HUMAN TECHNOLOGY

An Interdisciplinary Journal on Humans in ICT Environments ISSN: 1795-6889

www.humantechnology.jyu.fi Volume 5 (1), May 2009, 29–46

COGNITION IS NOT WHAT IT USED TO BE: RECONSIDERING USABILITY FROM AN EMBODIED EMBEDDED COGNITION PERSPECTIVE

Jelle van Dijk
Research Centre for Product Development, Utrecht University of Applied Sciences
and
Faculty of Industrial Design, Eindhoven University of Technology
The Netherlands

Abstract: *Embodied embedded cognition (EEC) has gained support in cognitive science as well as in human–computer interaction (HCI). EEC can be characterized both by its action-centeredness as well as its roots in phenomenology. The phenomenological aspects of EEC could be seen as support for trends in design emphasizing the user experience. Meanwhile, usability issues often are still approached using traditional methods based on cognitivist assumptions. In this paper, I argue for a renewed focus on improving usability from an EEC perspective. I draw mainly on a behavior-oriented interpretation of the theory, the key aspects of which are reviewed. A tentative sketch for an* embodied embedded usability *is proposed, doing justice to the embodied embedded nature of interaction while retaining the goal of developing technology that is easy to use in everyday practice.*

Keywords: *embodied embedded cognition; usability; human–computer interaction.*

INTRODUCTION: THE END OF USABILITY?

In cognitive science (Clark, 1997), as well as in human–computer interaction (HCI; Dourish, 2001), the theoretical framework of *embodied embedded cognition* has gained influence as a serious alternative to cognitivism, the traditional foundation of cognitive science (Fodor, 1983; Newell & Simon, 1972). Embodied embedded cognition (EEC) holds that intelligent behavior is *embodied* in the internal milieu and action possibilities of the body, as well as *embedded* in the structure of the environment. This is often contrasted with the view in which behavior is seen as the result of an internally constructed plan based on a mental representation of the world (Clark, 1997). Cognitivism has been a foundation for usability practice in HCI (Newell & Card, 1985). One might therefore be tempted to believe that an alternative theoretical paradigm, such as EEC, has serious consequences for usability as a practice. As it happens,

URN: NBN:fi:jyu-20094141409

major industries have been changing their focus from "usability engineering" to what is called "user experience design."[1] Consider this quote from a designer's blog:

> User-experience is not like usability—it is about feelings. The aim here is to create happiness. You want people to feel happy before, during and after they have used your product. ... It is a touchy feeling kind of thing. Why, for instance, does an Audi S6 give you a much better user-experience than a Ford Focus? I mean, in terms of usability they are pretty much the same. (Baekdal, 2006)

Such talk is in stark contrast with the aims of traditional usability practice, namely, improving functionality and ease-of-use (Nielsen, 1993). The user experience trend and the rise of EEC as a cognitive theory could be seen as independent developments had it not for the influential work of Paul Dourish (2001). Dourish explains how, based on an embodied interaction perspective, experience should indeed become the grounding concept for interaction design. Yet, a focus on experience, as a consequence of adopting the EEC perspective, is not straightforward. Several traditions can be discerned within the community. For the purposes of this paper, it is important to distinguish between two lines of thought. The first line of thought has its roots in phenomenological philosophy (Heidegger, 1927/1986; Merleau-Ponty, 1962; Verbeek, 2005). It rejects the existence of an objective, external world, favoring instead the metaphysical priority of experience. This is the tradition in which Dourish (2001) can be positioned. Dourish speaks about interaction mainly on the level of phenomenological reflection. He is concerned with the experiences that emerge in the user's mind during interaction with technology. He uses the term *embodiment* to "capture a sense of phenomenological presence" (Dourish, 2001, p. 115). I call this the *phenomenological approach* to embodied cognition (Dourish, 2001; cf. Merleau-Ponty, 1962; Varela, Thompson, & Rosch, 1991). In contrast, a second line of thought within EEC builds on the idea that cognition emerges in action, contingent on direct, ongoing interaction between the brain, body, and local environment. It is a materialist perspective that deals mainly with subconscious behavioral pattern formation. I call this the *behavior-oriented approach* to embodied cognition, paraphrasing Brooks' behavior-based robotics (Brooks, 1991; Clark, 1997). The behavior-oriented approach is central to the argument developed in this paper.

In order to get a feel of the difference between the two approaches, consider the Wigo (Bruns, Keyson, & Hummels, 2008). The Wigo is an interactive object vaguely resembling a pint-size milk bottle (see Figure 1). It is one of the *tangible* media that are currently gaining attention in HCI (Ullmer & Ishii, 2000). Wigo automatically detects patterns in the way you wiggle and roll it in your hand, and then provides haptic feedback on the basis of these patterns. If you feel stressed, this will show in your wiggling and rolling patterns. In turn, Wigo will start to counter your stressed movements with haptic feedback.

