Concept-Driven Interaction Design Research

Erik Stolterman [a] & Mikael Wiberg [b]

[a] Indiana University , USA

[b] Umeå University , Sweden

Published online: 15 Jun 2010.

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis
Taylor & Francis Group

Concept-Driven Interaction Design Research

Erik Stolterman[1] and Mikael Wiberg[2]

[1]Indiana University, USA
[2]Umeå University, Sweden

In this article, we explore a *concept-driven approach* to interaction design research with a specific focus on *theoretical advancements*. We introduce this approach as a complementary approach to more traditional, and well-known, user-centered interaction design approaches. A concept-driven approach aims at manifesting theoretical concepts in concrete designs. A good concept design is both *conceptually* and *historically grounded*, bearing signs of the intended theoretical considerations. In the area of human–computer interaction and interaction design research, this approach has been quite popular but not necessarily *explicitly* recognized and developed as a proper research methodology. In this article, we demonstrate how a concept-driven approach can coexist, and be integrated with, common user-centered approaches to interaction design through the development of a model that makes explicit the existing cycle of prototyping, theory development, and user studies. We also present a set of basic principles that could constitute a foundation for concept driven interaction research, and we have considered and described the methodological implications given these principles. For the field of interaction design research we find this as an important point of departure for taking the next step toward the construction and verification of theoretical constructs that can help inform and guide future design research projects on novel interaction technologies.

1. INTRODUCTION

At human–computer interaction (HCI) conferences and workshops, it is common that researchers introduce designs of artifacts and systems that manifest some new or improved form of interactivity. The designs are usually based on earlier related

---

Eric Stolterman is an interaction design researcher with an interest in Human–Computer Interaction Design; he is Professor and Director in the School of Informatics (HCI/d) of Indiana University, Bloomington. **Mikael Wiberg** is an interaction design researcher with an interest in Social Interaction Design and Interactive Architecture; he is an Associate Professor in the Department of Informatics of Umeå University and Research Director in the Umeå Institute of Design, Umeå University, Sweden.

CONTENTS

work in the field along with some new creative ideas and of course with some evaluations in accordance with the standards of the field. Finally, some results are reported and, because the design is only a first attempt to implement these new ideas, there is a suggestion of future research or development. In some cases, these presentations do not leave a lasting impression on the audience of fellow researchers, as the contributions do not address, challenge, or complement the existing body of theoretical knowledge within interaction research in an intentional way.

At the same time, many readers probably recognize names like the DynaBook and ActiveBadges; these concepts are examples of highly influential research *designs* in the field of HCI. By "influential" we primarily mean that they have contributed to the *intellectual* and *conceptual development* of the field of HCI research and are frequently referred to as landmarks and as focal points on the interaction research theoretical map. What is it that makes some concept designs more memorable and interesting than others? What makes them unique? How should we understand these concept designs? In addition, how do they influence the conceptual and theoretical developments in the field?

In our research, we address these questions by exploring a *concept-driven approach* as a *complementary* methodology in interaction research with a specific focus on *theoretical advancements*. We are not arguing that this is a new approach in interaction research. The way we define it, concept-driven interaction design research, has served as an *implicit* approach within the HCI research community for quite some time. We believe that it is important to make this implicit approach explicit as a way to improve research, to

strengthen the rigor and discipline in the research, and as a way to make a common research approach visible and recognized.

The purpose of this article is to strengthen the process of *theory construction* or *theorizing* in the sense developed by Karl Weick (1989). We argue that our proposed approach is in line with the kind of theorizing that Weick laid out in his seminal publication. One of our assumptions is that concept-driven interaction design research can be understood as rooted in *futuristic use scenarios* ("disciplined imagination," Weick's term) and in *reasoning grounded in theory* rather than in careful studies of present user conditions and situations. Furthermore, concept-driven design research is *explorative* in nature, aiming at manifesting *visionary theoretical ideas in concrete designs*. We see these assumptions falling within the definition of theorizing as defined by Weick (1989).

In addition to Weick's idea, we also argue that in a design field, not all knowledge can be fully expressed in text or other typical research outcome formats: They have to be designed and manifested as artifacts. These artifacts become an essential and crucial part of the theorizing process as carriers of knowledge that only is "visible" as emerging aspects of the design as a whole. By taking these ideas as a point of departure, we examine the more specific notion of concept-driven interaction design as a possible and valuable approach for theorizing in interaction design research.

1.1. Background

One fundamental goal within the existing traditions of interaction design *practice* is to understand users' needs and desires on such a detailed level that it could serve as a basis for design of (digital and interactive) solutions capable of addressing these specific needs (e.g., Mylopoulos, Chung, and Yu, 1999; Piper, Ratti, & Ishii, 2002). Interaction design is about "designing interactive products to support people in their everyday and working lives" (Preece, Rogers, & Sharp, 2002, p. 6). This means that within interaction design *practice* there is a strong focus on how to approach a specific problem domain—the situation at hand. Methods and techniques for exploring the situation, the condition and the user, have been at the center of the field (Bødker & Madsen, 1998; Kujala & Kauppinen, 2004).

More than ever, contemporary interaction design approaches are empirically oriented. This is true for many of the better-known (research based) approaches, such as user-centered design, participatory design, contextual design, activity theory, and ethnographically informed systems design (for overviews, see Carroll, 2003; Kaptelinin & Nardi, 2006; Rogers, 2004). Most of these approaches are built on the assumption that a suitable design proposal is to be grounded or even "found" through careful analysis of an existing situation. The purpose of these approaches is to explore and understand the particular situation and the users, to such a degree that the design solution becomes more or less obvious. This approach has proven to be highly successful, and it is the obvious starting point for any *practical* and *situated* design process.

In many cases, these approaches, mainly developed for design practice, are also used as approaches in interaction design *research*. When these approaches are used for research, they are valuable for their ability to support the development of deep insights

into the specifics of contexts and user behavior. However, these common approaches are not always suitable when the purpose is to develop more conceptual and theoretical contributions to the general understanding of the interaction between humans and digital artifacts. Our purpose here is not to argue against these commonly used and well-known approaches but to propose an alternative. Theoretical development in interaction design *research* with a focus on *interaction as such*.

There are other approaches in interaction research apart from the situation-oriented approaches just mentioned. For instance, the notion of *proof-of-concept* has sometimes been used in a related way to what we propose here. Although this term has recently gained popularity in the field (Randell & Bolmsjo, 2001; Ryokai, Marti, & Ishii, 2005; Soh, Jiang, & Ansorge, 2004), we do not find these attempts to fully take on the challenge on how proof-of-concept relates to theoretical advancements in the field. Proof-of-concept makes usually a more limited claim with focus on *feasibility* of a proposed design concept.

Based on the situation in our discipline, we argue that a lack of research approaches that focus on theoretical advancement *and* are design and concept oriented at the same time. We see concept-driven design research as one approach that could take on that role. Within such an approach,

1. The point of departure is conceptual/theoretical rather than empirical.
2. The research furthers conceptual and theoretical explorations through hands-on design and development of artifacts.
3. The end result—that is, the final design—is optimized in relation to a specific idea, concept, or theory rather than to a specific problem, user, or a particular use context.

