wat oefening kan de 36-jarige Simeon Vanquaillie het uit zijn trombone toveren. Eenarmig bovendien. "Ik kan terug op een comfortabele manier muziek spelen. Dat was enkele maanden geleden wel even anders. Na enkele minuten blazen, deed alles pijn."

Jong geweld uit Kortrijk zorgde in dit geval voor de muzikale verlichting. Jonas Maertens, Arne Malfait, Suzan Debruycker en Elien Vanhee – twee industriële ingenieurs en twee ergotherapeuten – bedachten een inventief systeem. Met behulp van een steunstuk rond de hals dat in verbinding staat met de trombone en een schouderband kan Simeon perfect trombone spelen. Zonder prothese en belangrijker nog: zonder pijn.

"Ik ben heel hard met muziek bezig", vertelt Simeon, vader van drie en spoorwegbediende bij de NMBS. "Vroeger speelde ik wat piano, gitaar en trombone. Gitaar lukt me niet meer en piano blijft bij wat eenhandig getokkel. Trombone daarentegen lukt me nu wel."

Drie jaar geleden verloor hij zijn rechterarm. "Tijdens een 'klassiek weekendongeval'. Een dronken chauffeur ramde onze wagen op de E17. Mijn vrouw en ik kwamen van een huwelijksfeest en waren op weg naar Antwerpen. De dader reed 170 kilometer per uur, wij nauwelijks 110. Hij heeft nog geprobeerd vluchtmisdrijf te plegen, maar was te zeer geïntoxiceerd."

De auto ging over kop en belandde uiteindelijk in de gracht. "Mijn vrouw zat achter het stuur. Toen ze bij bewustzijn kwam, zag ze dat ik niet langer in mijn stoel zat.

> 'Muziek maken is iets mooois. Het voelt oneerlijk als je het niet meer kunt. Van trombone wist ik dat het mogelijk moest zijn'
>
> SIMEON VANQUAILLIE

Door de slag was ik uit de auto gekatapulteerd. Mijn vrouw vond me twaalf meter

Arne Malfait (l.) en Elien Vanhee (r.) zorgden er samen met twee andere studenten voor dat Simeon Vanquaillie (m.) na zijn ongeval opnieuw trombone kon spelen.
© JONAS LAMPENS

zijn. Ik kon het instrument niet meer rechts vasthouden, dus had ik het idee om de trombone omgekeerd in elkaar te steken."

De eerste euforie was groot, maar algauw moest Simeon toegeven dat het te veel moeite en pijn kost. "Blijkbaar hield

ANDERE WINNAARS

'Design with a Heart 2013'

1 Verzorgingstafel voor Gilles
Gilles is een jongen met een meervoudige beperking. Als zijn ouders hem willen verzorgen, mogen ze hem geen seconde uit het oog verliezen. Om hun zoon veilig te kunnen verzorgen, bedachten zijn ouders een aangepaste verzorgingstafel. Die zorgt ervoor dat Gilles niet kan vallen. De papa van Gilles maakte de tafel met MDF-platen en enkele

Het probleem is dat die stoel telkens wegrolt. Hulpstukken om dat te vermijden zijn vaak op maat gemaakt en erg duur. Twee studenten van de Hogeschool West-Vlaanderen ontwierpen een low budget-rem voor Zurab. De basis van de rem is een oud fietswiel met rubberen lapjes. Het wiel wordt achter de bureaustoel op de grond geplaatst. Als het wiel op de rubber rijdt, ontstaat er een remmend effect.

'10 jaar Design with a Heart'

3 Oprijvaliesje

Design with a Heart

Design with a Heart is een jaarlijkse wedstrijd van Handicap International. Dit jaar is het de tiende keer dat de organisatie slimme uitvindingen voor mensen met een beperking beloont. Alle winnende uitvindingen komen met een soort Ikea-handleiding terecht op de website van Handicap International. Op die manier kunnen andere mensen de uitvindingen gemakkelijk namaken. De prijsuitreiking voor 2013 vindt vandaag plaats in Brussel.

voor iemand. Plots je lievelingsinstrument niet meer kunnen bespelen, is een enorme klap. Wekenlang hebben we het ene na het andere prototype gebouwd, een ultieme zoektocht naar dat ene hulpstuk dat het verschil zou maken."

Op maandag werden de stukken in elkaar geknutseld in het atelier op school, op zaterdag werd het resultaat daarvan getest bij Simeon thuis. En dat wekenlang. "Ze hebben zich daar echt op gestort", zegt Simeon. "Bewonderenswaardig vind ik dat. Je moet het maar doen: elke zaterdag opofferen om iemand opnieuw trombone te laten spelen. Ik hoop dat die mensen beseffen hoeveel plezier ze ons, 'gehandicapten', geven."

Doden tellen

Handicap International doet alvast zijn best om innovaties voor mensen met een beperking te belonen. Elk jaar gaat de organisatie voor de wedstrijd 'Design with a Heart' (zie kader) op zoek naar solidaire uitvindingen. Vaak eenvoudige tools die voor andersvaliden het verschil maken. Dit jaar valt onder meer de trombonehulp in de prijzen.

