Arne Berger*, Sören Totzauer, Kevin Lefeuvre, Michael Storz, Albrecht Kurze, and Andreas Bischof

Wicked, Open, Collaborative: Why Research through Design Matters for HCI Research

https://doi.org/10.1515/icom-2017-0014

Abstract: In contrast to the first and second wave of Human Computer Interaction, the third wave grapples with wicked problems. However, re-solutions to wicked problems embodied in *artifacts* frame and change the understanding of the problem itself. Research through Design (RtD) is a constructive methodology to understand this interplay of problem framing through designing artifacts. RtD is also suited to resurface the theory within those artifacts through annotation. These annotations expose and emphasize qualities, values and assumptions held within artifacts by its creators. In addition to those modes for annotation, we will suggest two additional abstract frames through which RtD artifacts can be further annotated: Open Research Agenda and Interdisciplinarity. We will apply both frames to one research artifact, Loaded Dice to distill qualities from this artifact's framing. Through this we will show how creating and deploying an artifact can change its environment which also includes its creators.

Keywords: Research through Design, Third Wave HCI, Interdisciplinarity, Wicked Problems

> *"the future job of a designer is to give substance to new ideas while taking away the physical and organizational foundations of old ones. In this situation, it is nonsense to think of designing as the satisfaction of existing requirements. New needs grow and old needs decay..."* (John Chris Jones)

***Corresponding author: Arne Berger,** Technische Universität Chemnitz, Computer Science, Chemnitz, Germany, e-mail: arne.berger@informatik.tu-chemnitz.de
Sören Totzauer, Kevin Lefeuvre, Michael Storz, Albrecht Kurze, Andreas Bischof, Technische Universität Chemnitz, Computer Science, Chemnitz, Germany, e-mails: soeren.totzauer@informatik.tu-chemnitz.de, kevin.lefeuvre@informatik.tu-chemnitz.de, michael.storz@informatik.tu-chemnitz.de, albrecht.kurze@informatik.tu-chemnitz.de, andreas.bischof@informatik.tu-chemnitz.de

1 Introduction

In this article, we will reflect on Research through Design (RtD) as part of the Third Wave of Human-Computer-Interaction (HCI). In particular, we will discuss the role and implications of Research through Design in shaping open research agendas and interdisciplinary research. We do so, by *re-annotating* a particular Research through Design artifact we developed to explore the design space of smart things for the home – while following a deliberately open research agenda.

The research device is called "Loaded Dice" and was first presented as a co-design tool to engage blind and visually impaired in co-creating smart technology for the home. First presented at NordiCHI 2016 and subsequent conferences and demo sessions. We *annotated* the artifact as proposed by Gaver [11] on the aspects of creative process, user-centeredness, developing design spaces, exploring material and attention to aesthetics [7]. With the article at hand, we will re-annotate the same artifact from two new perspectives. These perspectives are concerned with the research agenda surrounding the artifact and not its immediate attributes. The new annotations we present explore the scientific qualities of the research device, and aim to promote interdisciplinary, transdisciplinary, and participatory research within the human-computer interaction community. We investigate our own research strategies by re-annotating this research device.

This article is structured as follows. We will first present Research through Design as one mode of inquiry within the third paradigm of Human-Computer Interaction. This is followed by a short presentation of the "Loaded Dice" – a research device for exploring the design space of smart connected things within the home. We will then discuss the concept of resurfacing theory through the annotation of RtD artifacts. Lastly, we will use an annotation of this RtD artifact to explicate the role of Research through Design for open research agendas and interdisciplinary research within HCI.

We propose these readings to illustrate how RtD artifacts can be further annotated to generate multifaceted theory on multidisciplinary and transdisciplinary design

and development processes. These annotations we offer, are sketches of theory we propose – they are neither exhaustive nor exclusive to our interpretation. They are grounded in the situatedness of one particular research device which was developed to investigate the design space of smart things in the context within the home.

As such, these sketches of theory are meant to inspire HCI researchers on the opportunities of employing RtD methodology in future open participatory and interdisciplinary HCI research projects.

2 Research through Design

2.1 HCI Design Research Today

Scientific practice follows diverging paradigms as Kuhn [18] pointed out prominently. Other than in Kuhn's historic study of the change from the Ptolemaic system to Copernican heliocentrism the diverging paradigms of HCI exist concurrently, contending in the question, what HCI means and how it should work [15].

The first paradigmatic wave of HCI is mainly inspired by industrial engineering and ergonomics and aims to optimize the man-machine fit of interfaces. The interaction between man and machine is thereby understood as close coupling, that should be optimized in order to function well and safe. An instructive example for this kind of HCI is to research and improve the usability of ticket machines or similar, often graphical, user interfaces. *Thus, the first wave of HCI is concerned with fixing specific problems that arise in interaction between, e.g. a ticket machine and its user.*

This engineering approach is followed by a second wave originating from cognitive science, with a stronger emphasis on theory. It is characterized by a significant extension of the research interest to the question, what is happening in the human mind while interacting with a computer. In this paradigm, HCI is understood as information communication between entities that process this communication. The efficient design of graphical user interfaces and instruments in airplane cockpits is a prime example for this paradigm. *Here, the second paradigm of HCI asks the question, how the efficiency of the information processing between user and computer can be improved.*