Wigo's designers are foremostly interested in the affective experience that the Wigo elicits (Miguel Bruns, personal communication, February 20, 2008). The Wigo is intended to make one conscious of one's own bodily state. One must then consciously decide to take action in order to reduce stress, for example, by taking a walk in the park or signing up for yoga. With the focus on eliciting an embodied experience, Wigo's designers implicitly adhere to the phenomenological approach to embodiment. Their strategy may be very useful, but it is

Figure 1. The Wigo: a tangible interactive device responding to manual activity patterns with haptic feedback. (Image used with permission from Bruns, Keyson, & Hummels, 2008.)

not the only possible design approach that results from taking an EEC perspective. Instead, the behavior-oriented approach offers an important alternative that is not directed at creating experiences at all. Thus, when Dourish writes, "Embodiment does not simply mean physical manifestation. Rather, it means being grounded in and emerging out of everyday, mundane *experience*" (Dourish, 2001, p. 125; emphasis added), the behavior-oriented approach would replace the word *experience* with *actions* or *behavioral patterns*. The behavior-oriented approach does not (necessarily) need the concept of experience to explain user–technology interaction.[2] For example, envision an alternative version of the Wigo: the Wigo-Act, which controls the user's stress-levels directly, without the user even noticing it. The design objective of Wigo-Act would not be to elicit a user experience. It would instead be directed at creating an interactive behavioral coupling, which in turn maintains a desired bodily state. Such a system in principle could bypass conscious experience, not unlike the workings of a common pacemaker. But, unlike a pacemaker, Wigo-Act would not (necessarily) have to be positioned inside the body.

In fact, many of today's common tools elicit comparable effects, effects that may take place largely out of our immediate awareness. Consider the subtle ways in which using keyboard and monitor instead of pencil and paper may affect writing style, or even the content of the writing. Here, the user's experience does little in explaining how the tool influences her behavior. Likewise, the Wigo-Act does not have to be an object in the user's experience for it to work, just like the blind man's cane completely withdraws into the "experiential background" when it is used normally (cf. Merleau-Ponty, 1962). Most importantly, whatever the specific form a Wigo-Act may take, the quality of the interaction would be assessed primarily by its functionality and ease-of-use: Does the product produce the desired behavioral results without serious disturbances?

Reconceptualizing Usability from an EEC Perspective

Is usability practice still possible once EEC has been adopted as a theoretical foundation? This paper argues that accepting EEC as a theoretical framework does not mean rejecting usability as a goal. Even today, many of our tools (software and hardware) continue to create serious obstructions in everyday use. Too often devices do not work as expected, fail to provide the functionality needed, cannot be controlled as intended, or will not give useful feedback. In short, usability is still highly relevant (Landauer, 1995). In this paper, therefore, an EEC-based interpretation of usability is explored that does justice to the embodied, embedded nature of interaction, while at the same time retaining the original behavior-oriented objective of making products easy-to-use in practical contexts. In order to develop this interpretation, I claim the benefit of drawing on the behavior-oriented approach to embodiment.

Outline of the Paper

The remainder of the paper is organized as follows: The next section discusses some of the problems of traditional HCI and usability practice. The section that follows introduces EEC. Three related lines of research are reviewed: (a) the materialist, behavior-oriented view (Brooks, 1991; Chiel & Beer, 1997; Clark, 1997); (b) distributed cognition (Hutchins, 1995; Kirsh & Maglio, 1994) and situated cognition (Suchman, 2007); and (c) phenomenology proper (Dourish, 2001; Heidegger, 1927/1986; Merleau-Ponty, 1962; Varela et al., 1991; Verbeek, 2005). Next, the consequences of these developments for HCI are discussed, working towards an *embodied embedded usability*. The paper closes with a short discussion of the possibility of modeling embodied embedded interactions.

PROBLEMS IN TRADITIONAL USABILITY PRACTICE

The classic usability practice, grounded in the information-processing view of user cognition, aims to identify a set of tasks that the user[3] needs to carry out while using the technology in question in order to reach goals (Nielsen, 1993). Associated with each task is a set of mental representations of the aspects of the world relevant for carrying out the task. On the basis of perceptual input from the world, the user activates the relevant mental representation. On the basis of this representation, the user creates a plan for action that specifies which actions should be carried out and in which order. The actual behavior itself is conceived as the "mere" execution of an otherwise internal cognitive process (Newell & Simon, 1972). According to the vision of Newell and Card (1985), the success of HCI would depend on how well one could formally model this human computational system, based on a thoroughly objective, quantitative measurements of its behavioral output (Newell & Card, 1985).[4] Although the framework has provided a firm basis for a large tradition of HCI practices, there are also various shortcomings associated with the framework, which I will discuss presently.

> *Action Precedes Perception.* In most traditional models, perception is seen as a process prior to action. That is, action is modeled as the consequence of the internal processing of a perceptual input. As Gibson (1979) and others (e.g., Merleau-Ponty, 1962) have shown, perception itself emerges in the context of one's actions. A turn of my head opens up a new world for me to perceive. My running speed creates a correlated optic flow on my retina (Gibson, 1979). Standard computer desktops provide little opportunity for creating such action–perception couplings (Keller, 2005; Wensveen, 2005). Instead, action and perception are often explicitly conceptually

separated, as input to the computer and input to the user, respectively, or command and feedback (Albrechtsen, Andersen, Bødker, & Pejtersen, 2001; Dourish, 2001).