"Een verrassing", zegt ergotherapeute Elien Vanhee. "Wij waren eigenlijk al lang blij dat we iemand hebben kunnen helpen. Simeons

14. LIVING LAB PROJECTS

ADAPTATION BY PRODUCT HACKING

CASE STUDIES 2009

gitaarhulp 2.7

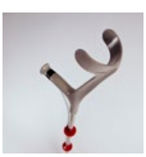
CLIENT : Karla en Niel, Dirk Deweer
IPO : Wouter Vanderhoydonk
Onderwijsafdeling van het Dominiek Savio Instituut

drinkhulp 1.5

IO : Maarten Dufourmont, Bart Vaneeckhout
ERGO : Fien Vens, Valerie Stragier
http://drinkhulp2009.blogspot.com/

rugzakhulp 1.11

CLIENT : Mathias, Dirk Deweer
IO : Robbe Vanneste, Florian Nachtergaele
ERGO : Sara Page, Ruth Valcke, Jolien Vanwettere
http://rolstoeltas2009.blogspot.com/



handsfree kruk 1.8

CLIENT : Sharon, Dirk Deweer
IO : Karen De Potter, Michaël Colson
ERGO : Esther Declercq, Tille Vanrobaeys
http://handsfreekrukken2009.blogspot.com/

MP3-speler 1.4

CLIENT : Stefanie
IO : Devenyns Stijn, Verhelst Ruben, Abid Yassine
ERGO : Stefanie Bodyn, Angelo Dhont, Simon Meersman, Dirk Deweer.
http://rolstoelmp32009.blogspot.com/

opzettafel 1.9

CLIENT : Freddy, Jan Seynaeve
IO : Nathalie De Beer, Ruben Serruys
ERGO : Hanne Dezegher, Lisselotte Scherpereel
http://opzettafel2009.blogspot.com/

ijsjeshulp 1.12

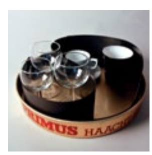
CLIENT : Sebastian
IO : Wim Magette, Birgitt Deckers
ERGO : Isabelle Swalus, Lieze Coulembier
http://ijsjeshulp2009.blogspot.com/

spraakcomputer 1.7

CLIENT : Aline
IO : Wannes Van den Bossche, Kenneth Coene,Thomas De Rycke
ERGO : Liselotte Callens, Frauke De Boe
http://spraakcomputer2009.blogspot.com/

ijsjeshulp 1.12

CLIENT : Sebastian
IO : Wim Magette, Birgitt Deckers
ERGO : Isabelle Swalus, Lieze Coulembier
http://ijsjeshulp2009.blogspot.com/



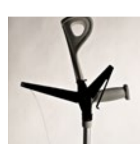
serveerhulp 1.12

CLIENT : De Oude Melkerij, Dirk Deweer
IO : Jef Peeters, Ruben De Baere
ERGO : Sofie Duhem, Silvia Dumazy
http://serveerhulp2009.blogspot.com/

spraakcomputer 1.7

CLIENT : Aline
IO : Wannes Van den Bossche, Kenneth Coene,Thomas De Rycke
ERGO : Liselotte Callens, Frauke De Boe
http://spraakcomputer2009.blogspot.com/

CASE STUDIES 2010



handsfree kruk 2.7

CLIENT : Howest -IPO
IPO : Bart Decroos, Adriaan Schelfaut
David Spiessens

nagelknipper 1.7

CLIENT : Gilberte
IO : Evy Allemeersch, Louis-Philippe Vancraeynest
ERGO : Charlotte Schatteman UZGent
http://nagelknipper2010.blogspot.com/

wandelstoel 1.9

CLIENT : Catherine & Hilde
IO : Ruben Martyn, Matthias Van De Walle
ERGO : Hilde Ramboer
http://wandelstoel2010.blogspot.com/

hometrainer 1.5

CLIENT : Joost
IO : Jan Leyssens, Thomas Vandendriessche, Jan Van Loo
ERGO : Griet Castelain
http://pedalokrukken2010.blogspot.com/

easyseat 1.7

CLIENT : Harry
IO : Sarah Grison, Philippe De Vos
ERGO : Devos Eline, Thomas Schotte, Jelle Ingelbrecht
http://easyseat2010.blogspot.com/

schommelkuip 1.8

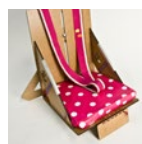
CLIENT : De Oude Melkerij, Dirk Deweer
IO : Jef Peeters, Ruben De Baere
ERGO : Sofie Duhem, Silvia Dumazy
http://serveerhulp2009.blogspot.com/

regenkap 1.3

CLIENT : De Oude Melkerij, Dirk Deweer
IO : Jef Peeters, Ruben De Baere
ERGO : Sofie Duhem, Silvia Dumazy
http://serveerhulp2009.blogspot.com/

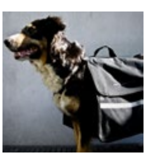
revalidatiefiets 1.5

CLIENT : Aline
IO : Mikhaël Kutlu, Sander Dumont, Thomas Dhaenens
ERGO :Vera Vercaemst
http://hometrainerhack2010.blogspot.com/



flexiseat 1.8

CLIENT : Méderic
IO : Delphine Depuydt, Arnaud Mahy
ERGO : Tineke Furniere, Femke Dendooven,
http://flexiseat2010.blogspot.com/



hondendraagtas 1.4

CLIENT : Hilde & Veerle
IO : Basil Vereecke, Levi Algoet
ERGO : Hilde Ramboer
http://honddraagtas2010.blogspot.com

trilspeelgoed 1.5

CLIENT : Océane
IO : Jelle Busschaert, Isabelle Waterplas
ERGO : Eveline Vangeenberghe
http://trilspeelgoed2010.blogspot.com/

autiklok 1.7

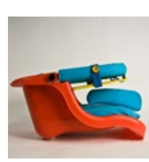
CLIENT : Clement
IO : Thomas Valcke, Jan De paepe
ERGO : Nena Verleyen, Justine Vanhee
http://autiklok2010.blogspot.com/

boodschappenkar 1.7

CLIENT : Marie Thérèse
IO :Hanne Cool, Thomas Onraet
ERGO : Charlotte Vercruysse, Leen Vandenborre
http://boodschappenkar2010.blogspot.com/

toiletoprichter 1.7

CLIENT : Elisabeth
IO : Bram Demets, Delphine Verstraete
ERGO : Sofie Nachtegaele, Charlotte Michiels, Sarah De Ruyck
http://toiletoprichter2010.blogspot.com/



bumboseat 1.5

CLIENT : Dylan
IO : Collie Fauve, Vanmaele Elke
ERGO : Paquet Lies, Theuninck Stéphanie
http://bumboseat2010.blogspot.com/

rollatorrem 1.8

CLIENT : Maria & Marcel
IO : Ruth Cleemput, Jonas Vleeschouwer
ERGO : Ann-charlotte Dutry, Clément Vermeulen, Delfien Cole
http://rollatorrem2010.blogspot.com/

badmintonshuttle 1.13

CLIENT : Korneel
IO : Dries Coutigny, Thijs Van Hooreweder
ERGO : Kevin Vuylsteke, Ben Mestdag, Tommy Nuyttens
http://badmintonracket-2010.blogspot.com/