Harrison, Tatar, & Sengers [15] identified a more recent third, phenomenological wave, consisting of approaches ranging from embodied interaction [10] to situated meaning [32] to social change [2]. These exceed the first two paradigms by emphasizing the role of situation and context of use, that might change the requirements of 'successful' interaction and the ways of achieving it. The understandings of HCI here is an interplay of people, interface and context. Lucy Suchman's work at Xerox PARC is an early example: She lead a work group researching how users' made sense of a copying machine [32]. The interaction with the machine was thereby not conceptualized as (failed) information exchange, but rather as construction and negotiation of meaning. Drawing on this example, the third wave of HCI tends to be more interested in what goes on *around systems*, rather than what is happening *at the interface*. *Here, the third wave of HCI asks the question, how people appropriate technologies, and how HCI design can support those appropriations within the complexity of man-machine-interaction.*

2.2 Wicked Problems in HCI: Why does Research through Design Matter?

In stark contrast to the first and second wave of HCI which tackle *complicated issues* of interaction, the goal of the third wave of HCI is to acknowledge and grapple the inherent *complexity* of the interaction between people and man-made-things. This draws on the notion, that HCI artifacts are generative and influence, even change, the circumstances in which they are employed. Paying close attention to the fact that novel HCI services and artifacts substantially alter the lives of people affected, we argue that research within third wave HCI is fundamentally concerned with problems that are *messy* [28], *infinite* [30], or even *wicked* [27]. It is widely acknowledged, that these classes of problems are inherent to every design activity, from urban planning [27] to HCI [33]. These problems are infinite and limitless in regards to technology, context, politics, individual use, belief, and circumstance. Because not all of these facettes can be completely explored, solutions to such wicked problems are situated and bound to the way *and to the expertise* designers and researchers frame the problem. As such, this kind of problems does not have a stopping rule: solutions to wicked problems are not right or wrong but rather good or bad depending on one's framing of the initial problem. Every solution is essentially unique, because every design proposal fundamentally changes the context of the problem. And thus, there is no ultimate test of a solution to those problems, because the solution does not exist independently of the problem framing.

By designing one possible solution to a wicked problem, both the problem *and* the solution are defined. As such, both problem and solution exist dependent of each

other, their scope and connection are the "best guess" of the designer. Overall, the designer's beliefs, values, and decisions that lead to a specific solution and to the rejection of competing solutions frame the problem, the solution and the connections between them as the so called *design space*. There are rather many feasible paths within the design space that connect a specific framing of the problem with one particular framing of a solution. There are also many paths within the design space that are not feasible – but are necessary preliminary steps for understanding the design space.

This is to say that a solution to a wicked problem contextualises the space in which the problem exists. In addition, the sum of the successful and unsuccessful solutions demarcate the design space. As such, understanding the proposed solution also allows us to understand the context of the problem.

To understand the methodological contribution of Research through Design it is important to acknowledge that this specific solution is the designerly equivalent to theory in scientific practice. *"The ultimate particular is a design concept of the same dignity and importance as truth in science"* (Nelson & Stolterman [24]), it is a *"theory nexus"* [9] that manifests not only the apparent solution, but also its aesthetics, the process that led to its inception, and the encompassing design space. As such, the *ultimate particular* is coagulated knowledge that comprises of a specific way in which a specific problem space and a specific solution space are connected through choices in regards to technology, context, politics, use, belief, and circumstance.

Design and most of HCI are concerned with creating artifacts like devices, interfaces, services, or algorithms as solutions. Making artifacts is generative, and, depending on which particular philosophy of science one follows, it is arguably the opposite of science [26]. How then, can design research contribute to a methodologically generalizable corpus of knowledge? In order to explain RtD, the next two sections will discuss how design research operates and how design research generates theory.

2.3 How Research through Design Operates

How shall researchers engage in designing and developing HCI artifacts, when these very artifacts change the problem they have been developed to resolve? The perhaps most concise definition of Research through Design and how to tackle this conundrum has been proposed by Gaver et al: *"we make things and let people try them, not to develop commercial products, but to learn both about people and new possibilities for technologies."* (Gaver http://www.datacatcher.org).

Likewise, an intentionally made intermediary – a research device – has the potential to unfold complex interactions and dependencies and thus can surface issues without the ramifications of shaping a readymade, blackboxed 'product' and unleashing it into the wild. Here, a research device is being developed, field tested, and analyzed in order to help the researchers understand how a specific design space unfolds. It is meant as a tool to better understand the interplay of artifacts, practices and design intention before they develop solutions for specific problems. By deliberately utilizing these research devices as intermediaries, the appropriation of these devices can be better analyzed and their ramifications can be better contained. Oftentimes, these research devices are deployed for periods of weeks to months, to let the interplay between people and these devices unfold. These field tests are usually accompanied by probe studies, participatory workshops, ethnography, interviews, and are framed as design inspiration and reflection. These modes of analysis most importantly do not hinge on a specific research question, but are deliberately kept open to understand the complex modes of interaction – paying close attention to the usage of the research devices, their appropriation, intended and unintended effects, unexpected use, and even non-use.

2.4 How Research through Design Generates Theory

Hence, Research through Design is based on two assumptions. First, the designed artifact is a theory nexus, which means, that the design artifact itself embodies theory [11]. It contains all the choices and decisions that led to its implementation. It also indirectly reveals the assumptions of its makers in regard to technology, context, and politics. As such, it also holds the beliefs and values its designers account to. It even contains the failed and not realized attempts competing solutions. But how then, shall the designed artifact speak? The second assumption is, that the designers themselves can reveal these issues by annotating these artifacts. By doing so, they can explain their aesthetic decisions, their beliefs in regards to user involvement, and their individual design process. By doing so, the knowledge about the design space that encompasses the design artifact, becomes accessible for understanding and reflecting. As such, annotating design artifacts may be the design equivalent to theory building.