We are aware of other approaches that might seem similar to the one we propose, but these approaches have radically different purposes and do not fulfill the three characteristics just mentioned. Some, for instance, while focusing on the design of artifacts advocate an almost nonintellectual approach to interaction design research, having no intention of fostering intellectual and theoretical development in the field. This is not our intention. Nor is it our intention to propose a research approach that is similar to what can be seen as an invention and innovation process in the business world. As we see it, the concept-driven design research approach is not an excuse to leave academic and intellectual rigor aside. Instead, we see it as a way to further a designerly approach with a focus on theoretical development.

1.2. Theory and Theorizing

When an object of study, such as *interaction*, becomes complex due to technological developments, changes in use behavior, or cultural and social changes, there is a growing need for theoretical and conceptual development. Addressing this need, we argue that in a design-oriented field, such as HCI, theory advancement cannot only be achieved through "traditional" theorizing. Weick (1989) described such a traditional

way of theorizing as *"*mechanistic, with little appreciation of the often intuitive, blind, wasteful, serendipitous, creative quality of the process*"* (p. 519). He argued that traditional theorizing does not pay enough attention to "the process where the theorists can act differently and produce theories of better quality." We argue that this is what we are trying to do in this article. We are focusing on the *theorizing process* with an ambition to *include a concrete and creative design element.*

In a research situation where the object of study is stable there is a possibility for accumulative theoretical advancements through theoretical refinements using tools of theoretical analysis and discourse. In our field, the object of study is constantly changing and refuses to be "stabilized" as an object for detailed theoretical analysis. We argue, therefore, that theoretical advancement also has to be done through a more concrete and exploratory process, involving design and artifacts as significant elements. In a constantly changing field, theorizing truly becomes a matter of "sensemaking" (Weick, 1989). Theorizing in such a field is manifested in the process by which researchers try to develop a theory with the intent, as Dubin stated, "to make sense out of the observable world by ordering the relationships among elements that constitute the theorist's focus of attention in the real world" (p. 26).

When it comes to design disciplines these aspects become even more crucial. The observable world is not necessarily "there," it is "becoming" as a result of design efforts. Theories on new forms of digital and interactive artifacts must therefore not only deal with the existing but with the not-yet-existing (Nelson & Stolterman, 2003). This is why the process of designing concepts and artifacts becomes a crucial and core activity in theorizing in any design discipline. Kuhn (1962) presented a famous argument for what happens when homogeneity created within a field rests solely on its already achieved knowledge base. He defines his notion of *paradigm shift* as a consequence of reality "striking back." According to Kuhn, new unexpected knowledge appears when the researcher discovers findings that do not fit the existing paradigm. These findings challenge established "truths" and more sensemaking theories enter the field. These new theories are almost always based on new assumptions and constitute a new way of understanding foundational properties and relationships. This kind of paradigm shift can be achieved through any kind of research approach. We argue that, in a dynamic field like HCI, the design and creation of concept artifacts is an approach for the purpose of not only finding out new usage of new technology but also even more as a way to challenge existing theoretical and conceptual foundations in the field.

In our approach, the notion of *theory* becomes central. We see theory as abstracted knowledge that tells us something about fundamental entities at the core of a discipline. Theory is condensed knowledge that on a general level explains properties, mechanics, dependencies, and relationships in a way that constitutes a foundational way of understanding reality as understood within a discipline. Sutherland (1975) defined theory as "an ordered set of assertions about a generic behavior or structure assumed to hold throughout a significantly [*sic*] range of specific instances" (p. 9). Weick, in reference to this definition by Sutherland, stated that the core terms in his definition are ordered, generic and *range* (Weick, 1989). This means that it is of importance to

know what a theory is *about*. We see the purpose of theorizing in interaction research to be about *interaction*. A *theory of interaction* contains knowledge that in an ordered and structured way tells us something about generic qualities and characteristics of interaction in a way that explains a range of instances of interactions. Weick argued that the strength of a theory increases when generalizations become more hierarchically ordered and more generic, and when the range of instances becomes broader. He also added that theory should not be seen as a category but as a dimension. Any academic field is striving towards the development of some core theoretical constructs that can serve as pillars in the common knowledge in the field.

In our work we build on the definition and understanding of theory and theorizing as presented by Weick (1989). It is an understanding that focuses more on the *process of theorizing* than on the notion of theory. Our approach is likewise about the process and we argue that, so far, what many have seen as nontheoretical efforts in HCI can be transformed, with conscious efforts, into legitimate forms of theorizing.

The way of fostering theoretical development that we are proposing is somewhat similar to what has been proposed by Zimmerman, Forlizzi, and Evenson (2007). The model proposed in their paper is a thoughtful approach that appreciates the specifics of intentional *competence* that goes into good design work. They also made the case that such an approach can lead to artifacts that in themselves open up a *design space* and people's understanding of what is *possible* and also *desired*. It is possible to see the process they proposed as a pretheoretical activity, that is, it presents a design space that later can be theoretically examined. They also mentioned that the process can lead to insights that can contribute to "supporting" disciplines involved in the process (such as engineering and social science). The proposed model by Zimmerman et al., however, is *not* intended to address specifically theorizing around the concept of interaction, at least not as a primary goal.

1.3. Situation-Driven Versus Concept-Driven Research

We are proposing a designerly research approach that although being design oriented has the primary goal of supporting theorizing about interaction. In Figure 1, we show how it is possible to see interaction research in relation to *theory* and *use*. Many interaction design research approaches have as a primary goal to create a (concept) design that would support the *use situation* (Arrow 2). We are proposing an interaction research process that leads to concept designs and has as the primary goal supporting *theoretical development* (Arrow 1). Both these approaches are *design oriented* and both lead to designs, but the *measure of success* is radically different.

The model presented by Zimmerman et al. (2007) is in relation to this model (Figure 1) a combination, or more correctly a third variant, where the primary focus is the improvement of the use situation, while contributing to theory in supporting disciplines but with a couple of differences. First, there is the issue of *purpose*. The Zimmerman approach is based on the idea that the research process can be a design process aimed at the creation of artifacts addressing real-world issues. The overarching purpose is that the design will lead to a more desired situation than the present.

FIGURE 1.   Relationships between the research process, theory, and use.
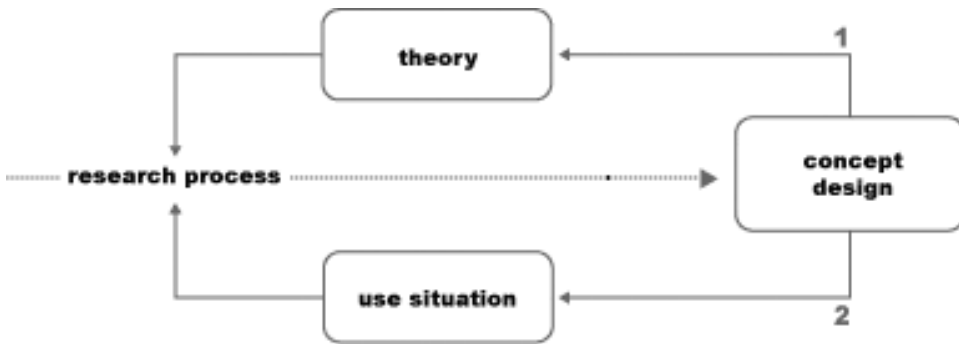
This means that, although their approach also produces knowledge, it is a combined approach where the outcome, as an artifact, and its success also is part of the evaluation. In the concept-driven approach, the overall purpose is knowledge production in the form of theoretical development, which means that the actual design outcome, as a design that address real issues, is not necessarily important. Second, in the Zimmerman approach knowledge production is primarily understood as contributing to what they see as the *supporting disciplines*, that is, social sciences and engineering. In the concept-driven approach, the aim of producing knowledge is primarily for the internal theoretical development of 'interaction' as an object of study. Of course, these distinctions are subtle and in real situations might be impossible to distinguish. The Zimmerman approach, however, is among existing approaches in our field the one most similar to what we are proposing in this article.