Knowledge is Not in the Head. Furthermore, the purported set of mental representations and computations that models the world quickly grows exponentially large for even the simplest of tasks, leading into problems of search and relevance: How to have access to the relevant knowledge at the right time (Haselager, 1997; van Rooij, 2008)? In contrast, as Don Norman (2002) famously showed, in many practical circumstances representations need not be in the head as internal models at all. People make use of all kinds of externally represented knowledge. This is information that is not stored in the brain but off-loaded onto the environment itself: for example, when one quickly writes down a telephone number on the back of a matchbox. The drawback however is that if the environment is not accessible (if one should lose the matchbox), the knowledge is lost (see Norman, 2002, p. 79). I will return to the embedded nature of knowledge representation when I discuss the framework of distributed cognition in the next section.

Action is Prior to Planning. The plan-like character of the way people carry out tasks has been attacked quite radically by Lucy Suchman, who shows that, in practice, people often use ad hoc, improvisational means to reach goals. Plans are constraining forces that emerge out of the real-time interaction itself, not preconditions for behavior (Suchman, 2007). That is, action is prior to, or at least in parallel with, planning. The procedural character of traditional models, such as in use-case diagrams (Bittner, Spence, & Jacobson, 2003) or hierarchical task analysis (HTA; Diaper & Stanton, 2003), tend to ignore the fact that most of the actual behaviors of users are messy, improvised, and thoroughly pragmatic. People often use serendipitous opportunities available in the here-and-now, which can never be modeled by an HTA (Suchman, 2007).

Tasks are (Bad) Descriptions. The notion of a task itself is in some way problematic, as has been discussed by others as well (e.g., Procter & Williams, 1992). A strong focus on describing activities in terms of tasks might lead one to believe that these tasks actually represent some real underlying cause. The cognitivist model is in part responsible for this belief, since in its strongest form it conceives of behavior as the outcome of internally represented computational procedures (Newell & Simon, 1972). Research shows that the actual causes of the observed behavior often do not correspond to some observer-defined computational procedure at all (Hutchins, 1995; Suchman; 2007; Wakkary & Maestri, 2007). As Randall, Hughes, and Shapiro (1991) state,

> aspects of work do not come conveniently labeled as adhering to one or another task, and in practice activities will spill out promiscuously into each other and fan out into an unending succession of elements which relate more or less vaguely with ramified sets of tasks and subtasks. (p. 4)

Randall et al. (1991, p. 4) conclude that “designing on the basis of these judgments will in the event prove disruptive rather than supportive of work activity.” If this is true for work activity, the problematic nature of task analysis might be even stronger for less constrained activities, such as in the home environment or in the public domain (cf. Wakkary & Maestri, 2007). Tasks might therefore best be seen as observer-dependent, normative descriptions of what users are doing (Blomberg, Giacomi, Mosher, & Swenton-Wall, 1993).

The Context Issue. Following a classical modular line of reasoning, Newell and Card (1985, p. 14) stated, “the human-computer interface is, in fact, a psychologically limited micro-world. Many issues of the wider world ... do not arise.” However, in their everyday practices, people tend to carve up the world into parts that were not foreseen by the design model. The user who reads the password of a sticky note attached to the monitor before manually copying it into a dialog box in a software application conceives of the physical sticky note and the digital dialog box as an integrated whole, part of the same interaction (Jacob, Ishii, Pangaro, & Patten, 2002). Moreover, subtle contextual elements in the global setting do in fact influence user activities in unexpected ways: Context matters (Moran & Dourish, 2001; Norman, 2002).

In conclusion, classical usability practices are confronted with several problems. These problems pertain to difficulties in separating action from perception; defining the knowledge representation, action-plans, and user-tasks; and addressing how to deal with context effects. Interestingly, the theory of EEC emphasizes the way action and perception are coupled, as well as how knowledge may be grounded in the local environment and the bodies’ local action possibilities. EEC therefore may hold the potential to overcome at least part of the problems in traditional usability.[5] I now turn to a more detailed introduction of this alternative theoretical framework.

EMBODIED EMBEDDED COGNITION

This section introduces several research traditions within the general EEC philosophy. It highlights those aspects that are of direct importance to a behavior-oriented reinterpretation of usability in HCI.

Basic Tenets of EEC

EEC rejects the classic internalist character of cognitivism (Clark, 1997; Keijzer, 2001; Thelen & Smith, 1994). Instead, EEC holds that intelligent behavior is an emergent property arising out of situated, historically determined dynamics within a network of interrelated factors (Kelso, 1995; Skarda & Freeman, 1987; Thelen & Smith, 1994). This causal network transcends the brain to include not only the neural processes but also the musculoskeletal constraints of the body, homeostatic variance in the body (with strong influence on the brain’s emotional systems; cf. Damasio, 1994), and, last but not least, the physical and cultural constraints present in the environment (Clark, 1997; Hutchins, 1995).