This notion has been elaborated by Zimmerman [34] and Gaver [11]. Both argue, that the artifact can be annotated, either through four lenses (process, invention, relevance, extensibility) [34] or shared values (creative process, user-centeredness, developing design spaces, exploring material, attention to aesthetics) [7]. Interestingly, STS literature and empirical research follows a similar approach by reconstructing the "scripts" and theories which are embedded in (even mundane) artifacts [1, 17].

We share Gavers [7] hypothesis, that an array of annotated design examples is the core of what Research through Design can add to the HCI discourse: These "annotated portfolios" and annotated artifacts help in reflecting and understanding made things – ultimate particulars – and also the surrounding design space. As such, RtD is "theory building" in a designerly way [8], because it explicates the decisions, beliefs, circumstances the designers encountered when exploring the design space. This resurfacing of embedded theory is illuminating the aspects that surfaced during making, analyzing, describing, and understanding of this particular design space. And these annotations allow researchers and designers to understand the problem and solution space, the path in between, their interplay, and the ramifications for people and society at large.

The various documentations of the Data Catcher [6, 7, 12] are the prime example of how to annotate a specific research device. The Data Catcher is *"a location-aware, tangible and embodied mobile device that displays a continuous stream of statements about its location that are drawn from a large number of data sources and which speak to sociopolitical issues."* (Boucher & Gaver [7]). It is an intermediary for exploring the design space of participation in location based big data and emerging sociopolitical issues. Its designers annotated this research device from three perspectives. First in a pictorial [6] to explicate decisions and questions that accompanied the *making* of the artifact and aesthetic decisions in addition to the prime research interest. The methodological approach and the results from a field trial of 130 of these Data Catchers is presented in Gaver [12], where questions regarding *user involvement* and user empowerment were brought to the fore. Lastly both the *design process* as well as the prime research questions that surfaced are presented in Boucher [7].

As such, these annotation of the Data Catcher can explicate issues that emerge from putting a specific design research device into experimental context, and allows researchers to explore design opportunities arising.

We acknowledge, that the theory building presented here is mainly concerned with making and material, user involvement and empowerment, design methods and processes in order to describe the design space. However, we wish to take this multi-faceted approach of annotation as a starting point and will offer two further lenses for preliminary exploration, we believe are oftentimes under-determined in annotating research devices: interdisciplinary research and open research agendas.

The following section presents Loaded Dice, a research device we proposed to explore the design space of smart connected things for the home together with both expert and lay co-designers. First, we will briefly present this research device and the scope of its application.

We will then contextualize RtD within HCI research on the home and will further elaborate on the use of Loaded Dice for interdisciplinary research within an open research agenda. Employing the research device in various scenarios, a variety of issues and opportunities emerged that we believe are a useful annotation of this device for its merits within an open research agenda and interdisciplinary research.

3 Loaded Dice

In this section we will briefly summarize the Loaded Dice artifact in its functionality and its design implications as well as the environment in which the artifact was used. The research device itself has been presented and discussed in full detail elsewhere [4, 20, 21]. In particular the merits of Loaded Dice for specific user groups have been discussed in [20], the design process, material exploration, and aesthetic choices are detailed in [21]. And finally, [4] contrasts material choices in regards to user appropriation for a specific user group. In the following section we will apply these designated lenses of open research agenda and interdisciplinary research to it and discuss the resulting implications.

3.1 Introduction: What are Loaded Dice

The tool consists of two Arduino based, 3D-printed cubes. One of the devices is equipped with a different sensor on each of its six sides, while the other is equipped with a different actuator on each side. Whichever side is on top is active and communicates wirelessly over distance with the top side of the other cube. Loaded Dice support creativity, imagination and exploration in design processes of smart and multisensory devices and services, especially in early ideation stages.

Loaded Dice (Figure 1) are a co-design tool to explore the design space of smart connected things to-

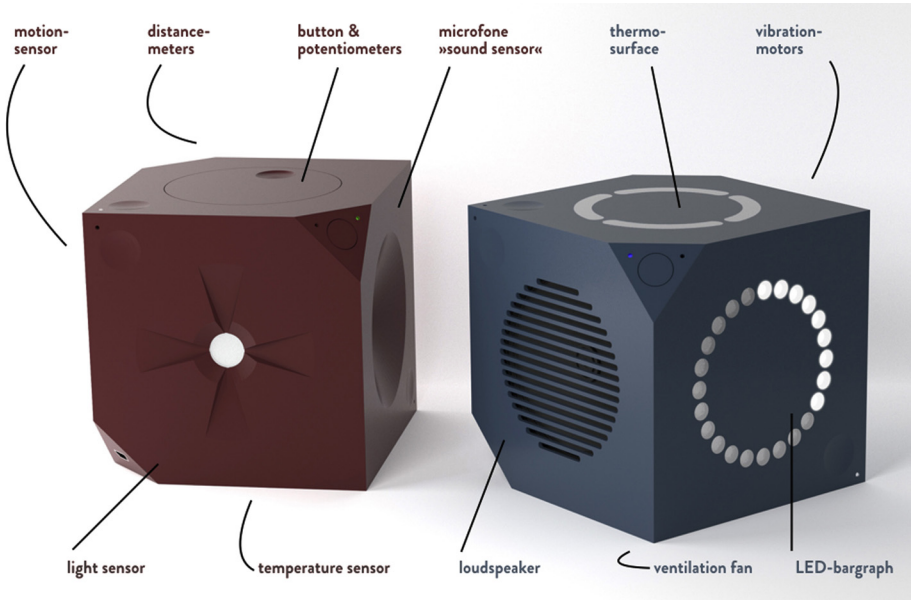

Figure 1: The Loaded Dice with Sensor Die (left) and Actuator Die (right).