CASE STUDIES 2011

oprijvalies 2.3

CLIENT : Eveline
IO : Oliver Dewolf
MANTELZORER : Julien scheers
http://oprijvalies2011.blogspot.com/

intellikeys 1.3

CLIENT : Karel
IO : Maerschalck Lennert, Desmadryl Célestin
ERGO : Stevens Jasmien, Dhuyvettere Nathalie
http://intellikeys2011.blogspot.com/

loopschip 1.3

CLIENT : Lucas
IO : Verbrugge Steven, Elena Martinez, Filip Gerits
ERGO : MPI Zonnebloem
http://loopschip2011.blogspot.com/

weegschaal 1.5

CLIENT : Henk
IO : Desmet Arne, Seynaeve Bram, Odette Moreno Lopez Pedraza
ERGO : Arne Vanneste, Elise Cornelissens
http://weegschaal2011.blogspot.com/

flessenhouder 1.3

CLIENT : Nicole
IO : Callewaert Kjill, Anthony Ballegeer
ERGO : Sharon Messiaen, Girzie Fockenoy
http://flessenhouder2011.blogspot.com/

prismabril 1.7

CLIENT : Fred
IO : Jeff Stubbe, Joris Bellens
ERGO : Moerman Flore, Beddeleem Céline
http://prismabril2011.blogspot.com/

saunarolstoel 1.6

CLIENT : Damien
IO : Huyghe Xavier, Raeves Bart
ERGO : Lore Vanstaen, Lisa Houzet
http://saunarolstoel2011.blogspot.com/

toiletverhoger 1.5

CLIENT : Hilda
IO : Joren De Temmerman, Katrien De Schepper
ERGO : Sofie Eveveraert
http://toiletverhoger2011.blogspot.com/

drinkhulp 2.3

CLIENT : Marc
IO : Julien De Nys, Thijs Leroy
ERGO : Liesbeth Vanwezer
http://drinkbeker2011.blogspot.com/

tandenpoetshulp 1.6

CLIENT : Freddy
IO : Catoor Bart, Kock Maaike
ERGO : Jan Seynaeve, Shana Rondelez, Naaike Delcour
http://tandenborstel2011.blogspot.com/

reisstoel 1.5

CLIENT : Damien
IO : Bens Eva, Denolf Olivier
ERGO : Deborah Vandemeulebroecke, Lies Geldof
http://tafelmes2011.blogspot.com/

snijhulp 1.4

CLIENT : Damien
IO : Bens Eva, Denolf Olivier
ERGO : Deborah Vandemeulebroecke, Lies Geldof
http://tafelmes2011.blogspot.com/

transportrollator 1.6

CLIENT : Peter
IO : Thijs Platteau, Bram De Craecker
ERGO : Lisa Surmont, Stephanie Vervaecke
http://transportrollator2012.blogspot.be/

laptophulp 1.7

CLIENT : Cathérine
IO : Deprez Kevin, Van Strydonck Marc
ERGO : Ine Moentjens, Fien Pollie
http://laptophulp2011.blogspot.com/

communicatieboek 1.6

CLIENT : Sofie
IO : Vanhoucke Maarten, Simon Dessauvage
ERGO : Annelies Catteeuw
ORTHO : Cellini De Langhe
http://communicatieboek2012.blogspot.be/

schilderhulp 1.4

CLIENT : Ludwiene
IO : Charlotte De Ruytter, Wouter Velle, Paulina Hernandez Santamaria
ERGO : Hilde Ramboer, Heleen Sabbe.
http://speelmat2011.blogspot.com/

jashulp 1.5

CLIENT : David
IO : Niels Lehouck, Birger Stilten
ERGO : Suzan Ghillemyn
http://jashulp2012.blogspot.be/

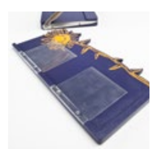
CASE STUDIES 2012

flessenhouder 2.9

CLIENT : Nicole
IO : Yorick Stuyts, Wouter Robeyns
ERGO : De Ruyck Stephanie
http://flessenhouder2012.blogspot.be/

pastahulp 1.2

CLIENT : Bart
IO : Benjamin Camarillo, Salvador Ortiz
ERGO : Inès Merveillie
http://pastahulp2012.blogspot.be/



briefplooier 1.4

CLIENT : Ann
IO : Ivo Six, Lenn Tilley
ERGO : Bossuyt Tine
ORTHO: Cellini De Langhe
http://briefplooier2012.blogspot.be/

kussenvulhulp 1.8

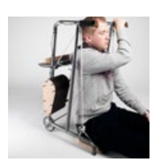
CLIENT : Maude
IO : Judith Lievens, Laurenz Tack
ERGO : Saar Gouwy , Yoeri Vermeersch
http://kussenvul2012.blogspot.be/

fototoestelhulp 1.3

CLIENT : Bart
IO : Cesar Vandevelde, Annelies Rollez
ERGO : Justin Couturon
http://fototoestel2012.blogspot.be/

grondtiller 1.7

CLIENT : Henk
IO : Dries Bovijn, Carolina Gamper
ERGO : Janne D'Hu, Laure Lisabeth
http://grondtiller2012.blogspot.be/