Materialist Embodied Cognition: Inspiration from Robotics

The materialist version of EEC (Clark, 1997; van Dijk, Kerkhofs, van Rooij, & Haselager, 2008; Haselager, van Dijk, & van Rooij, 2008) draws mainly from work in robotics (Beer, 2008; Brooks, 1991; Chiel & Beer, 1997). Behavior-based robots (Brooks, 1991) show how intelligent behavior arises from the coupling between a creature's body and the physical constraints of its immediate environment. These robots need no internal knowledge representation of the task. In fact, "representations and models simply get in the way" (Brooks, 1991, p. 1). Brooks (p. 1) famously proposed instead to "use the world as its own model." Andy Clark (1997) elaborated on this idea, showing how people go about their daily affairs mostly "on autopilot" (van Dijk et al., 2008), guided by local dynamic couplings. Clark coined the "007-principle": An intelligent agent knows "only as much [it] needs to know in order to get the job done" (Clark, 1997, p. 46). If the environment provides clues for action at the right place and time, there is no need for costly computations over internal representations. Likewise, Don Norman (2002) discussed the related concept of *knowledge in the world*, and how behavior is guided by external constraints, affordances, and natural mappings, often in favor of *knowledge in the head* (Norman, 2002).

EEC emphasizes that cognitive action arises out of a continuous and parallel flow of input and output between organism and environment (Kelso, 1995). It claims that the classic metaphor of discrete message passing is wrong. Perception is not the passing of a message from the environment to the brain, and action is not the passing of a message to the environment (Clancey, 1997). This is an important concept for HCI since the standard metaphor has been precisely that: Users are telling the computer what to do and computers are telling people what state they are in (Abowd & Beale, 1991; Newell & Simon, 1972).

Materialist EEC tries to explain intelligent *behavior* (Clark, 1997), not experience as such. The ad hoc, embedded, autopilot nature underlying the bulk of human behaviors is emphasized. The brain relies on information being locally available as people interact with the environment (Beer, 1997). Conscious, deep thoughts should be seen as an additional control layer upon—and contingent on—more basic situated body–world dynamics (Brooks, 1991, van Dijk et al., 2008; Haselager, et al., 2008). In sum, materialist EEC tells us that much what is usually called intelligent action might in fact be based on local couplings between bodily structure and environmental constraints, not unlike the way less complex organisms operate (cf. Godfrey-Smith, 2002).

Distributed and Situated Cognition: Inspiration from Cultural Studies

A separate line of research originates in sociocultural investigations (Hutchins, 1995; Suchman, 2007; see also Clancey, 1997; Winograd & Flores, 1986). Suchman's situated cognition has explicit phenomenological roots (Dourish, 2001). Based on careful analysis of conversations between users while they collaboratively engaged with machines, Suchman concluded that, in the normal case, our behaviors are not at all caused by internally created plans for action based on mental models of the world. Like in Brooks' robots, in Suchman's account of cognition, action in the world is given priority as an explanatory concept to planning and internal representation. In the normal case, through our actions in the world, plans evolve in an ad hoc, improvised manner. One may, of course, engage in explicit planning activities, but these are, according to the situated cognition approach, the exceptional cases that require effort and are in any case not natural to our normal ways of dealing with the everyday world. As discussed earlier, this may have serious consequences for the traditional method of task analysis.

Hutchins's (1995) distributed cognition is based on ethnographic analyses of behavior and talk aboard a navy ship. Activities such as making a location "fix" on a chart are coordinated achievements of *systems*, consisting of the brains and bodies of several people, as well as the physical tools used. That is, cognitive processes are distributed processes. Hutchins, like Clark (1997) and Clancey (1997), argues that internal representations should not be assumed when this is not necessary for explaining behavior. Moreover, behavior is often not directed at carrying out some task directly. Rather, the user's behavior is geared towards providing the necessary complement to the autonomous workings of external tools, such as charts and tables. In other words, a user does not have to know how the tool works, only how to work the tool. This is precisely what makes tools handy: One can off-load part of the cognitive load onto the environment. Likewise, David Kirsh distinguishes between pragmatic versus epistemic actions (Kirsh & Maglio, 1994; Neth et al., 2007). Pragmatic actions directly contribute to achieving a goal state, whereas epistemic actions reorganize the world in such a way that further action will be less computationally burdening. Taking out a pen and paper would be an epistemic action that makes a hard calculation less difficult, because what one needs to know in order to do a calculation on paper is less complex than what one needs to know in order to do the calculation in the head (Wilson & Clark, 2008). Again, we see a correspondence to the way Donald Norman (2002) showed how people not only use, but also create, knowledge in the world, such as remembering to take something needed outside the home by putting it near the door so it will be stumbled over as one is leaving.