gether with co-designers. Those lay co-designers provide expertise from their everyday experience and thus valuable, qualitative input for the design of innovative smart connected things for those lifeworlds. However, the co-designers have varying levels of expertise in using and understanding technical devices, and the processes of designing them. The Loaded Dice serve the purpose to bridge the gaps between those different levels in co-designers and us as HCI researchers and enable meaningful discussions and ideation on equal terms.

3.2 Related Work: Co-Design Support Tools for Designing IoT for the Home

Bringing co-designers and experts on a more equal footing proves challenging, and there exist ample ways to bridge these gaps in either way. In order to re-annotate our artifact in this paper, we will position it among other co-design tools. Those tools employ one of two strategies to bridge the experience gap. One is reducing the technical and skill expertise required for co-designers. This is often done by employing analog support tools which aim at non-functional abstract ideation, e.g. in form of cards representing the problem and solution spaces, actors, environment and dynamics. The other strategy aims for functionality in ideation, supplanting required expertise for co-designers.

Related work as discussed here, focuses on tools supporting both expert- and lay-designers in the reflective conversation between idea exploration and idea generation for smart connected things within the IoT. It also employs either one of the two aforementioned strategies. Therefore we consider support tools as *analog* if they employ the strategy of non-functional, abstract ideation and *digital* if they provide supplanted functionality.

3.2.1 Analog Tools

Analog Tools tend to comprise a design space and frame the involved components, e.g. actors, environment and their relationships as detailed in [16]. They aim at fostering creativity and imagination as well as giving an overview of involved components to designers [22]. The main characteristic of analog tools is the substituted functionality. For these purposes cards receive prominent focus. Whether they categorize involved elements in a meaningful way (*KnowCards*) or formalize dynamics as game rules (*Tiles Cards*, [23]), they abstract the problem and solution design spaces in meaningful ways. However, the quality of abstraction often relies on the expertise of their users and is subject to the users immersion, knowledge and imagination.

3.2.2 Digital Tools

Digital tools provide the functionality analog tools substitute by abstraction and thus allow (co-)designers to cre-

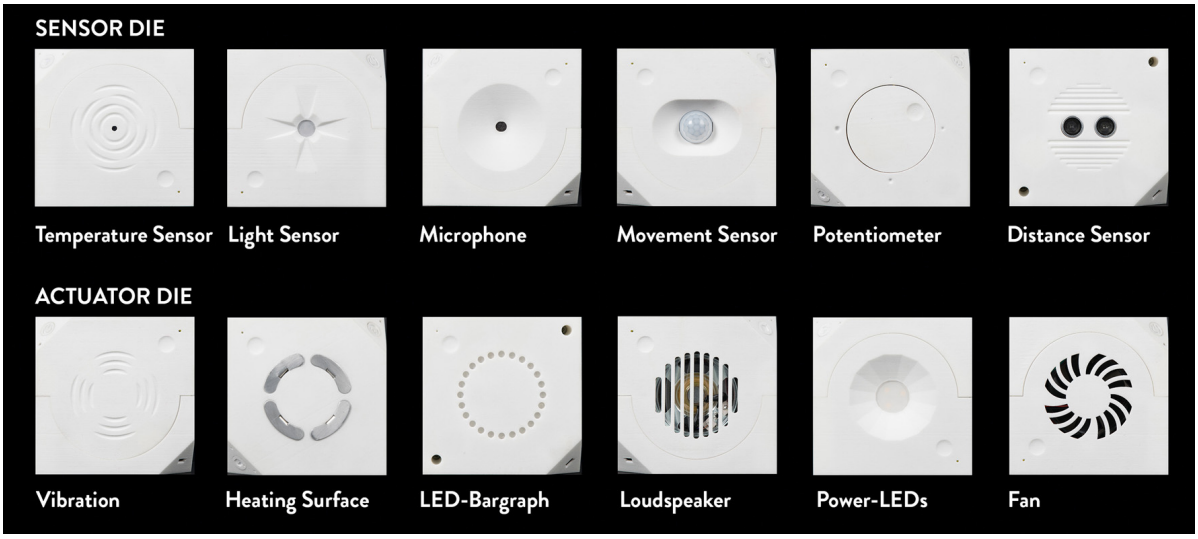

Figure 2: The Loaded Dice consist of these sensors and actuators.

ate and experience functional prototypes. Often they are arranged into component kits, allowing for creativity and flexibility. For instance, *littleBits* allows combining working sensors and actuators [3] without programming. On the other side tools like *WoTKit* allow prototyping software services [5]. In these cases basic understandings of electronics are required, a task for which there are also specific digital tools like *Cube-in* [25]. However, to achieve their goals those tools demand certain skills, limit the scope of design to certain paradigms or shift the focus from ideation to learning the demanded skills.