As previously mentioned, a distinguishing aspect of these different forms of research is their *measure of success*. Research aimed at improving a use situation will (must) be evaluated in relation to how well the result resolves an unwanted situation and creates a desired one. Whether the result is valid from a theoretical point of view is of lesser interest in such a case. Research aimed at theorizing has another measure of success, which is whether or not the research leads to improvement of theoretical concepts. Of course, the notion of "improvement" has to be made explicit, for instance, in the sense defined by Weick. Whether such theoretical advancements lead to improvements of a situation is of lesser interest, or maybe even of no interest at all. We argue that concept-driven research is one way for interaction research to advance theory using a designerly approach that is different from other forms of research aimed at theoretical development based on nondesignedly approaches, such as critical discourse analysis or empirically grounded hypothesis testing: approaches aimed at examining the correctness of existing theories. The difference is not so much in that the concept-driven approach leads to different results but more that it uses different forms of competences, activities, and outcomes (concept designs) to explore theoretical and conceptual foundations.

It is interesting that the two different forms of research (shown in Figure 1) are in many ways similar. They both depend on good design work, but although situa-

tion-driven research finds inspiration and restrictions in the (empirical) situation at hand, the concept-driven approach finds inspiration and restrictions in earlier theories and conceptual constructs. Although situation-driven research has a *client* and a *problem* to solve, concept-driven research is an *exploratory investigation* of established theories with the overall aim of improving and widening the range of theory and knowledge.

We would also argue that whether or not some specific research is of one or the other kind is a question of *intention*. There might be situations when situation-driven research leads to theoretical developments as a side product, which is fine, but what we are arguing is that there is a need of intentional and deliberate theorizing about the nature of interaction and that a concept-driven research approach is one way to achieve that.

Our work is also based on another important assumption, which is that concept-driven research, as we define it, is what many researchers in the field of HCI and interaction design are already doing. We may even argue that it is a common research approach because, in many instances, the research process commonly used in HCI bears a resemblance to the way we define concept-driven research. However, this similarity is not necessarily the result of a conscious decision by researchers to be concept driven or theory focused; instead, it can be seen as an implicit consequence of a tradition of practice that has grown and is becoming established as a norm.

We claim that we need to make theorizing a conscious purpose in HCI research and those we can see concept-driven research as an intentional research activity with its own rigor and discipline suitable for that purpose. We also argue that in many cases HCI design research is already being conducted in a way that can be described as concept driven to some extent. Therefore, we find it important and necessary for the field to *describe explicitly* this practice with the purpose of making it *visible* and possible to *examine critically* and to *develop* further. To make this possible we need a well-defined description and understanding of what theorizing using a concept-driven research approach would entail when it comes to procedures, rigor, limitations, and possibilities. In establishing an understanding of an existing practice, we believe that it will open the field for debate and for a more intense and focused critique.

2. DESIGN CONCEPTS AND ARTIFACTS AS CARRIERS OF KNOWLEDGE

In HCI as in most other research fields, there has been an ongoing effort to develop research approaches that guarantee cumulative knowledge production. On the other hand, there has also been a sense of doubt concerning the possibility of combining such an effort with the more immediate purposes of exploring the constantly expanding design spaces and while creating good designs that take advantage of the dynamic evolution of digital technology.

Over the years, several attempts have been made to explore alternative approaches to the dominant situation-centered approach in HCI design (see, e.g., Burns,

Dishman, Verplank, & Lassiter, 1994). Some of these alternative approaches have a more theory-centered design account in common. One example is the work done by Carroll and Kellogg (1989) on "artifacts as theory nexus" in which they discuss how traditional HCI theories can be expressed "in" or "with" designed artifacts. Another example is the work conducted by Carroll and Rosson (1992) on the so-called task-artifact cycle in which they take on the challenge of merging activities directed at understanding (or theory construction/knowledge creation) with those aimed at design. According to Carroll and Rosson, their purpose was to develop "an 'action science' approach to human-computer interaction (HCI), seeking to better integrate activities directed at understanding with those directed at design" (p. 181).

A similar attempt has more recently been made by Wiberg (2003), who has suggested a design-centered and theory-oriented approach to interaction design. A similar discussion on design-oriented research has also been presented by Fällman (2003). Whittaker, Terveen, and Nardi (2000) also attempted to merge design activities with a knowledge creation agenda. In their work, they suggested that the HCI community should strive to focus on *reference tasks* in their design efforts as a way of starting a cumulative tradition within the field and of collecting valuable experiences and results around these central reference tasks.

More closely related to our idea of concept-driven research, are attempts such as *proof-of-concepts* tests (Toney, Mulley, Thomas, & Piekarski, 2003), *concept design* (Gaver & Martin, 2000; Kerne, 2002; Pedersen, Sokoloer, & Nelson, 2000), and *concept development* through normative writing (Jensen & Skov, 2005). However, these researchers have not explicitly attempted to formulate how to conduct concept-driven interaction research. Nor have they attempted to describe how concept-driven research is currently being conducted in the HCI research field, even though several interaction design projects have used the term *concept-driven interaction design* as a general label for their research method (e.g., Ishii et al., 2000). More recently, there has been another turn to the artifact through the development of the notion of *interaction criticism* (Bardzell, 2009; Bardzell & Bardzell, 2008). Criticism as an approach is a way of revealing the intrinsic and extrinsic qualities of designed artifacts, with the aim to generate innovative design insights.

All these attempts illustrate the *existence* of a concept-oriented focus in interaction research at the same time as these attempts also demonstrate the *need* for a better understanding of concept-driven interaction research in general, and we see this palette of approaches as a *motivational factor* for further exploration into the essence and process of concept-driven interaction research. Although we, in these other approaches, have the *need*, and the *motivation* in place, we notice that these attempts are developed for the purpose of *capturing* some specific activities carried out in research projects rather than for the purpose of theorizing and the development of theories on interaction. In addition, maybe more important, they have not been developed with the aim to establish a broader understanding of how their respective approach fits within the field of HCI and how their approach relates to research in general. From our standpoint, we find it crucial that any attempt aimed at developing a "new" research approach recognizes both existing research practices and established research approaches.

2.1. Characteristics of Concept Designs

We argue that exploiting concept-driven design research allows us to develop knowledge that cannot be fully expressed in text or other typical research outcome formats. A theoretical concept manifested as a designed artifact can be seen as externalized knowledge; the concept itself carries most of the experience and results from the design process. The concept design becomes a carrier of knowledge but also establishes a conceptual framework and challenge for future design work. We argue that the concept's capacity of carrying knowledge is highly desirable from a research perspective.