Situated and distributed cognition often deal with the user's intentions and (explicit) thoughts.[6] This is understandable, since conversation analysis is based on statements in natural language made by people about themselves and their environments. The focus is therefore somewhat different from the robot-inspired models of behavioral dynamics discussed earlier; it also does not stress the idea of embodiment. Yet, when the question concerns how intelligent behavior comes about, both lines of research are consistent in their emphasis on the embeddedness of cognitive processes.

Embodied Experience: Inspiration from Phenomenology

While phenomenology is considered to be the prime philosophy of experience, important lessons nevertheless can be drawn from how users and technology interact behaviorally. Consider Heidegger's famous example of the carpenter who, involved in his hammering, is not directed at the hammer but rather at the work he is producing through the hammer (Heidegger, 1927/1986, p. 69). The hammer is seamlessly integrated into the carpenter's activities, and thus is "withdrawn" (Heidegger, 1927/1986; see also Dourish, 2001; Dreyfus, 1990; Verbeek, 2005). The product is said to be "ready-to-hand" (*zuhanden*; Heidegger, 1927/1986, p. 69). Another example in this regard concerns the blind man who reports sensing the pavement directly with the tip of his cane, without explicitly interacting with the cane itself (Merleau-Ponty, 1962, p. 165). Now, when the cane becomes wet and slippery, the blind man becomes aware of the grip of his hand on the cane, turning his focus toward the cane and not the pavement. Heidegger would state the cane is now "present-at-hand" (*vorhanden*): an explicit object to be inspected (Heidegger, 1927/1986, p. 73).[7] Note that many tools work satisfactory precisely when they are ready-to-hand, managing the interaction between user and environment in the background. The tool itself is however withdrawn, that is, it is not at all present in one's experience. In contrast, when a product is present-at-hand, meaning when it comes back into one's consciousness, open to reflection, it often does so because of a problem. Fine tools operate much like a well-mannered butler: discretely, effectively, and reliably present in the background, but not drawing explicit attention.

A related view is that of Varela's *embodied mind* (Varela et al., 1991), rooted in the works of Merleau-Ponty (1962). Varela's biologically inspired work is based on the premise that the main objective of organisms is to maintain themselves. In this continuous struggle, the niche that the organism inhabits is not formed independently from the creature's own behavioral and evolutionary history. Organisms "make a living" based on their sensory capacities and behavioral repertoire, creating at the same time their niche, or what Uexkull has called an *umwelt* (Haselager et al., 2008; von Uexkull, 1934; Ziemke & Sharkey, 2001). The organism, therefore, enacts not only itself but also its world. Selecting an appropriate action is taking place in an environment with which the organism already has an intimate relationship. In line with the distributed cognition thesis, this means that it is impossible to draw a strict line between the user and the technology.

EMBODIED EMBEDDED USABILITY

In this section, I take the first steps towards describing an interpretation of usability that is based on EEC. This interpretation is nonetheless oriented toward user behavior, with the principle objective to improve functionality and ease-of-use.

User Cognition

In the EEC view, users generally do not hold internal representations of the task environment, nor do they plan their actions internally before executing them. From the materialist perspective, it was determined that autopilot behavior often comes before deep thought and the workings of mental representations. Emergent behavior depends heavily on the available knowledge in the world (Clark, 1997; Norman, 2002). Many tangible interaction designs (Hornecker & Buur, 2006; Ullmer & Ishii, 2000) make use of this principle. As an illustration, consider just one example, the design of a video recorder power outlet by Djajadiningrat, Wensveen, Frens, and Overbeeke (2004). Figure 2 shows how manipulating the physical form of a power-outlet creates a *natural mapping* (Norman, 2002) between the user's actions and the resulting effects on the system. By turning the knob, the pattern of lines can be made to either continue smoothly, suggesting that electrical current can flow through, signaling that the machine is on. Or, the line pattern can be broken, which suggests blocking the flow of electrical current (as if making a dam), thereby turning the machine off. The tangible form thus creates an environmentally embedded representation of the electronic state (power on or off).

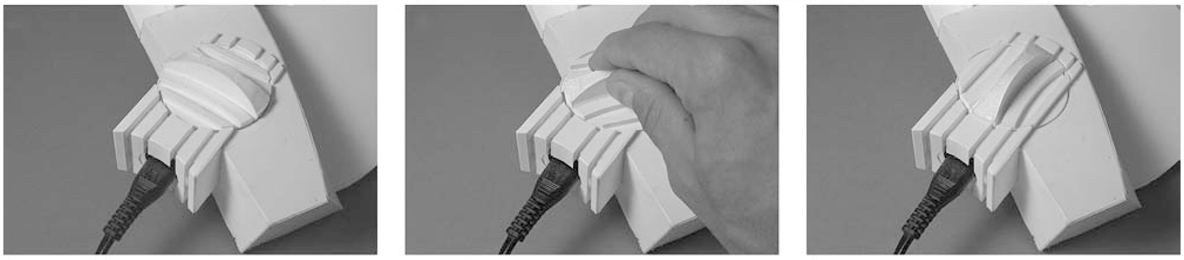

Figure 2. A tangible power-outlet, in the off position (left), being turned on (middle) and in the on position (right). (Images from Djajadiningrat, Wensveen, Frens, & Overbeeke, 2004; used with permission.)