3.3 Design Concept: Playful Exploration

The main aim of our tool is supporting early stages of design processes, specifically ideation and exploration of smart connected products in domestic settings. The embodiment of the "Loaded Dice" is thereby reduced to a fundamental form, allowing the combination of six by six sensor / actor pairs (Figure 2). This serves our premise, that people have to actively experience functions and connections of actuators and sensors in order to gauge their effects and experiences. We deem this crucial to allow the ideation of design solutions that are novel, creative and incorporate the respective expertise of the co-designers. For that premise our support tool allows for spontaneous connection of one sensor and one actuator at a time. We chose sensors and actuators that are commercially off-the-shelf available in order to reside in the current boundaries of the IoT solution space. Thus, the translation and incorporation of prototypes into domestic applications is kept outside of the laboratory.

To engage in spontaneous prototyping, the Loaded Dice had to make it as easy as possible to re-combine sensors and actuators. We did so by breaking down functionality, interactivity and appearance to elementary inputs and outputs that are open to immediate re-configuration [20].

By choosing the form of a cube we aimed to incorporate three benefits of this form into our design principle. First, by having six equal sides, a cube offers enough space for six sensors or actuators in one hull, without lending any special preference to one of them. Second, the cube form is common enough that it allows for intuitive manipulation, handling and reading. In our case this means the fact that the top side is the active one that communicates. This transports the reading and meaning of an actual die to the users. Splitting actuators and sensors in one Loaded Die each allows for quick one-to-one pairing by rotation of the cubes, experiencing sensor-actuator mappings on the fly. The devices themselves do not force a "right" combination of sensors and actuators, e.g. sound input and sound output (Figure 3). The implemented wireless communication between the Loaded Dice also enables spatial configurations involving different rooms and floors. Thus, sensed physical qualities can be transported over long distances and transmuted into different physical qualities. This way, users can use the microphone to transport sound to the actuator cube where it is translated into heat. This allows to experience new multisensory mappings and thereby help envision creative and innovative use scenarios or design fictions.

Figure 3: The Loaded Dice sense heat and transmits it as light.

3.4 Playfulness in Play: Individual Workshops

In order to explore design scenario building in context, we conducted several workshops with different participant groups. From this we want to present two cases as qualitative sample. Workshop #1 was held with visually impaired and blind students aged 13–17 with a total number of 11 participants from 8th and 9th grade [20]. Workshop #2 involved a mixed group of older adults (aged 60–79) and students (aged 20–30) for a total of 10 participants.

The workshops were held with one researcher as facilitator in their role as expert designer and groups from two to four participants. The participants were given the Loaded Dice and asked to explore the devices and discuss their functions and form. Later they were asked to reflect on problems they faced in their everyday life and imagine how sensors and actuators could solve them. If necessary the facilitator would state, that the envisioned solutions could vary both in form and functional details (e.g. type of sound) from the Loaded Dice. The sessions were concluded by an open discussion about sensor and actuator based technology in general and how participants felt about them. Thus, ending a session was an implicit communication process between facilitator and participants.

Workshop #1 was held as a one-day-workshop for two classes were the Loaded Dice would be explored by the students and compared to another ideation tool, *littleBits*. The classes were divided into mixed groups of two to four students. The ideation was mixed between technical inspired solutions like an orientation-system for blind people using sonic vibrations to more poetic everyday objects like a weather station using bird voices to communicate if it was dry or wet outside.

Workshop #2 consisted of four sessions with differing participants. Scenarios were ideated in relation to everyday lives of the participants. The framing question was, how sensors and actuators could augment such scenarios. Some scenarios from one session were used as basis for sparking the discussion in another session. By experimenting with the Loaded Dice, the ideation explored many different contexts such as augmenting pets, communicating emotions, or technically hacking clothes. By employing the Loaded Dice, effects such as stigmatization could be discussed. For instance, blind students from workshop #1 remarked how they disliked speaking watches and apps as they marked them as blind and thus ‘handicapped’. As such ideating sensor and actuator based solutions which were not stigmatizing the users was prominent. Also, solutions were imagined beyond technical possibility, incorporating a certain poetic component – proofing the research

device to be more than a functional demonstrator. This was evident in an ideated communication scenario where plants would communicate their wants to their owners.

This section should have given the reader an impression of our co-design tool Loaded Dice and its fielding in workshops with co-designers. The next section will discuss the meaning of our artifact when viewed through two more abstract lenses: *open research agenda* and *interdisciplinary research*.

4 HCI for the Home: Re-Annotating the Loaded Dice

The goal to develop smart connected devices for homes and neighborhoods benefits greatly from the situated understanding of third wave HCI and the methodological frame of RtD. Especially when designing for everyday worlds such as living rooms, apartment houses and community centers, researchers and engineers have to take into account, what these places, practices and artifacts mean to the people inhabiting these worlds. As shown, RtD provides a design tool to understand the conditions and consequences of these meanings and practices in interplay with technological artifacts.

We want to propose RtD as a methodological middle ground to explore technologically feasible, yet usability-wise open products and applications, like IoT technology. Applying RtD as a resource for design and development in HCI can not only help researchers to explore the design space and unfold different scenarios with co-designers. In our understanding it is likewise a way to empower people to understand technology and what it can do for them and can thereby foster debates on smart devices and their use.