Concept designs have one obvious and valued quality—anyone can almost instantly get an overall understanding of the *character* of the concept without any expertise or special training. The *character* of a concept design is the *overall organizing principle that makes up the composition of the design as a whole* (Nelson & Stolterman, 2003). This idea is based on the assumption that the whole reveals emergent qualities that cannot be made visible or measured as the sum of the part's qualities. This is a core quality of any concept design and is the major reason for why concept designs have a value different from text statements or other traditional theoretical formats. The concept as a whole brings forward aspects difficult to extract as abstract externalized statements. The degree to which it is possible or not to combine theoretical aspects into a design becomes a sign of how well the theoretical aspects are commensurable.

Concept designs are mainly used to portray future designs. They can also be seen as *probes* or *measuring instruments* used to get a sense of how people (or a market) will "read," react, and respond to the character and composition of a design. Even though they can be seen as a prototype, concept designs are far from that. A prototype is a manifestation of a specific idea for a *specific* design solution (Lim, Stolterman, & Tenenberg, 2008). It is a way to explore whether the specifics of a design will satisfy the particular desires and needs of a well-defined group of users and clients. In contrast, the concept design is an exploration of new ideas and constitutes a new composition from the perspective of the researcher with the intent to address and challenge existing theoretical concepts and frameworks.

The key here is that the concept carries and manifests all the combined knowledge that has influenced the design. It is in this way that *knowledge is embodied in the artifact*; it is not necessarily expressed in words or other descriptions, even though such descriptions do complement and strengthen the experience and understanding of the concept design.

To capture, intellectually, the idea of concept design it is usual for a single word or short sentence thought to express the essence of the proposed design. For instance, a new interactive device can be described as the "portable communicator" or the "music player phone." The concept combines expected qualities from two quite opposing desires and the design challenge is to combine all of these aspects into one single design. The purpose of the concept design is to express this combination in a complete composition with new interesting qualities.

Therefore, a typical concept design is *futuristic* and *new*; it is founded in visions of future use scenarios. At the same time a good concept design, one that is both *conceptu-*

ally and *historically grounded*, bears signs of the intended theoretical considerations. The integration of and tension between the traditional and futuristic aspects may be one of the hardest challenges for any concept design. This means that a good interaction design researcher has to be able to, in the design, manifest both something that is theoretically relevant and new as well as paying tribute to existing established theoretically concepts.

Concept designs also serve another future-oriented purpose. A concept design sets the *agenda* for forthcoming research that will pick up theoretical elements from the concept design. As such, the concept design should serve as a guide or raw model for other researchers. This purpose is not just a question of the concept design functioning as a template but also of how a concept design can lead to stimulating, intellectual, and creative theoretical explorations in a certain *direction*.

Concept design also strives to illustrate and express specific, radical, and even extreme *values*. Good concept designs thus require a good understanding of emotions and affective aspects of design in relation to concept modeling, explorations, and expressions in design. In interaction design research, this means that a new concept design has to express the underlying theoretical concepts it is supposed to manifest in a *true* and *authentic* way. This is where *intimate analytical studies* of a concept design become part of the theoretical analysis of a design. This process is not well developed but has been discussed (see Carroll, 2003; Lakoff & Johnson, 1999; and Lund, 2003).

In any design field, new materials are at the core of new design developments. Concept design illustrates how cutting-edge technology can be used as a design material in the realization of new ideas. To find new ways to use these materials is a sign of a creative and inventive designer and a sign of interesting design research that pushes the field ahead, at least if it is done in the name of the common good. In interaction research this means that concept designs are a way to explore and experiment with new technology in ways that would not be asked for or wished by any user. The challenge is, of course, to do this with an intention to develop a theoretical understanding and not just to create anything that is possible because "we can."

2.2. Three Examples of Concept-Driven Interaction Design Research

Even though concept-driven design has not been a common label in interaction design research, examples of designs that have served as real concept designs do exist. We have chosen to mention and describe three such examples —the DynaBook (Kay, 1972), ActiveBadges (Want, Hopper, Falcão, & Gibbons, 1992), and Bricks (Fitzmaurice, Ishii, & Buxton, 1995). These examples have different qualities. For instance, the DynaBook was never implemented as a working prototype because the needed technology was not available at the time. On the other hand, ActiveBadges was a technologically simple design, easy to implement with existing technology. Bricks opened up a new way of viewing material and interaction that could be implemented in numerous ways. We have chosen concept designs that can be seen as seminal in the field of interaction design research. None of the examples led directly to any market or commercial breakthrough products. We have not chosen these examples because they had

impact on the practice of interaction design. Instead, these three examples all show the typical traits of a strong concept design, that is, they functioned as a design *composition*, bringing together technological advancements with functionality and focusing strongly on use, while inspiring *theoretical* and *conceptual development* in the field.

DynaBook

Led by computer scientist Alan Kay, the Learning Research Group at the Xerox Palo Alto Research Center created the DynaBook vision in the early 1970s. The DynaBook was a concept design that inspired the design of the modern laptop computer but at the time of its creation was not technologically possible to build. It was born as a vision grounded in the context of learning (Kay, 1972). The idea was to create a concept design that would incorporate the functionalities and use options needed for a good learning experience for children. To achieve this, the designers had to invent a new interaction forms, interface solutions, technology and software. For instance, the laptop had a low-powered flat screen that did not exist (Kay wrote about the screen, commenting that "it does not currently exist but seems possible."). The attempts to implement the DynaBook as a prototype led to results that were too expensive, clumsy, slow, and in most ways useless. However, the way in which the concept design was imagined intrigued people over the years to come. The DynaBook was never implemented as a real product, yet its design concept was extremely influential and led to a number of designs that were implemented and used.

The DynaBook concept still functions as a model for the development of small laptop computers. The first part of the concept, "Dyna," indicates that this artifact is "dynamic" and interactive, and the last part of the concept, the "Book," says something about the size and physical format of this interactive/digital artifact. The DynaBook concept pointed in the direction of a future development toward partly digital, book-size computers. Today, we can still see the strength of this concept in, for example, Apple's naming of their laptop computer a "MacBook." At the same time, we can now see how they try to challenge the "book" part of the concept by going for a more magazine-like size in their development of the "MacBook Air" laptop computer, that is, an ultrathin version of the more traditional MacBook. The DynaBook has provided conceptual inspiration for the field for decades and serves as a reference point in the history of interaction design.

Today we are accustomed to working on laptops that incorporate many of the qualities envisioned in the DynaBook. The most important aspect of the Dynabook was, however, its *conceptual strength*. It has in many cases filled the same function in academic research referencing as is common for foundational theoretical contributions.