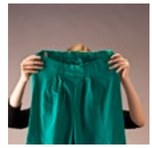


stijgzit 1.5

CLIENT : Cornelis
IO : Engels Pieter, Lefebvre Mathieu
ERGO : Stacey Zeebroek, Saubain Thoma
http://stijgzit2012.blogspot.com

boekenhouder 1.6

CLIENT : Cornelis
IO : Jasmien Decancq, Maarten Van Overbeke
ERGO : Kylie Biesbrouck
http://boekenhouder2012.blogspot.com/



harnaskledij 1.7

CLIENT : Bernoux, Dominique Demeulemeester
IO : Hanna Eggermont, Samantha Werbrouck
ERGO : Jynke Raeymaekers, Shade Debonnez
http://harnaskleding2013.blogspot.com/

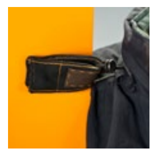
fietsrem 1.9

CLIENT : Simeon
IO : Jan Hellemans, Pieterjan Aerts
ERGO : Pieter Ruyskensvelde
ORTHO: Cellini De Langhe
http://fietsrem2012.blogspot.be/

strandmobiel 1.5

CLIENT : Michiel
IO : Maxim Solomaniuck, Alexandre De Bie
ERGO : Febe Collie, Lieselot Seynaeve
http://strandmobiel2013.blogspot.be/

CASE STUDIES 2013



jashulp 2.5

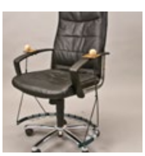
CLIENT : David
IO : Cloë Vandamme, Dieter Van den Stockt
ERGO : Ellen Vandenheede, Jolien Van Den Heede
http://jashulp2013.blogspot.com/

kookhulp 1.5

CLIENT : Alain
IO : Stephanie Van Haecke, Thomas Walgrave
ERGO : Kim Casselein, Jana Vanackere
http://kookhulp2013.blogspot.com/

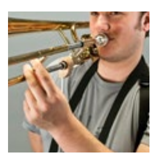
kabelschoenhulp 1.8

CLIENT : Eddy
IO : Mathijs Casteele, Jan Folens
ERGO : Soenen Marlies; De Rycke Ashley
http://kabelschoenhulp2013.blogspot.com/



stoelklem 1.5

CLIENT : Zurab
IO : Joke Wellens, Olivier De Bie
ERGO : Jens Claus
http://stoelklem2013.blogspot.com/

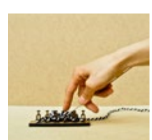


trombonehulp 1.8

CLIENT : Simeon
IO : Arne Malfait, Jonas Maertens
ERGO : Elien Vanhee, Suzan debuysere
http://trombonehulp2013.blogspot.com/

leeshulp 1.7

CLIENT : Claire
IO : Mwenge Sikuli, Sten Verhaegen
ERGO : Christophe Vandeginste
http://leeshulp2013.blogspot.com/



breihulp 1.3

CLIENT: Carine
IO: Eva Van Breuseghem, Xavier Vandenberghe
ERGO: Julie Deschepper, Jolien Goemaere
http://breihulp2013.blogspot.be/

opraaphulp 1.6

CLIENT : Els
IO : Lander Herreman, Peter Mortelmans
ERGO : Hanne Desimpelaere
http://opraaphulp2013.blogspot.com/

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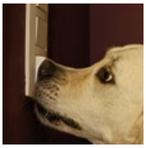

neuslichtschakelaar 1.5

CLIENT : Julie & Eclips
IO : Simon Boury , Niels Kinds, Jonathan Van der Smissen
http://dominolichtschakelaar2014.blogspot.be/
ism hachiko vzw

drinkbakhulp 1.3

CLIENT : Kathleen & Bengo
IO : Robin Debeuf, Simon Millecam, Sam Van Landuyt
http://drinkbak2014.blogspot.be/
ism hachiko vzw

leibandsysteem 1.8

CLIENT : Caroline
IO : Korneel De Viaene, Esmee Vanbeselaere, Ana-Maria GarciaPena
http://leiband2014.blogspot.be/
ism Hachiko vzw

vuilnisbakhulp 1.4

CLIENT : Bernoux, Dominique Demeulemeester
IO : Hippolyte Christiaens, Enzo Martin en Thomas Van Glabeke
http://vuilnisbak2014.blogspot.be/
ism hachiko vzw

voedingssyteem 1.7

CLIENT : Bart & Bento
IO : Clotilde Destrebecq, Jeroen Van Belleghem, Louis Muylle
http://voedingssysteem2014.blogspot.be/
ism Hachiko vzw

beddraaihulp 1.3

CLIENT : Sylvie
IO : Jonas Callewaert, Wout Mareen, Sievert Van Esch
http://beddraaihulp2014.blogspot.be/
ism Hachiko vzw

knoplichtschakelaar 1.4

CLIENT: Heleen & Gyproc
IO: Maarten Aerts, Jonathan Engels, Lynn Vandecasteele, Alejandro Pitarch
http://kleinelichtschakelaar2014.blogspot.be/
ism hachiko vzw

treklichtschakelaar 1.5

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IO : Lotte Boury, Simon Jackson, Marie Van den Broeck
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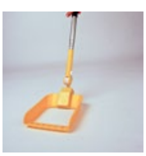
ism Hachiko vzw



poepschepper 1.4

CLIENT : Jaak
IO : Asha Derumeaux, Thibaut Simoens, Willem Vercruysse
http://poepschepper2014.blogspot.be/
ism Hachiko vzw

tennisbalwerper 1.5

CLIENT : Jana & naam hond?
IO : Jente Ameye, Francis Foubert,Lore Vandemaele, ClaudiaMarcoAguilera
http://tennisbalwerper2014.blogspot.be/
ism Hachiko vzw

koffiedrinkhulp 1.7

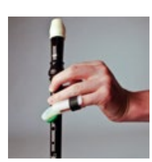
CLIENT : Luc
IO : Bruno De Naeyer, Bert Peters, Francis Van Poucke
http://drinkhulp2014.blogspot.be/
ism Hachiko vzw

toestenbordhulp 1.6

CLIENT: Kurt
IO: Arne Maes, Jan Wellens
ERGO: Hanne Verstraete, Damienne Sabbe
http://toetsenbordhulp2014.blogspot.be/

koekjesmachine 1.7

CLIENT : Luc
IO : Ward De Doncker, Eline Nobels, Gilles Vanneste
http://koekjesmachine2014.blogspot.be/
ism hachiko vzw