Consider that the meaning of common LED-signals on today's machines has to be actively learned and remembered, since their visual form connects purely arbitrarily, not intrinsically, to the meanings they encode. One realizes this whenever one is in doubt on whether the flashing red light of a DVD player means that the system is off, or in stand-by mode, or perhaps demanding battery charge, or any other arbitrary meaning that the designer decided upon. The literal form of a red light presents no intrinsic bias towards one or the other optional meanings. In contrast, as in the power-outlet discussed above, the on/off state of the machine does not have to be remembered, since it is readily available for visual inspection. Nor is this state transferred from the system to the user in the form of an arbitrary symbolic relation. Instead, using natural, tangible mappings, the state of the machine relies on intuitive perceptual affordances.

One of the drawbacks of a reliance on embedded structure is, of course, that people are quickly confused or frustrated when this structure turns out not to be present at the right time and place (Norman, 2002). One challenge for the design of computational devices is precisely to overcome that problem, and let computing power and network technology create environments where information is externally available precisely at the locations and times when it is needed by a user who is operating in autopilot mode. Current developments in mobile and context-aware systems are investigating this problem (e.g., Steen, van Eijk, de Koning, & Reitsema, 2009; Streefkerk, van Esch-Bussemakers, & Neerincx, 2008).

Interaction

EEC implies that, in our everyday interactions, there needs to be no explicit message passing from human to machine and back. People and technologies interact much more directly, in analog ways, grounded in the way their bodies interact, situated in the physical environment. Even cognitive interaction is in many ways very much like dynamically steering a bicycle (Dreyfus & Dreyfus, 1990). The appropriate metaphor is not so much message passing as it is "structural coupling" (Chiel & Beer, 1997). In this view, interaction emerges as a self-organizing process within sets of constraints (Kelso, 1995). Hence, designers might be better off creating such constraints (Norman, 2002), rather than attempting to specify (by means of procedural models) how the interaction should unfold. Several attempts have been made at tapping into the low-level body–world couplings more directly (see e.g., Hummels & Overbeeke, 2008; Ishii et al., 2004; Underkoffler & Ishii, 1998). The current popularity of the commercially available Wii controller has given rise to interesting new strategies for interaction using the whole of the body.[8]

What the User Does

People act on improvisation, guided by local, ad hoc opportunities (Suchman, 2007).[9] One of the consequences is that abstract task definitions do not necessarily map onto the actual dynamic structure that determines the user's behavior in situ (Suchman, 2007). Users may temporarily suspend tasks, or even drop certain goals altogether, if the effort needed for achieving them turns out to be outweighed by other emerging opportunities for action (Haselager, 2004). Although a rough description of a task may be very useful in defining the design problem, designers must not forget that task descriptions are ad hoc, loose descriptions, in which both the desired behavior under investigation as well as elements from the observer-dependent perspective are fused (Blomberg et al., 1993). Users need to be able to act epistemically (Kirsh & Maglio, 1994), creating their own environmental "scaffolds" (Clark, 1997) that in turn serve as useful external support for the unfolding cognitive process. One intriguing example of this is presented in Block, Haller, Gellersen, Gutwin, and Billinghurst (2008), who developed the means for users to create for themselves physical interaction controls on the fly, to be used instantly as interface elements for computer software. Some of these personal buttons might only serve a purpose for a particular user in a particular context; they would never have been developed on the basis of generic task analyses. Yet, such buttons can be highly functional and increase usability, that is, for that user in that context.

The (Designed) Environment

As discussed earlier, many tools operate best when ready-to-hand (Heidegger, 1927/1986). Whenever, for example, my mobile phone becomes present-at-hand, it is primarily when some problem occurs or when the thing requires my explicit attention in order to determine how I can get it to do what I want it to do. This is a case of low usability, where, in Norman's terms, the *gulf of execution* (i.e., the gap between the intention to make something happen and knowing what action to take in order to do so) is large (Norman, 2002). Designers do not always acknowledge the users' desire for a smooth, mindless, ready-to-hand relation with their surrounding technologies, perhaps because, for designers, the product is almost always present-at-hand: It is, after all, the explicit focus of their attention.

More generally, however, people are not passive consumers of fixed environments. Instead, they bring forth a world in which to maintain themselves (Varela et al., 1991). Traditionally, the usability of a device is seen as the property of an external object people need to address. Using a product is like solving a problem, and if the problem becomes too complex, usability is low (Norman, 2002). Following Varela et al. (1991), we can understand how technology, once it is integrated into one's practice (i.e., is ready-to-hand), becomes a genuine part of the user. If we conceive of devices as coming to function as an extension of the body (Merleau-Ponty, 1962), usability becomes an issue of internal harmonization between body parts, rather than something that happens between two systems (i.e., the user and the device). In ubiquitous computing and ambient technologies, we see the same reconceptualization of what we mean by the interface (Dey, Ljungstrand, & Schmidt, 2001). Here, the interface is both everywhere and nowhere (depending on the perspective), distributed as it is in space and time, and mediated by various kinds of physical structures in the environment that connect to all of the sensory-motor channels users have at their disposal (Dey et al., 2001, Weiser, 1994, but see Dourish, 2001, p. 200–203).