ActiveBadges and Interpersonal Awareness Systems

Active Badges (Want et al., 1992) are small mobile devices that support location tracking of people indoors. When it was introduced, the device was a clear and simple concept; throughout the years, several systems have built upon this initial idea, although each has unique variations. One example of such a variation is the Humming-

bird system (Holmqvist, Falk, & Wigström, 1999), which supports colocated groups with presence awareness. Another example is the "Forget-me-not" system (Lamming & Flynn, 1994), which supports sensing of the user's environment and automatic data capture of an event's location, people present during an event, and an event's focus. Although these systems support different use scenarios, the fundamental idea is still the same— to collect location data (via absolute or relative positioning) on a mobile device and then to build various applications on top of the fundamental concept of "*interpersonal awareness systems*." The basic concept design as it was presented proved to be not only new but also stable over time and inspired other researchers to further develop the concepts, as seen, for instance, in the location-based technologies in today's cell phones.

One strength with the development of a strong concept such as interpersonal awareness system is that this concept can help designers to visualize clearly how this concept could be realized in a prototype. It can also function as an *intellectual tool* for considering possible future use scenarios and fundamental problems related to a certain design. As an example, if you design an "interpersonal awareness system," then, apart from the technical implementation, you will quickly realize that such a system needs to deal with the classic dilemma concerning how to protect individual privacy while using personal data (e.g., a person's tapping on a keyboard) as input to a shared system that can provide information about this person's activity status to the friends on his or her buddy list, or any similar representation of someone else's activities. If we could improve our understanding of the relationships between fundamental concept designs and likely use scenarios, we could foresee many results related to the use of digital artifacts. A quick search on the keywords *awareness* and *integrity* on ACM's digital library (http://www.acm.org/dl) resulted in a result list of 663 papers that have documented this issue.

From a concept-driven research point of view, the concept of "awareness" might be one of the most elaborated concepts in the field of HCI (if not counting the concept of "interaction" itself). Looking at the ACM digital library we can find almost 8,000 papers that address the issue of awareness as a fundamental aspect of interaction. In addition, if we look at how the concept has developed over the years, and look at attempts made at narrowing the concept down to more specific concepts (e.g., "situational awareness"), we can still find almost 500 papers focusing on this specific concept.

Bricks and Tangible User Interfaces

The Bricks system is another example of a concept design expressed as a prototype. Fitzmaurice et al. (1995) developed the Bricks system, which allowed the manipulation of digital objects by way of physical bricks placed on a large horizontal computer display surface called the ActiveDesk (Benyon, Turner, & Turner, 2004). As such, this installation served as the first tangible computing proof-of-concept of what have been called tangible user interfaces (TUIs), in contrast to traditional graphical user interfaces (GUIs). After this groundbreaking concept design, many similar instal-

lations have been created, each a variation of this fundamental theme; these include *graspable* UIs (Fitzmaurice et al., 1995), *squeezable* UIs (Weinberg, Orth, & Russo, 2000) and *multiuser* TUIs (e.g., Hilliges, Sandor, & Klinker, 2006; Pangaro, Maynes-Amin-zade, & Ishii, 2002). There have also been experiments conducted with variations of the tangible material itself, including wood interfaces (Ullmer, Ishii, & Glas, 1998), clay interfaces, such as the illuminating clay project (Piper et al., 2002), and water interfaces (Mann, 2005). Finally, the initial installation of the Bricks system led to theorizing and model construction around the fundamental concept of tangible interaction, including "embodied interaction" (Dourish, 2001), "tangible bits" (Ishii & Ullmer, 1997), "model-view-control" models (Benyon et al., 2004), and the MCRpd-model (Benyon et al., 2004).

2.3. Examples in Perspective

Researchers have regarded these three examples as seminal concept designs in the field, and they have been heavily cited. We see the success of these examples as a sign that these concept designs have had scholarly significance. According to Google Scholar, 528 papers have cited the DynaBook concept, 974 have cited the original paper describing ActiveBadges, and 297 cited the Bricks system. Even more important, researchers have also frequently cited follow-up projects built upon the same basic concept design—for example, 997 have cited the Tangible bits project (Ishii & Ullmer, 1997) and 400 the DigitalDesk project (Wellner, 1993). Similar numbers can be found for DynaBook and ActiveBadges. As such, they can be thought of as concept designs that have opened up a new field, a new approach, a new application, and more important, a new way of thinking. It is also interesting to note that successful concept designs make a name for the designer in many cases. This is true for the three examples we just discussed. The names might not be famous for a broader audience, but they are in the professional field.

Each of the followers of these seminal designs has tried to expand, copy, or refine some aspects of the original concept design. As we have stated, these concept designs have not only led to further design developments in the form of new designs but, more important, led to substantial theoretical development. There are a number of other examples that have the same characteristics as the ones we have just mentioned, for example, Apple's Knowledge Navigator. This observation has led us to believe that there is a strong need for careful analysis and examination of these examples. It would probably be useful to develop a way of describing and analyzing these examples over time and to develop a sense of how these examples have influenced the field and how distinct qualities have matured and evolved over time.

To summarize, one of the qualities of good concept designs is that they function *both* as an exciting actual product design composition and as an inspiration and challenge for theoretical development. This observation connects back to our introductory paragraph. A concept design has to be strong *both* as a concept and as a design composition. Although introduced to a large number of new designs and ideas at conferences today, we remember few of them. It is possible that many of these, however

exciting and challenging, only manage to fulfill one of these criteria. We conclude that good concept design is difficult and, hence, not often successful.

3. PRINCIPLES FOR CONCEPT-DRIVEN INTERACTION RESEARCH

A basic, pragmatic model of concept-driven interaction design research is not necessarily complex (see Figure 1). In this section, we further discuss some of the fundamental principles underpinning concept-driven interaction research and address some aspects of what constitutes a concept-driven design research process. We have divided our proposal for a possible research model around *basic principles* and *methodological considerations*.

3.1. Basic Principles

We have formulated a set of basic principles that we would argue constitute the foundation for concept driven interaction research. We have identified the following four principles:

- Concept design research means to design and create a concept and an artifact that manifests desired theoretical ideas as a compositional whole.
- The final artifact has the potential power to function as an argument for the quality of the proposed concept and the intended theoretical argument.
- The quality of the artifact as a reflection of the concept and as an argument is a consequence of the careful crafting of the underlying theoretical ideas, the concept, and the artifact.
- The careful crafting of the artifact is a process of refining and including essential characteristics of the concept while excluding features and functions that do not add to the understanding and evaluation of the concept and the theoretical argument.

Taken together, these principles show that even though making a concept design as a way of developing knowledge may sound like a straightforward task in relation to traditional research approaches, the successful creation and development of a concept design is complex and difficult and seldom leads to results that answer to all these principles.

When these principles are related to Figure 1 it is possible to see how complex the process becomes. It becomes important to be able to make a convincing argument that the development of the concept and artifact is based on earlier theoretical work in the field and that the final concept and artifact are carriers of theoretical insights of value to the field.

3.2. Methodological Considerations

To a large extent, the basic activities in a concept-driven design research are similar to the ones found in any design process. This similarity means that they also are

alike in their requirement of knowledge and skills. This resonates with the argument made by Zimmerman et al. (2007) when they argue that the basic competence and skills of design can be exploited as a way to do research and to produce knowledge and not only as a way to produce a design.

The methodological activities involved in concept-driven design research are the following: *concept generation, concept exploration, internal concept critique, design of artifacts, external design critique, concept revisited,* and *concept contextualization.* Even though some of these concepts are well known to any designer (and design researcher), they do differ in certain crucial aspects.