The example of the "Loaded Dice" as research device illustrates these opportunities of RtD within HCI. The "Loaded Dice" became a "theory nexus" for an underdetermined problem: How shall we design smart assistance for the home? This considerably broad research interest involved diverging questions like, how to deal with ramifications in regards to data intimacy and privacy, questions of preferences of use but also non-use, as well as considering the appropriation of products by the users in an overarching process of developing and designing such technology.

The "Loaded Dice" as a research device encapsulate these research questions and the design space of designing assistive IoT for the home. By describing the methodical iterations we conducted with participants, we want to underline, that the "Loaded Dice" are a suitable tool to communicate and negotiate this design space between experts in design and experts in everyday life, between us as designers and the addressed users as co-designers. We want to discuss this role of the"Loaded Dice" as research device in terms of RtD and its results concerning two lenses we elaborated above: interdisciplinary research and open research agendas.

The presented procedure has been grounded in the notion that HCI artifacts are generative and influence, even change, the circumstances in which they are employed. We want to highlight upfront that this understanding of HCI research and design as "wicked problem" is not 'solved' by applying RtD, but rather acknowledged. Applying a situated perspective on HCI does not break the complexity of socio-technical systems and situations of use down to a universal sequence of procedures. Instead the variety of disciplinary perspectives involved, the organizational circumstances of doing research in academic context and the aim to actively include heterogeneous users groups become challenges to the design and development of HCI artifacts themselves. The methodology for *designerly* tools of research in HCI, RtD, is an adaption to these challenges.

4.1 Multi-Perspectivity of HCI Work

Combining researchers and perspectives from different research fields is necessary to tackle complex problems and common to HCI work. Third Wave HCI involves especially perspectives on interaction and situation types, derived from micro-sociology, communication studies and anthropology, as well as reflections on policy and design as process, derived from Science and Technology Studies, design research and innovation studies. With that comes a rich set of methods helping to investigate users interacting with digital devices and designers interacting with users' lifeworlds like ethnography or even outreach work towards vulnerable communities. These methods focus to understand and explain socio-technical phenomena, they are useful to grapple with the complex intertwining of cultural factors, social interaction, technology, collective sensemaking, etc. But these methods come with an epistemological impediment for design: They are suited for understanding, not for making own (material) contributions in the first place. Developing technology for the smart home thus involves creative practices like projecting potential use cases, innovating shapes and functions and the engineering work of actually constructing a functioning product.

The design space of a certain wicked problem – like for example initiating social interaction in an intergenerational apartment house – changes depending which perspective and framing of the design problem is applied. We argue to distinct between disciplinary perspectives from sociology, anthropology, psychology etc. as rather *reconstructive*, while the aim to transform a given status by creating artifacts – typical for engineering, design and HCI – as *constructive* epistemology. In order to grapple with the complexity of socio-technical arrangements we argue beyond RtD to refine the distinction between reconstructive elements and constructive elements within a research and development process, as we want to show with our example.

4.1.1 How did "Loaded Dice" Involve Different Disciplinary Perspectives?

With the cascade of workshop types we showed that the "Loaded Dice" enabled a co-evolution of making and reflecting, encouraging the researchers to switch between constructing, reflecting and re-construction. The initially undetermined problem forces researchers and designers to move back and forth between reconstructing phenomena of socio-technical interaction and actively making decisions and embody them in new RtD prototypes. By creating a research device like the "Loaded Dice" we were able to catalyze this process with an artifact. As a RtD artifact, the "Loaded Dice" reveal the burden of proof for HCI work: A research device is not primarily developed to prove its functioning and adequateness for a specific lifeworld, instead it helps to explore it.

The goal to develop the pair of dice as a prototype and to deploy it in co-ideation workshops did not just help to coordinate the work within our heterogeneous group. The implementation of a working prototype led to a refinement of research questions and thereby the exploration of the design space. A crucial feature therefore was the radically simplified shape and interaction modes of the "Loaded Dice". Through their embodiment of universal IoT functionalities, they enabled the exploration and reflection of materiality and functionality for the further design process.

This catalyst role is not limited to the group of researchers developing the tool [34]. The "Loaded Dice" also help to spark debate with other researchers on the semiotics of yet to be developed products for example. We argue that a research artifact is thereby far more as an example or conversation starter between attendants of a conference. The "Loaded Dice" as an apperceptive interactive artifact became a boundary object [29] that enabled varying references by diverging stakeholders. A product designer may see it mainly as an unfinished tool used for workshops to get the answers they desire. An engineer views the "Loaded Dice" as a technical state-of-the-art exploring tool, discovering what is and is not possible yet. A design methodologist may ask, how the users appropriated the tool and what how that inform the design itself. A sociologist might be interested in how the Loaded Dice are used, by whom and for which purpose. Also, how does the use of the Loaded Dice change the users and the researchers?

4.2 Open Research Agendas

While interdisciplinary research in HCI is nowadays the norm – including artifact based research – methodological models to shape the processes of design and development for this multi-perspectivity remain scarce. We propose open research agendas for a nuanced view from all included parties and as chance to *explicitly* negotiate the problem and solution space of design proposals within HCI. This goal may sound mundane, but it is not when we have a look at the circumstances under which HCI in academia is organized: The funding of research requires a proper time framing of the undertaking. Additionally, there is a strict temporal limit to the researchers' and designers' work due to the end of the funding period or time for completing a qualification. This causes a paradox in planning: Project executives often have to outline a time frame before they actually get involved with the situations of use and lifeworlds of addressed users. Furthermore, the time scale of most project funding does not match the "Eigentime" [14] of involving people and building relationship to their lifeworlds e.g., [19].