DISCUSSION

The fact that Don Norman's (2002) *The Design of Everyday Things*[10] is still heavily quoted and used in classrooms throughout the world already hints at the fact that basic usability is still an issue needing attention, even though significant progress towards more user-friendly systems has been made (Carroll, 1997). As described in this paper, the main difficulties stem from issues concerning the nature of knowledge representation, internal versus external computation, planning versus improvisation, and the role of context. I have discussed the potential virtues of the EEC as a promising alternative theoretical framework for HCI. In this I closely follow Paul Dourish (2001), who has advocated a similar move. In contrast to Dourish, however, the position taken in this paper is less focused on phenomenological experience than on the ways in which people behave with their bodies in the physical world. With this shift in perspective, I hope to be able to connect the insights from EEC more directly to the practical issues of usability that still confront interface designers today.

On User Experience

One might argue that usability is simply a *part* of user experience (Morville, 2008). Indeed, if the aim is to make people happy (Baekdal, 2006), then basic usability issues need to be solved in order to achieve happiness. But a designer/engineer can spend only so much time on any project, and usability has to compete with a multitude of other important themes huddling under the eclectic umbrella of user-experience design (cf. Sharp, Rogers, & Preece, 2007). Moreover, as the discussions of Heidegger's readiness-to-hand and EEC's autopilot behavior suggest, objects with good usability may not enter the user's experience at all. When one wants to design for absorbed, ongoing behavioral user-technology couplings, achieving this or that experience might just not be the relevant design goal.

All of this should not be seen as a plea against experience design, as such. Still, this paper distinguishes between on the one hand, the field of user-experience design, grounded in a phenomenology of experience and, on the other, an embodied usability practice, grounded primarily in a behavior-based version of EEC. I have made this distinction because it might otherwise be assumed all to quickly that once one adopts the EEC framework, the only option left is to start designing for experience, thereby abandoning usability as a goal altogether. On the contrary, an embodied embedded usability aims to untangle the various ways in which local constraints and affordances, history-of-use, epistemic actions, and ad hoc plan formation influence the basic autopilot-style behavioral couplings between users and technology.

On Formal Models

An issue left untouched until now is the question of whether (and, if so, how) it would be possible to formally model embodied interactions between users and technologies. Computer science has a special relation to formal models because, in a way, modeling is what defines the field. The possibility of abstract explanatory models of the observed behavior has been one of the main strengths of the information-processing account, also in HCI (Carroll, 1997; Fodor, 1983; Newell & Card, 1985). Some of the EEC research described above is actually sympathetic to an information-processing interpretation, albeit one that flexibly reaches out into the environment (Hollan, Hutchins, & Kirsh, 2000; Hutchins, 1995). However, there also have been various criticisms pertaining to the difficulty of modeling user behavior, precisely because it is embodied and embedded in nature. Consider this quote:

> Human behaviour ... is complex … subject to a broad range of influences ... poorly defined, hard to predict and highly contingent. ... As such it is impossible to capture and represent human social behaviour formally by the kinds of quantitative methods of mainstream HCI. (Procter & Williams, 1992, p. 3)

EEC seems at odds with the idea of formal models. As Dourish (2001, p. 189) states, "Embodiment is about … the peculiar rather than the abstract ... practice rather than theory, directness rather than disconnection." It would seem a daunting task indeed to create a formal model of something that seems to be just about everything a model is not (i.e., given that models are disembodied, abstract, theoretical, disconnected). In fact, in behavior-based robotics, much research is based on physical simulations, where the robot itself *is* the model (Brooks, 2002). We can see the same case-based strategy in tangible interaction design (Djajadiningrat et al., 2004).

Another strategy is to describe the behavioral dynamics of the system using the vocabulary of nonlinear dynamical systems (i.e., attractor state spaces, control parameters, order parameters, initial and boundary conditions; see Beer, 1997). Analogously, one could conceive of HCI research in which one does not define tasks but rather task spaces: systems of task-related variables in which certain goal-directed behaviors are likely to emerge in a self-organizing way. However, dynamical systems models (Beer, 2008) are a long way from being easily applicable to HCI in any practical sense (Neth et al., 2007).