Concept Generation

One of the most important activities is the *generation of possible concepts.* As we have described in Figure 1, for the generation of concepts to be valuable it has to be based on earlier theoretical work in the field. The generation of new concepts is of course a process not possible to prescribe: It may be done by working with associations, metaphors, conflicting or opposing theoretical concepts, theories from other design fields, and historical or other paradigmatic examples. One distinct quality sought for in this activity is search for the unexpected; a new concept design must provide something new, either in the way it combines earlier qualities or in the way it manifests a whole. Maybe the most important requirement is that the design researcher is intimately aware of theory in the field.

Concept Exploration

As in most design projects, the design researcher must go beyond the initial idea and explore the unknown. Usually, this means working hands-on with materials; creating models and prototypes; and experimenting with unusual materials, forms, and content in the exploration of new design spaces. Concept design is about opening up and exploring new design spaces or finding unseen parts of already known spaces. The exploration should lead to new ideas that challenge the prevalent theoretical understanding. Concept design research does not strive to refine or test established ideas; instead, it explores new territories and design spaces. For the purpose of refinement, testing, and evaluation, traditional research methods are probably more efficient and suitable.

Internal Concept Critique

Once a few central concepts have been identified, explored, and externalized through simple sketches, prototypes, and low-tech mock-ups, there is a need to examine the strength of the chosen concepts before moving on to a more formalized design. In this phase, it is important to relate the design and its underlying concepts to the established theoretical foundation. The success of this phase relies on the identification and establishment of (a) the uniqueness of the chosen core concepts and (b) to what extent the concepts relate to existing theory, and (c) how well these concepts can be clearly expressed in a concrete design.

Design of Artifacts. In this phase, the essential design concept should be carved out and expressed in a concrete artifact. The artifact has to be a concrete manifested composition that incorporates the concept design as a "whole." This means that the development of the actual manifestation becomes part of the design process and of the theoretical development. This is where concept-driven design research relates theoretical development with the skilled craft of making artifacts that manifest the full meaning of a theoretical concept—the process of artifact crafting is therefore also a process of theorizing.

External Design Critique. Traditionally, testing is the process that follows design and development. In most approaches, testing includes a question of *user acceptance* (as is the case in usability testing from the perspective of user-centered design, see Figure 1). In concept-driven design research, testing means instead that the conceptual design is exposed to a public and critiqued as a composition. It is an evaluation of the idea, the concept, and the inherent theoretical principles that the design manifests. In its ultimate form, this critique is an intellectual process of validating the conceptual and theoretical assumptions embodied in the manifested design.

Concept Revisited. Because the exposing of the artifact will lead to critique, the concept usually has to be revisited and revised. Maybe the basic idea is flawed, maybe the composition is not appropriate or suitable, or maybe the components are not sufficient. The challenge working with concept design is that there is almost impossible to isolate the variables and factors responsible for the reactions that the concept received.

Concept Contextualization. When the final concept has been defined, expressed in a prototype/artifact, and validated though a process of both internal and external critique, an important step remains: the work of relating and valuing this new concept against the current body of concepts and theory in the field, to position it against similar concepts, and to show how it contributes to previous work. This task of carving out the research contribution is sometimes tricky because it is important to simultaneously show the uniqueness of the new concept and at the same time be clear about how it relates to already established concepts which sometimes are "hidden" in other related prototype systems. Although the previous steps are important in order to conduct clear-cut concept design, this final step is crucial for the knowledge-gaining process of conducting concept-driven interaction design research and an important step in order to contribute to the current body of knowledge.

Taken together, these methodological considerations present a frame for the concept-driven research process. Because many of these considerations are well known to experienced designers and researchers, we want to stress two crucial aspects. First, to the experienced *designer*, the strong focus on theory and on relating concepts to the existing body of knowledge in the field might be less recognized. Second, to the experienced *researcher*, the strong focus on the need for and value of the detailed crafting of the artifact in its concrete form might be less recognized. Together these two aspects, the *theoretical grounding* and the *artifact crafting*, are commonly not seen as this tightly related. Nevertheless, in this approach they are closely intertwined and cannot be separated.

3.3. Implications for Interaction Research

Throughout this article we have suggested concept-driven research as a valid approach in interaction design research. We have suggested this approach as a complement to existing research approaches in the field. This approach is focused on identifying and working with innovative concepts that lead to intellectual development through definitions, conceptual constructs, and theories. We have labeled it a new method or approach although we are certain that the approach is already quite common though not recognized as such, within the field of HCI and interaction design research. We believe, however, that making this approach more explicit will allow us to reflect on how we as a research community should and could carry out concept-driven design research in the best way, and how we could further elaborate upon this approach to arrive at more developed interaction design theories.

In our own work in HCI and interaction design research, we have noticed a gap between practical, straightforward guideline approaches and "how-to" checklists, on one hand and, on the other, grand theories, usually "imported" from disciplines in the social and behavioral sciences. Some researchers argue that neither of these two forms of knowledge, the *hands-on* or the *grand theory*, are well suited for informing practice and are questioning their possible positive influence of the design of digital artifacts (Rogers, 2004; Stolterman, 2008). We think that the proposed concept-driven design approach could serve as a *mediator* between these two forms of knowledge. In the establishment of a focal design concept, it has to be related to grand theories within which similar and "competing" concepts are used. We believe that this process allows a creation of midrange theories (Rudström, 2005), conceptual constructs, and interaction theories that are both intellectually interesting and applicable to interaction design.

To arrive at this stage in interaction research we argue that the next step from concept-driven interaction research would be to focus on *conceptual constructs*. As a verb, the notion of construct is to form (an idea or theory) by bringing together various conceptual elements, typically over a period of time. As a noun, a construct refers to an idea or theory containing various conceptual elements, typically one considered to be subjective and not based on empirical evidence. Further, a construct can also refer to "an intellectual or logical construction," according to Webster's dictionary (1988, p. 489). As such, the development of conceptual constructs could here include the research methods applied, that is, the *process* of interaction design research, as well as the prototypes, that is, the *products* constructed according to a certain concept. The notion of constructs could also be seen as a *midway* between a single concept and an all-encompassing theory. Instead of being intimidated by the expectations of building theory, interaction researchers can, through the concept-driven approach, focus on combining individual theoretical concepts into constructs that bring together earlier findings in new concepts and artifacts.

The approach proposed in this article is about the communication of theoretical design constructs through the design of digital artifacts. From a research point of view, we are convinced that this approach enables a more systematic exploration of the field and that it will contribute to the building of a cumulative tradition within the field, in-

stead of just pushing the technological envelope (Whittaker et al., 2000). Furthermore, instead of focusing on prototype-specific differences in terms of features, technical platforms, and application domains, the concept-driven approach focuses on the conceptual foundation, thus making it easier to identify, contrast, and compare different concept artifacts. Through this approach, a part of the prototype design work itself becomes a theoretical and philosophical process and not solely a matter of practical nature. Such an approach should enable a more intellectual and academic debate around prototype and paradigmatic systems and exemplary artifacts, allowing discussions that go beyond specific functions, look-and-feel, and whether users would like to use the system.