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CLIENT: Jan
IO: Julie Leirman, Sebastiaan Vernimmen
ERGO: Lisa Verhaeghe Laurence Vanbiervliet
http://blokfluithulp2014.blogspot.be/

tubesluiter 1.7

CLIENT : Anthony
IO: Isabelle Lanssens, Julie Vermeylen
ERGO: Fien Vanhamme, Lieselot Verbeke
http://tubesluiter2014.blogspot.be/

lormhandschrifthulp 1.7

CLIENT: Peter
IO: Thomas Perdieus, Julie Demeyere
ERGO: Cathleen Seculier
http://lormhandschoen2014.blogspot.be/

communicatieboek 1.4

CLIENT: Rosa
IO: Tobias Knockaert, Celine Verclyte
ERGO: Michelle Tanghe, Charlotte Dewaele
http://communicatieboek2014.blogspot.be/

eibreekhulp 1.4

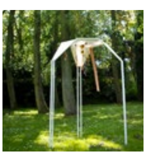
Cliënt: M.
IO: Max Halsberghe, Karel Vanalderweireldt
ERGO: Stefanie Buyse
http://eibreekhulp2014.blogspot.be/

schotelvod uitwringer 1.4

CLIENT: Bart
IO: Sander Klomp, Pieter Vanoverberghe.
ERGO: Emiel tanghe , Sharon Dejaeghere
http://schotelvoduitwringer2014.blogspot.be/

ritshulp 1.6

Client: Fabien
IO: Pieter Decabooter, Steffi Mussly
ERGO: Steffi Eeckhout
http://ritshulp2014.blogspot.be/

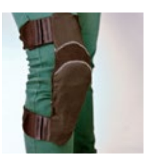


droogdouche 1.6

CLIENT: Bart
IO : Sofie Havegeer, Fien Vanderbeke
ERGO: Shana Depover, Ellen Deleu
http://droogdouche2014.blogspot.be/

outdoorpantoffel 1.5

CLIENT: Inneke
IO: Mattias Bovijn, Pieterjan Mollé
ERGO: Pieterjan Catteeuw, Wouter Reybrouck
http://outdoorkousen2014.blogspot.be/



knielap 1.6

CLIENT: Feline
IO: Timothy Demaegdt, Mindy Pauwaert
ERGO: Stijn Labeeuw
http://knielap2014.blogspot.be/

activitycenter 1.5

CLIENT: Bernoux
IO: Bert Boute, Ward Meeus
ERGO: Sarah Carbon
http://activitycenter2014.blogspot.be/

plooibaare zithulp 1.5

CLIENT: Kobejoren
IO: Carolle Geldof, Emily Quartier
ERGO: Sahin Vanneste, Jaana Caes
http://plooibaarzithulp2014.blogspot.be/

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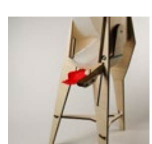
brievenbushouder 1.6

CLIENT: Christine
IO: Elizabeth Goetvinck, Jan Slabbinck
ERGO: Lore Bertel
http://brievenbusopenhouder2014.blogspot.be/



koekjeshulp 1.5

CLIENT: Olivier
IO: Robbe De Clerck, Niel Liesmons, Giulia Ligeia Galli
ERGO: Ermien Caron
http://koekjeshulp2015.blogspot.com/

puzzelhulp 1.4

CLIENT: Heleen Bartsoen
IO: Thomas Gruwez, Miguel Di Az
ERGO: Sien Roose
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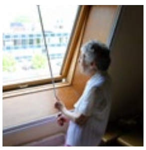

veluxhulp 1.9

CLIENT: Sigfrieda
IO: Darline Vandaele, Carmen Vandevoorde
ERGO: Anouk Vanneste
http://veluxhulp2015.blogspot.com/

bokaalhulp 1.6

CLIENT: Carine
IO: Robbe Terryn, Lennart De Meulemeester
ERGO: Jill Gremonprez
http://bokaalhulp2015.blogspot.com/

brilhulp 1.6

CLIENT: Yoeri
IO: Charles Degeyter, Guillaume Segaert
ERGO: Charlotte Deman
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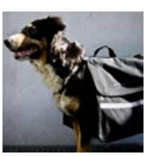

hondendraagtas 1.4

CLIENT : Hilde & Veerle
IO : Basil Vereecke, Levi Algoet
ERGO : Hilde Ramboer
http://honddraagtas2010.blogspot.com/

wiibowlinghulp 1.6

CLIENT : De Oude Melkerij, Dirk Deweer
IO : Jef Peeters, Ruben De Baere
ERGO : Sofie Duhem, Silvia Dumazy
http://serveerhulp2009.blogspot.com/

donshulp 1.6

CLIENT : Méderic
IO : Delphine Depuydt, Arnaud Mahy
ERGO : Tineke Furniere, Femke Dendooven, Jan Seynaeve
http://flexiseat2010.blogspot.com/

kabelhulp 1.6

CLIENT: Babette
IO: Pauline Delaere, Jilke Maelfeyt
ERGO: Nikita De Leersnijder
http://kookhulp2015.blogspot.com/