A key goal of developing the "Loaded Dice" as research artifacts was, to not shape beforehand, how they will be used. In particular the definition of the problem that should be solved by the assistive interactive system we create, should carefully emerge from negotiations with users. Thus the major methodological challenge was to enable and maintain such an open-ended process, and to empirically ground decisions in data from the addressed users. A common frame to iteratively investigate in lifeworlds is the Grounded Theory Methodology [31]. This methodology proposes a research process that is reflective and explicit on its decisions on the basis of constant change between gathering and analyzing data. Furthermore the slogan "All is Data" [13] underlines, that Grounded Theory is appropriate to artifact centered methods like RtD.

4.2.1 How did Loaded Dice Enabled an Open Research Agenda?

In designing the "Loaded Dice" it became apparent that there is a tension between technical realization, infield validation and the requirements of a 'proper' academic project. The question "How does and should it work (with people)" could only be answered by giving birth to a research device, using it, gathering and interpreting data and by refining it. The resulting research agenda seeks to engage with multiple stakeholders in an early project stage, in order to methodologically narrow down possible situations of use as well as defining communities to work with and finally understanding design opportunities emerging from deploying the research artifacts.

In order to do so we conducted different types of workshops, as reported in section 2. First we worked with blind and visually impaired teenagers, that can be seen as 'extreme users' in a sensory way, which makes them a very instructive group of people to work with. By analyzing how they explored the pair of dice, we realized that non-sensorily impaired users might also use the "Loaded Dice" for co-ideation workshops. After developing scenarios of use with older adults in a Living Lab, we shifted the focus of user involvement a second time to generalize from concrete users to designing experts and introduce the tool to them.

The interpretative flexibility of the "Loaded Dice" as a research device described above allowed us to work on those different research questions in parallel. For product design and design methodology the dice meant to be co-ideation tools for different user groups to generate design scenarios. For the engineering part they became a playful embodiment of IoT technology, initiating expert talks and appearances at industry events. Sociologist interest in our group focussed around the adoption and use of the tool by participants in our workshops in order to understand the exploration of embodied IoT technology.

While the reported stage of the "Loaded Dice" is a very early project stage, we aim to include research devices in the forthcoming phases of our research: The focus of future user involvement lies on working participatory with one larger neighborhood, before the iterated prototypes are deployed and reiterated with diverging types of neighborhoods. While this goal emerged from reflecting on the deployed and analyzed research device, the iterated research device following up specifies the scope of the exploratory research questions to the social context of neighborhoods.

The sequence of building a prototype and engaging with users is neither new, nor extraordinary. By going into detail in our processes here, we want to highlight, how much the "Loaded Dice" changed the way, we think about research goals and processes: Instead of focusing on the "Loaded Dice" as an enclosed product, we still consider it as a research device. Improvements and iterations are still done as of writing this paper, but it is not our aim to finalize the "Loaded Dice" as such. Rather this tool challenges our beliefs about how HCI work should and in fact can be done properly in order to explore a design space. The mean to develop the "Loaded Dice" was not to optimize an artifact, but to learn about the means of people using it.

Acknowledgment: We thank our reviewers for their valuable feedback and the encouragement to "keep the thought provoking" tone.

Funding: This research is funded by the Federal Ministry of Education and Research (BMBF) under grant number FKZ 16SV7116.

References

[1] Akrich, M. (1992). *The de-scription of technical objects*. MIT Press.

[2] Bardzell, S., & Bardzell, J. (2011). Towards a Feminist HCI Methodology: Social Science, Feminism, and HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 675–684). New York, NY, USA: ACM. https://doi.org/10.1145/1978942.1979041.

[3] Bdeir, A. (2009). Electronics As Material: LittleBits. In *Proceedings of the 3rd International Conference on Tangible and Embedded Interaction* (pp. 397–400). New York, NY, USA: ACM. https://doi.org/10.1145/1517664.1517743.

[4] Bischof, A., Lefeuvre, K., Kurze, A., Storz, M., Totzauer, S., & Berger, A. (2016). Exploring the Playfulness of Tools for Co-Designing Smart Connected Devices: A Case Study with Blind and Visually Impaired Students. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts* (pp. 93–99). ACM. https://doi.org/10.1145/2968120.2987728.

[5] Blackstock, M., & Lea, R. (2012). IoT Mashups with the WoTKit. In *2012 3rd International Conference on the Internet of Things (IOT)* (pp. 159–166). IEEE. https://doi.org/10.1109/IOT.2012.6402318.

[6] Boucher, A. (2016). The Form Design of the Datacatcher: A Research Prototype. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems* (pp. 595–606). ACM. http://dl.acm.org/citation.cfm?id=2901907.

[7] Boucher, A., & Gaver, W. (2017). Designing and Making the Datacatchers: Batch Producing Location-Aware Mobile Devices. In *Proceedings of the Tenth International Conference on Tangible, Embedded, and Embodied Interaction* (pp. 243–251). ACM. http://dl.acm.org/citation.cfm?id=3024971.