In contrast to the typical design-oriented approach currently used in HCI, the concept-driven approach is both *design centered* and *theory oriented*. We believe that this will also bring the field of HCI closer to other traditional design disciplines, such as architecture and product design. Such a turn will increase the source of knowledge and history upon which researchers in HCI could draw.

If we revisit our model (as proposed in Figure 1) we can now see how this process is both *design centered* and *theory oriented*. In terms of *a design-centered* process we can, in Figure 2, see a *task-artifact cycle* (Carroll & Rosson, 1992), or a cycle that starts in a use-situation followed by some research activities directed towards the design of a prototype, that is, a concept design, which then leads back to a new, and we hope improved, use situation that again can serve as a point of departure for another round in this design-centered cycle (Cycle 2 in Figure 2).

Further, on, we can also see a *theory-oriented cycle* in this model (Cycle 1, Figure 2), in which the creation of prototypes serve as input to the development of interaction theories. Here, the important implication from this model is that the design and realization of concrete and particular concept designs becomes a necessary and completely integrated part of the process of creating new or developed interaction theories. However, what we find most important in this model is not these two separated cycles but the fact that these two cycles are highly intertwined and, in both practice and theory, completely inseparable from each other.

FIGURE 2. Proposed research process revisited: A design-centered and theory-oriented research approach.
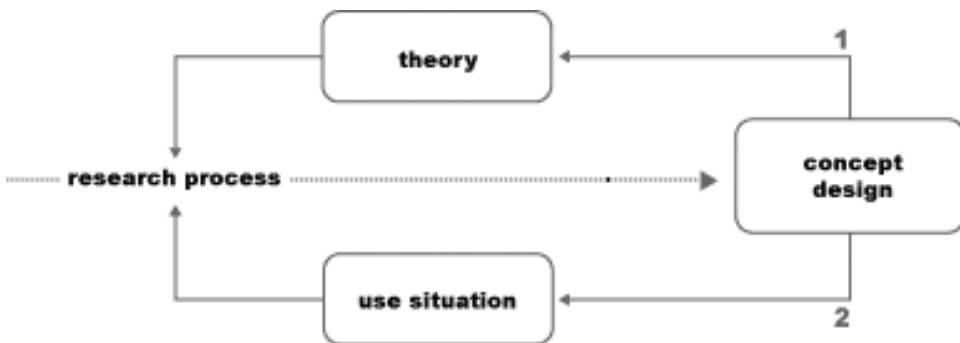
As a closing remark, we believe that good concept designs are extremely difficult to create. To be successful, a concept design must clearly express the qualities of a specific concept while mutually excluding other related concepts; it must also stand out as a unique new contribution to the field while being simple enough for others to refer to and develop variations around. We think that creating such designs requires (a) good analytical skills to carve out core and recognizable important new concepts; (b) a good understanding of digital technology as a design material; (c) a good understanding of users, use contexts, and use; and finally (d) some amount of artistic skill to express a general concept in one compositional design.

Further on, to make use of these designs from a research perspective we must not only move from particular *concept designs* to *conceptual constructs*, but also, as a field of research, do this together and to *co-construct* our knowledge and move toward a situation where it is possible to collectively build more general theories about interaction and how it can be manifested in digital artifacts.

4. CONCLUSIONS

In this article, we have introduced concept-driven interaction design research as a complementary approach to more traditional and well-known user-centered interaction design approaches. Moving beyond a user's situation and particular needs, we have taken the need for theoretically explorative design projects as an explicit starting point for our methodological exploration. One point of departure is the observation that researchers within the area of HCI and interaction design have a tradition of designing "proof-of-concept" designs or concept prototypes. We have illustrated the value of interaction concept designs to the research community by exemplifying this implicit tradition through short descriptions of three well-known and well-cited concept designs—DynaBook, Active Badges, and Bricks.

We have also demonstrated how a concept-driven approach can coexist and be integrated with common user-centered approaches to interaction design through the development of a model that makes explicit the existing cycle of prototyping, theory development, and user studies. Through our work with the formulation of a concept-driven approach to interaction design research, we have also formulated a set of basic principles that could constitute as a foundation for concept-driven interaction research. We have also considered and described the methodological implications given these principles. For the field of HCI and interaction design research we find this an important point of departure for taking the next step toward the construction and verification of theoretical constructs that can inform and guide future-design research projects on novel interaction technologies.

As a concluding remark, we are convinced that a better understanding of concept-driven interaction design as a valid research approach is valuable for researchers who want to contribute to the current body of knowledge in design-oriented

fields like HCI through the design, implementation, and evaluation of prototype systems. A body of knowledge, as an abstract thought system, *can* be expanded through the development of concepts and artifacts. Although philosophy might be one approach to do this, this article has illustrated how concept explorations can be done through practical, and well structured, concept-driven interaction design studies.

NOTES

Authors' Present Addresses. Eric Stolterman, Professor and Director of Human-Computer Interaction Design, School of Informatics, Indiana University, 901 East Tenth Street, Bloomington, IN 47408. E-mail: estolter@indiana.edu. Mikael Wiberg, Associate Professor, Department of Informatics & Umeå Institute of Design, Umeå University, SE-901 87 Umeå, Sweden. E-mail: mikael.wiberg@informatik.umu.se.

REFERENCES

Bardzell, J. (2009). Interaction criticism and aesthetics. *Proceedings of ACM CHI '09 Conference on Human Factors in Computing Systems.* New York: ACM.

Bardzell, J., & Bardzell, S. (2008). Interaction criticism: A proposal and framework for a new discipline of HCI. *Proceedings of ACM CHI '08 Conference on Human Factors in Computing Systems.* New York: ACM.

Benyon, D., Turner, S., & Turner, P. (2004). *Designing Interactive Systems—People, activities, contexts, technologies.* Essex, UK: Addison-Wesley.

Burns, C., Dishman, E., Verplank, B., & Lassiter, B. (1994). Actors, hair-dos and videotape: Informance design; using performance techniques in multi-disciplinary, observation based design. *Proceedings of the CHI'94 Conference Companion on Human Factors in Computing Systems.* New York: ACM.

Bødker, S., & Madsen, K. (1998). Context: An active choice in usability work. *interactions, 5,* 17–25..

Carroll, J. M. (Ed.). (2003). *HCI models, theories, and frameworks toward a multidisciplinary science.* San Francisco, CA: Morgan Kaufmann.

Carroll, J. M., & Kellogg, W. A. (1989). Artifact as theory-nexus: Hermeneutics meets theory-based design. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: Wings for the Mind CHI '89.* New York: ACM

Carroll, J. M., & Rosson, M. B. (1992). Getting around the task-artifact cycle: how to make claims and design by scenario. *ACM Transactions on Information Systems, 10,* 181–212.

Dourish, P. (2001). *Where the action is. The foundations of embodied interaction.* Cambridge, MA: MIT Press.

Dubin, R. (1976). Theory building in applied areas. In M. D. Dunnette (Ed.), *Handbook of industrial and organizational psychology* (pp. 17–39). Chicago: Rand McNally.

Fällman, D. (2003). Design-oriented human-computer interaction. *CHI '03: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. New York: ACM.