kookhulp 1.7

CLIENT: Siegfried
IO: Thoma Velghe, Zino Vansummeren
ERGO: Tiffany Ramon, Julie Vanrobaeys
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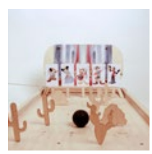
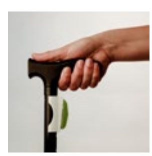
CASE STUDIES 2016



bowlspel 1.6

Client: Broes
IO: Jamil Joundi, Thomas Vervisch
ERGO: Indy Lonnoy
http://speelgoed2016.blogspot.be/



oordoptas 1.4

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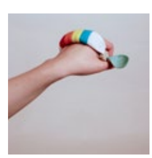
IO: Katrijn Haezebrouck, Thomas Van den Langen-bergh
ERGO: Laura Coudron
http://antiprikkel2016.blogspot.be/



eetlepel 1.7

Client: Brenda
IO: Julie Maes, Mathieu Baesen, Tamara Rotaris
ERGO: Joyce Claeys
http://lepelhulp2016.blogspot.be/

toiletstoelhulp 1.6

Client: Inge
IO: Adela Pedro Signes, Pauline Maes, Pieter-Jan Belles
Ergo: Matthias Van De Walle
http://wchulp2016.blogspot.be/

fototoestel 1.7

Cliënt: Philippe Durnez
IO: Max Schoepen, Yannick Stoelen
ERGO: Tine Dierick
http://fototoestel2016.blogspot.be/

transcribecontroller 1.6

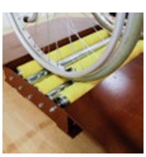
Client: Inge Blockmans
IO: Charlotte Belliard, Agustín Martinez Bleda, Laurens Nollet
ERGO: Matthias Van De Walle
http://transcribecontroller2016.blogspot.be/

tillift1.8

Client: Emmanuel
IO: Nicolas Van de Wege, Bert Heirweg
ERGO: Elien Vanden Bussche
http://optrekrolstoel2016.blogspot.com/

laptophouder 1.6

Cliënt: Benjamin Vanderstichele
Mantelzorger : Caroline
IO: Yves Born, Jolan Soens
Ergo: Céline Bruyneel
http://laptophouder2016.blogspot.be/



rolstoelwieldroger 1.5

Cliënt: Marc Detremmerie
IO: Ana Ribera Hernandez, Tim Picavet
Ergo: Gilles Deleu
http://douchetransfer2016.blogspot.be/

accuschroef 1.7

Client: Bart Grimonprez
IO: Natan Doms, Claire Vandenameele
ERGO: Céline Bruyneel
http://accuschroef2016.blogspot.be/

spanriemhouder 1.7

Cliënt: Kristien Vanhaverbeke
IO: Rob Cardinaels, Aaron Roose
ERGO: Gilles Deleu
http://spanriem2016.blogspot.com/

daisylezer 1.9

Cliënt: Leon Allais
Begeleidster: Nadja de Leersnijder
IO: Marieke Maertens, Fay de Haan
Ergo: Elien Vanden Bussche
http://daisylezer2016.blogspot.com/

drinkbekerarm 1.7

Cliënt: Frans
Opvoedster: Steffi Dejaeghere
IO: Arnaud D’hont, Servaas Strobbe
ERGO: Joyce Claeys
http://drinkbeker2016.blogspot.be/

15. INFORM CONSENT

ADAPTATION BY
PRODUCT HACKING

INFORMED CONSENT FORMULIER

Uw deelname aan dit project is vrijwillig. U kan uw medewerking op elk moment stopzetten zonder verdere gevolgen. De resultaten worden uitsluitend voor onderzoeksdoeleinden gebruikt. Dit onderzoek wordt uitgevoerd door Lieven De Couvreur, assistent industrieel ontwerpen aan de Hogeschool West-Vlaanderen (Howest). Voor vragen kan u terecht op lieven.de.couvreur@howest.be .

Hiermee geef ik toestemming aan de Hogeschool West-Vlaanderen (Howest) voor het gebruik van:

- Herkenbare foto's;
- Herkenbare filmfragmenten;
- Enkel het gebruik van de voornaam.

Van de persoon in kwestie met als doel en in de context van :

- Het kader van wetenschappelijk onderzoek;
- Het onderwerp van het wetenschappelijk onderzoek is het co-design proces;
- Op basis van deze lichamelijke beperking wordt een hulpmiddel ontworpen.

Foto's en aanduiding van de persoon in kwestie met de voornaam worden gebruikt tijdens het verspreiden van resultaten van het wetenschappelijk onderzoek onder de vorm van:

- Wetenschappelijke Publicaties;
- Cursusmateriaal & Presentaties ;
- Online ontwerp blogs;
- Website design for (every)one, http://designforeveryone.howest.be/