[8] Bowers, J. (2012). The Logic of Annotated Portfolios: Communicating the Value of 'Research through Design'. In

Proceedings of the Designing Interactive Systems Conference (pp. 68–77). ACM. http://dl.acm.org/citation.cfm?id=2317968.

[9] Carroll, J. M., & Kellogg, W. A. (1989). Artifact as Theory-Nexus: Hermeneutics Meets Theory-Based Design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 7–14). New York, NY, USA: ACM. https://doi.org/10.1145/67449.67452.

[10] Dourish, P. (2004). *Where the action is: the foundations of embodied interaction*. MIT press.

[11] Gaver, W. (2012). What Should We Expect from Research Through Design? In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 937–946). New York, NY, USA: ACM. https://doi.org/10.1145/2207676.2208538.

[12] Gaver, W., Boucher, A., Jarvis, N., Cameron, D., Hauenstein, M., Pennington, S., …Ovalle, L. (2016). The Datacatcher: Batch Deployment and Documentation of 130 Location-Aware, Mobile Devices That Put Sociopolitically-Relevant Big Data in People's Hands: Polyphonic Interpretation at Scale. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (pp. 1597–1607). ACM. http://dl.acm.org/citation.cfm?id=2858472.

[13] Glaser, B. G. (2002). Constructivist Grounded Theory? *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, 3(3). http://www.qualitative-research.net/index.php/fqs/article/view/825.

[14] Gläser, J., & Laudel, G. (2004). *Experteninterviews und qualitative Inhaltsanalyse*.

[15] Harrison, S., Tatar, D., & Sengers, P. (2007, April). The three paradigms of HCI. In *Alt. Chi. Session at the SIGCHI Conference on Human Factors in Computing Systems*, San Jose, California, USA (pp. 1–18). http://people.cs.vt.edu/~srh/Downloads/HCIJournalTheThreeParadigmsofHCI.pdf.

[16] Hornecker, E. (2010). Creative Idea Exploration within the Structure of a Guiding Framework: the Card Brainstorming Game. In *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction* (pp. 101–108). ACM. https://doi.org/10.1145/1709886.1709905.

[17] Jim Johnson, Mixing humans and nonhumans together: The sociology of a door-closer. *Social Problems*, 35(3), 298–310. 1998.

[18] Kuhn, T. S. (1967). *Die Struktur wissenschaftlicher Revolutionen*.

[19] Le Dantec, C. A., & Fox, S. (2015). *Strangers at the Gate: Gaining Access, Building Rapport, and Co-Constructing Community-Based Research* (pp. 1348–1358). ACM Press. https://doi.org/10.1145/2675133.2675147.

[20] Lefeuvre, K., Totzauer, S., Bischof, A., Kurze, A., Storz, M., Ullmann, L., & Berger, A. (2016). Loaded Dice: Exploring the Design Space of Connected Devices with Blind and Visually Impaired People. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction* (pp. 31:1–31:10). New York, NY, USA: ACM. https://doi.org/10.1145/2971485.2971524.

[21] Lefeuvre, K., Totzauer, S., Bischof, A., Storz, M., Kurze, A., & Berger, A. (2017). *Loaded Dice: How to Cheat Your Way to Creativity*. https://doi.org/10.6084/m9.figshare.4746976.v1.

[22] Lucero, A., & Arrasvuori, J. (2010). PLEX Cards: A Source of Inspiration when Designing for Playfulness. In *Proceedings of the 3rd International Conference on Fun and Games* (pp. 28–37). ACM. https://doi.org/10.1145/1823818.1823821.

[23] Mora, S., Divitini, M., & Gianni, F. (2016). Tiles: An Inventor Toolkit for Interactive Objects. In *Proceedings of the International Working Conference on Advanced Visual Interfaces* (pp. 332–333). New York, NY, USA: ACM. https://doi.org/10.1145/2909132.2926079.

[24] Nelson, H. G., & Stolterman, E. (2003). *The design way: Intentional change in an unpredictable world: Foundations and fundamentals of design competence*.

[25] Oh, H., & Gross, M. D. (2015). Cube-in: A Learning Kit for Physical Computing Basics. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction* (pp. 383–386). New York, NY, USA: ACM. https://doi.org/10.1145/2677199.2680597.

[26] Owen, C. (2007). Design thinking: Notes on its nature and use. *Design Research Quarterly*, 2(1), 16–27.

[27] Rittel, H. (1972). *On the Planning Crisis: Systems Analysis of the 'First and Second Generations.'* Berkeley: University of California.

[28] Schön, D. A. (1983). *The reflective practitioner: how professionals think in action*. New York: Basic Books.

[29] Star, S. L., & Griesemer, J. R. (1989). Institutional ecology, translations' and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907–39. *Social Studies of Science*, 19(3), 387420.

[30] Stolterman, E. (2008). The nature of design practice and implications for interaction design research. *International Journal of Design*, 2(1).

[31] Strauss, A., & Corbin, J. (1998). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*.

[32] Suchman, L. (2007). *Human-machine reconfigurations: Plans and situated actions*. Cambridge University Press.

[33] Wakkary, R., & Maestri, L. (2008). Aspects of everyday design: Resourcefulness, adaptation, and emergence. *Intl. Journal of Human–Computer Interaction*, 24(5), 478–491.

[34] Zimmerman, J., Forlizzi, J., & Evenson, S. (2007). Research through Design as A method For Interaction Design Research in HCI. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 493–502). ACM. http://dl.acm.org/citation.cfm?id=1240704.