Fitzmaurice, G. W., Ishii, H., & Buxton, W. (1995). Bricks: Laying the foundations for graspable user interfaces. *Proceedings of the CHI'95, SIGCHI Conference on Human Factors in Computing Systems*. New York: ACM.

Gaver, B., & Martin, H. (2000). Alternatives: Exploring information appliances through conceptual design proposals. *CHI '00: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. New York: ACM.

Grove, P. B., ed. (1988). *Webster's Third New International Dictionary of the English Language, Unabridged*. Springfield, MA: Merriam.

Hilliges, O., Sandor, C., & Klinker, G. (2006). Interactive prototyping for ubiquitous augmented reality user interfaces. *Proceedings of the IUI '06 11th International Conference on Intelligent User Interfaces*. New York: ACM.

Holmquist, L. E., Falk, J., & Wigström, J. (1999). Supporting group collaboration with inter-personal awareness devices. *Journal of Personal Technologies, 3,* 13–21.

Ishii, H., & Ullmer, B. (1997). Tangible bits: Towards seamless interfaces between people, bits and atoms. *CHI '97 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. New York: ACM.

Ishii, H. (2000). Retrieved February 12, 2007 from http://web.media.mit.edu/~jaylee/project-archive.html

Janlert, L-E., & Stolterman, E. (1997). The character of things. *Design Studies, 18,* 297–314.

Jensen, J., & Skov, M. (2005). A review of research methods in children's technology design. *Proceeding of the IDC '05 Conference on Interaction Design and Children*. New York: ACM.

Kaptelinin, V., & Nardi, B. (2006). *Acting with technology: Activity theory and interaction design*. Cambridge, MA: MIT Press.

Kay, A. (1972). "*A personal computer for children of all ages.*" Palo Alto, CA: Xerox Palo Alto Research Center. Available from http://www.mprove.de/diplom/gui/ Kay72a.pdf

Kerne, A. (2002). Concept-context-design: A creative model for the development of interactivity. *Proceedings of the 4th Conference on Creativity & Cognition*. New York: ACM.

Kuhn, T. S. (1962). *The structure of scientific revolution*. Chicago: University of Chicago Press.

Kujala, S., & Kauppinen, M. (2004). Identifying and selecting users for user-centered design. *Proceedings of the Third Nordic Conference on Human-Computer Interaction, NordiCHI '04*. New York: ACM.

Lakoff, G., & Johnson, M. (1999). *Metaphors we live by*. Chicago: University of Chicago Press.

Lamming, M., & Flynn, M. (1994). "Forget-me-not" intimate computing in support of human memory. *Proceedings of FRIEND 21, '94 International Symposium on Next Generation Human Interface*. Meguro Gajoen, Japan.

Lim, Y., Stolterman, E., & Tenenberg, J. (2008). The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. *ACM Transactions on Computer-Human Interaction, 15,* 1–27.

Lund, A. (2003). *Massification of the intangible: An investigation into embodied meaning and information visualization*. Unpublished doctoral dissertation, Informatics, Umeå University, Umeå, Sweden.

Mann, S. (2005). "fl Huge UId streams": Fountains that are keyboards with nozzle spray as keys that give rich tactile feedback and are more expressive and more fun than plastic keys. *Mul-*

timedia '05, Proceedings of the 13th Annual ACM International Conference on Multimedia. New York: ACM.

Mylopoulos, J., Chung, l., & Yu, e. (1999). From object-oriented to goal-oriented requirements analysis. *Communications of the ACM, 42,* 31–37.

Nelson, H., & Stolterman, E. (2003). *The design way—Intentional change in an unpredictable world.* Englewood Cliffs, NJ: Educational Technology Publications.

Pangaro, G., Maynes-Aminzade, D., & Ishii, H. (2002). The actuated workbench: computer-controlled actuation in tabletop tangible interfaces. *Proceedings of the 15th Annual ACM Symposium on User Interface Software and Technology.* New York: ACM.

Pedersen, E., Sokoler, T., & Nelson, L. (2000). PaperButtons: Expanding a tangible user interface. *Proceedings of the Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques.* New York: ACM.

Piper, B., Ratti, C., & Ishii, H. (2002). Illuminating clay: A 3-D tangible interface for landscape analysis. *CHI'02: Proceedings of the SIGCHI conference on Human Factors in Computing Systems.* New York: ACM.

Preece, J., Rogers, Y., & Sharp, H. (2002). *Interaction design.* New York: Wiley and Sons.

Randell, L., & Bolmsjo, G. (2001). Database driven factory simulation: A proof-of-concept demonstrator. *Proceedings of the 33nd Conference on Winter Simulation.* New York: ACM.

Rekimoto, J., Ullmer, B., & Oba, H. (2001). DataTiles: A modular platform for mixed physical and graphical interactions. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* New York: ACM.

Rogers, Y. (2004). New theoretical approaches for human-computer interaction. *Annual Review of Information, Science and Technology, 38,* 87–143.

Rudström, Å. (2005). *Co-construction of hybrid spaces.* Unpublished doctoral dissertation, Stockholm University and SICS, Stockholm, Sweden.

Ryokai, K., Marti, S., & Ishii, H. (2005). Designing the world as your palette. *CHI '05 Proceedings of Human Factors in Computing Systems.* New York: ACM.

Soh, L-K., Jiang, H., & Ansorge, C. (2004). Agent-based cooperative learning: a proof-of-concept experiment. *Proceedings of the 35th SIGCSE Technical symposium on Computer Science Education, 36,* 368–372.

Stolterman, E. (2008). The nature of design practice and implications for interaction design research. *International Journal of Design, 2,* 55–65.

Sutherland, J. W. (1975). *Systems: Analysis, administration and architecture.* New York: Van Nostrand.

Toney, A., Mulley, B., Thomas, B., & Piekarski, W. (2003). Social weight: Designing to minimize the social consequences arising from technology use by the mobile professional. *Personal and Ubiquitous Computing, 7,* 309–320.

Ullmer, B., Ishii, H., & Glas, D. (1998). mediaBlocks: Physical containers, transports and controls for online media. *Proceedings of the 25th Annual Conference on Computer Graphics and Interactive Techniques SIGRAPH'98.* New York: ACM.

Want, R., Hopper, A., Falcão, V., & Gibbons, J. (1992). The active badge location system. *ACM Transactions on Information Systems, 10,* 91–102.

Weick, K. E. (1989). Theory construction as disciplined imagination. *Academy of Management Review, 14,* 516–531.

Weinberg, G., Orth, M., & Russo, P. (2000). The embroidered musical ball: A squeezable instrument for expressive performance. *CHI '00 extended abstracts on Human Factors in Computing Systems.* New York: ACM.

Wellner, P. (1993). Interacting with paper on the DigitalDesk. *Communications of the ACM, 36,* 87–96.

Whittaker, S., Terveen, L., & Nardi, B. (2000). Let's stop pushing the envelope and start addressing it: A reference task agenda for HCI. *Human Computer Interaction, 15,* 75–106.

Wiberg, M. (2003). Explorative engineering: Towards a Scandinavian approach 2.0. *Proceedings of the IRIS 26 Conference*, Porvoo, Finland.

Zimmerman, J., Forlizzi, J., & Evenson, S. (2007) Research through design as a method for interaction design research in HCI. *CHI '07, Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* New York: ACM.