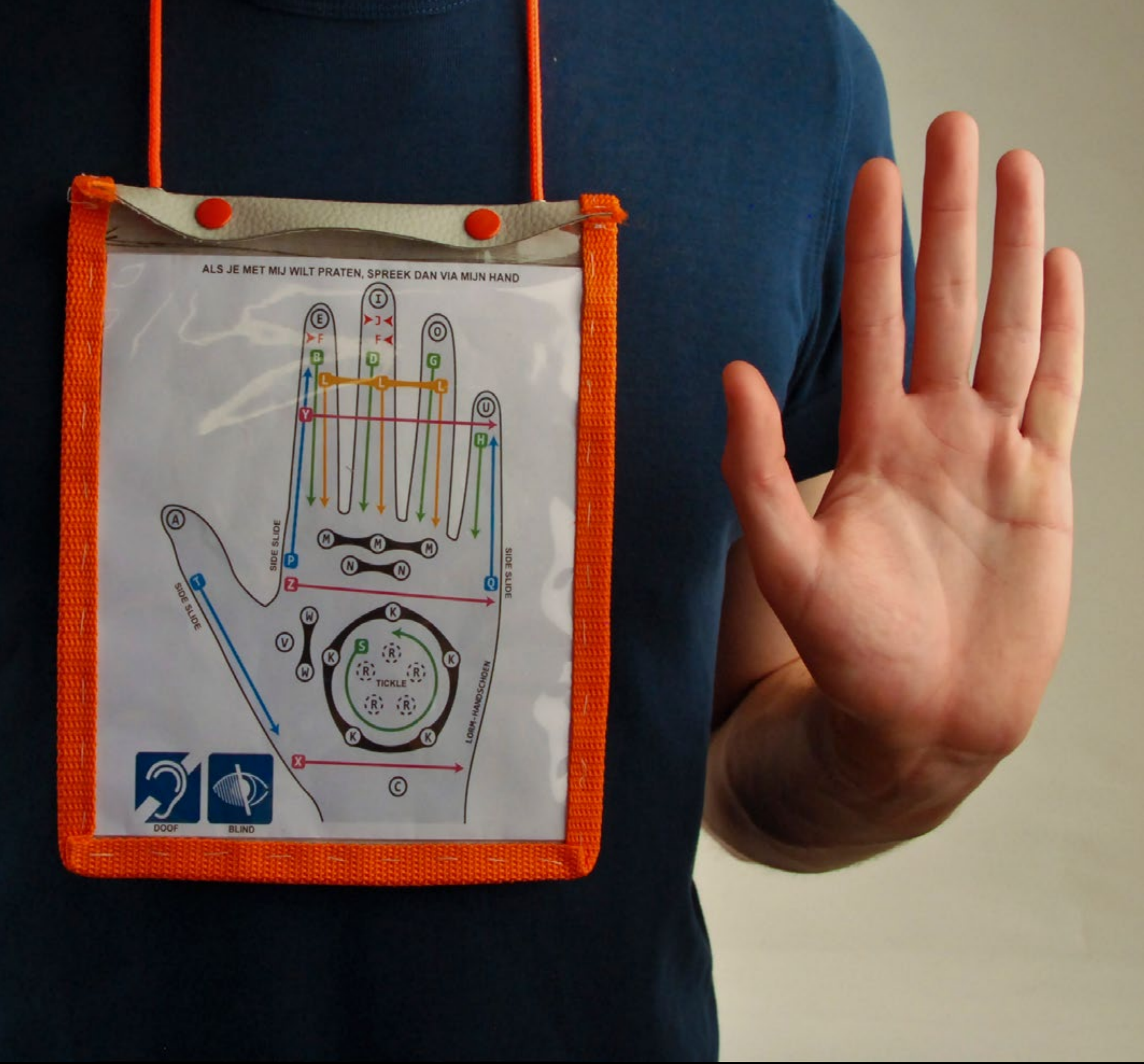
Ik heb deze informatie gelezen (of deze werd mij voorgelezen). Mijn vragen werden beantwoord en ik weet dat ik later altijd nog vragen kan stellen. Ik geef mijn toestemming om aan dit onderzoek deel te nemen.

Toestemming vanwege de persoon in kwestie of voogd:

Voor Howest:

(handtekening + datum)

(handtekening + datum)



16. ACKNOWLEDGEMENTS

ADAPTATION BY
PRODUCT HACKING

ACKNOWLEDGEMENT

This Phd thesis is dedicated to all the people who helped me throughout the last seven years. For this reason it is the result of their support and contribution. During my Phd, I had been lucky to develop my research skills at two universities.

In the Netherlands, I was part of Medisign group at the TU delft. First of all I would like to thank Richard. Performing this Phd in cooparation with the IDE faculty was an unique opportunity. You gave me the time to explore my topic and the confidence to make my first steps into the brave new world of scientific design research. I especially want to thank you for your trust, positivisme and support, they were a great catalyzor. I will remember my long trips to Delft, which were always very dense and efficient but also warm and empathic.

In Belgium, I was part of the Howest IDE Program which recently integrated within UGent. Thank you Lode and Frederik to create the oxygen in which this wonderful project could be born and nurtured seven years ago. Being able to combine the Phd research with a part-time teaching activity appear to be a blessing and created a wonderful synergetic effect.

Dear Jan, it has truly been a great experience to work with you over the years. Indeed, I am intentionally saying "to work with you" an not "to work for you". I will remember the spontanious and unexpected conversations we had in corridors, elevators, classrooms or the technical workshop. Thank you for letting me steer my own course. I wish you and the entire IO-team all the luck in these transformative second order times.

Dear Walter, I cannot imagine this research complete without your input as a former teacher, collegea, researcher and friend. You have had such an enormous influence on my thinking and doing over the past fourteen years that it is hard know where to start. Since the beginning of the project you were deeply involved. The many profound conversations we have had over the years have been a highlight of my time as a PhD student and fellow collegea. You let us activily experience with the essential design aspects: the limits of our language, the liberation through human creativity, the power of tangible but yet tacit prototyping and the crucial role of emergence. This Phd is build on your fundaments and is partly the result of your unique view on industrial design engineering. Thank you!

Dear Bart, partner in crime and firestarter of many projects at the Industrial Design Center. Your impact on *design for (every)one* was obviously hugh. Your fearless can-do attitude has partly triggered me to start this Phd. Thank you for all of your time and material support regarding the students and the clients.

Dear Katrien, our many ginger lemonade disccussions gave me an instant boost. Your enthousiasm and dedication are so contagious. You made us aware of the subtilities that can make or break true empowerment and inclusion.

I am also very thankful to the occupational therapy group at Howest. We bodly went where no occupational therapist was gone before and evolved from ‘lost in translation’ to an entire new minor on ‘adaptation & design’. Thank you Bart, Magda, and... last but not least Anne! I do hope that we can continue to collaborated in the future and take the living lab project to another level.

Through my journey I discovered a lot of new research groups which triggered and inspired me. Therfore I like to mention “Disabilities studies“ at UGent with Geert, Elisabeth & Katrien, “the Institute for positive design ” at the TUDelft with Pieter, Anna & Steven and “the Global brain Institut” with Francis and Mixel. Thank you for the past collaborations, and for sharing your meaningful work!

During my PhD I have met several people from the non-profit industry who have given me the opportunity to test our theories and tools in their real-world projects and gave us exposure. Thank you, Jan & Nicole from Handicap International. Thank you also Caroline from Hachiko vzw. The co-design sessions with the service dogs were epic! Thank you Lode and his crew from UZGent rehabilitation center. We, practice-based researchers, truly need people like you in the medical field who are willing to invest time in exploring new ways of doing practice.

Over the last seven years I met many talented people, who were eager to apply hacking design in their projects and studies. Dear Francesca, it still feels unreal and both flattering that you decided so resolute to come over to Kortrijk to enrich your research on open-ended design. You are a true unexpected enrichment for the entire IO-team. Secondly, thanks to the graduation students whom I had the privilege to supervise. Maarten & Sievert, thank you for your eager work on the videologging project. I could’nt have done these experiments without your technical and creative help. Matthias, Indy and Robbe. Thank you for further exploring the body of practice in new and refreshing ways.

Lastly, I am grateful to the all the students who participated in the *design for everyone* living lab that we organized over the years in Kortrijk. They gracefully lent their talent and enthusiasm for the purpose of design science. Furthermore, my gratitude goes out to my graduation committee for assessing this thesis, providing constructive feedback and being part of the Phd defence ceremony.

Writing this dissertation was possible thanks to the practical support of many people. Thank you Leen, Katrien, Becky and Griet for proofreading parts of this thesis. Cristina and Peter, my statistical gurus. Dries, if this Phd ever gets fully translated into Dutch, the original Schön-matrix will have to make way for the revised “watskeburt”-matrix.

Apart from the colleagues who were directly involved in my research, there are many colleageas who indirectly supported me along this Phd journey. Thank you mothership Howest-Kortrijk and its adventurous captain Roel. I want to especially thank Ronald as program coordinator from IPO Howest. Despite the heavy workload you and the IPO team made it possible for me to complete my Phd process. I will never forget that guys. I’m excited that I can excute my education tasks with such a great team of fellow teachers and researchers. Next to many other international design schools the Industrial Design Center in Kortrijk is no longer a best kept secret. Its crew, drive and attitude are unique.

Our dear local friends; Kristof, Lien, Dries, Frauke, Hannes, Bram, Valerie, Stijn, Lisa, Thomas, Evita, meta-Andy, Elena, Wim, Izabel, Diedert, Joke, Manu, Gregory, Joris, Saartje, Arne, Lies, Mieke and Joachim.

My dear family and family in law. I would like to express my immens gratitude to my parents. If it wasn't for you I would have never discovered the field of industrial design engineering in the first place. Thank you for being so instant thoughful and caring, your love really help us through some hard times!

Finally, and most important of all I want to thank my lovely wife Linds and my two children, Tuur and Rozanne. Linds, I love you! Thanks for putting up with me during the zombinating stages of writing. At the end of those seven years - welcoming two children, renovating a new house and a career switch to nursing later - we can truly say that we have survived! You have made this thesis possible, thanks to your inner strenght and dedication. I admit, doing a phd within a familiar discipline is highly challenging, but starting a totally new profession from scratch demands even more courage and determination. I'm so proud of you!

Dear Tuur & Rozanne, thank you for bringing both simplicity and complexity into my life. We are so thankful for the little big things you over us day-to-day. I promise to love you more and never less, you mean everything to me! And yes... now its time to build that treehouse!

Whatever you may have heard about product hackers, the truth is they do something really, really well. In short: “hackers build things, crackers break them.” Through their experiential and social approach product hackers discover new possibilities in a frugal manner with the local resources and skills at hand. The human race has built up a rich history in adapting and designing his living environment and surrounding artifacts. Although the phenomenon of product hacking has been around for a long time, it’s manifestation has drastically changed through several paradigm shifts within the DIY culture which lead to open-design. These shifts imply that professional designers are no longer placed above users when determining what is right or wrong for them. Within the context of design for disability this perspective opens-up a complementary alternative to universal design. Today there are a lot of people with disabilities whose assistive devices have not yet come about, due to unique needs and challenges. A new generation of makers and occupational therapists are seizing this opportunity by producing one of a kind product adaptations in people’s homes, sheltered workshops and rehabilitation centers.

This dissertation explores the role of professional designers within this new and open-ended context. In general the research focus is on the epistemic dynamics of hacking behavior within the pursuit of making a tailored product adaptation for a single user. Generally speaking collaborative hacking activities are a form of self-organizing co-design activities driven by participatory prototyping-interactions. For this reason, the starting point of this thesis was the question : “How do specific prototyping-interactions influence general adaptation within participatory hacking behavior?” To answer this question we propose a framework which illustrates hacking entities as a self-regulating systems. A cybernetic design approach was chosen to develop a framework to explain the circular causality and relationships within local hacking ecologies. We list the minimum conditions and elements of an autonomous hacking entity in order for it to be able to adapt to changing circumstances and ‘to get what it wants’. With his holistic thinking, it integrates the surroundings as part of the a self-regulating system by means of two adaptation types, namely single and double-loop adaptation. Both loops enact respectively as an (1) active (agents actively change their environments through external adaptation) and (2) passive (agents compulsory change their internal construction of the environment through internal adaptation) component of adaptation. Although both type of adaptations are strongly intertwined we tried to illustrated them through the variety of data from living lab practices and illustrate how they self-organize the hacking process.

TU Delft

howest / we develop people

INDUSTRIAL DESIGN CENTER

GHENT UNIVERSITY