In conclusion, taking embodied interaction seriously means asking the complex question of how to understand its workings, without losing "it" at the same time within a disembodying transformation. One speculative option is whether a participatory design process (Schuler & Namioka, 1993), in which users function as active participants in the design process,[11] could provide a loophole by which abstract models are bypassed altogether. In such a participatory set-up, users, designers, and design environments (prototypes, sketches, mock-ups) interact closely, on multiple iterations. The evolving product is always presented in a tangible form so as to be able to interact with it and make changes on it in an active, embodied way (Buxton, 2007). User and technology can thus be said to coevolve (Carroll, Chin, Rosson, & Neale, 2000), a process that, as a design strategy, would itself be embodied and embedded, reminiscent of Varela's *bringing forth*, or *enacting*, a world (Varela et al., 1991).

CONCLUSION

Once the design community accepts EEC as a theoretical foundation for HCI, some might feel that this necessarily entails a design for experience. Perhaps this is due to the explicit coupling of HCI to a phenomenological interpretation of EEC, most notably by Dourish (2001). The result is that user-experience designers are able to draw from the recent trends in embodied theorizing, while those interested in “good-old-fashioned” usability are dependent on traditional methods and principles. Meanwhile, many of today’s interfaces are still not easy to use, and so improving usability is still a relevant goal. This has nothing to do with user experience per se. The main claim of this paper is that EEC can be seen as a theory about behavior and, as such, it has important things to say about how to conceptualize the behavior of users that are in the process of forming structural couplings with their technological environments. This, in turn, opens the way to an embodied embedded usability practice. It is presently an open question whether it is possible, or even necessary, to formally model embodied embedded couplings as part of a design project. In sum, this paper has presented a tentative sketch for an embodied embedded usability, doing justice to embodied practices without abandoning the original question: How to make technologies functional and easy-to-use in the everyday world.

ENDNOTES

1. See, for example, IBM’s website (https://www-306.ibm.com/software/ucd/), as well as popular sources on user experience design (UXD), such as Peter Morville (http://semanticstudios.com/) and Jesse James Garrett (http://blog.jjg.net/).
2. This paper remains agnostic with respect to the question of whether and how conscious experience may affect ongoing interactions between user and technology.
3. In the remainder of this paper, I use the term *user*, simply because there seems to be no satisfactory alternative.
4. Their radical thesis was attacked by Carroll (1997).
5. Many of these problems are also addressed in activity theory, which grew out of an altogether different (i.e., Soviet psychology) tradition (Bødker, 1991). Although EEC is generally more focused at subpersonal explanations of cognitive processes and activity theory has a stronger focus on social settings and practices, they share many of the conclusions described in this section (e.g., Bødker, 1991).
6. Note that the field also explicitly discusses social and cultural embeddedness, which I leave unaddressed in this paper. See Dourish (2001) and Clancey (1997) for extensive accounts.
7. Heidegger’s (1927/1986) language is dense and full of original terms he felt he needed to use in order to say precisely what he wanted. The original language regarding the ready-to-hand mode of the hammer showing up in the skilled carpenter’s activity is “*Das Hämmerns selbst entdeckt die spezifische 'Handlichkeit' des Hammers. Die Seinsart von Zeug, in der es sich von ihm selbst her offenbart, nennen wir die Zuhandenheit*” (p. 69). Here, the word *Zeug* is translated by Dreyfus (1990) as equipment, to be placed in contrast to the kinds of things we usually call objects in our scientific mode of understanding, since the mode of being of equipment can only be understood as an “in order to” (an affordance, as it where; cf. Gibson, 1979), that is, linked to other equipment having a bearing on each other in a referential whole (Dreyfus, 1990). Sometimes interacting with the world leads to conflict, which then leads to another mode of being called present-at-hand: “*Das nächstzuhandene Seinde kann im Besorgen als unverwendbar, als nicht zugerichtetfür seine bestimmte Verwendung angetroffen werden. ... In solchem Entdecken der Unverwendbarkeit fallt das Zeug auf. Das Auffallen gibt das zuhandene Zeug in einer gewissen Unzuhandenheit. ...* [after which] *Die pure Vorhandenheit meldet sich am Zeug”* (Heidegger, 1927/1986, p. 73).
8. Several intelligent examples of using the Wii, engineered by Johnny Lee, can be found at http://www.wiimoteproject.com/
9. For many intriguing examples of what this amounts to in everyday life, see Suri & IDEO (2005)
10. The book was originally published in 1988 as *The Psychology of Everyday Things.*
11. In practice it is very difficult to really incorporate end users in the design process. The term *participatory design* has been used for various practices in which there is either more or less actual user involvement (Steen, 2008).

REFERENCES

Abowd, G. D., & Beale, R. (1991). Users, systems and interfaces: A unifying framework for interaction. In D. Diaper & N. Hammond (Eds.), *People and Computers VI: Proceedings of the HCI '91* (pp. 73–87). Cambridge, UK: Cambridge University Press.

Albrechtsen, H., Andersen, H. H. K., Bødker, S., & Pejtersen, A. M. (2001). *Affordances in activity theory and cognitive systems engineering.* Roskilde, Denmark: National Laboratory.

Baekdal, T. (2006). The battle between usability versus user-experience. Retrieved March 3, 2009, from http://www.baekdal.com/articles/usability/usabilty-vs-user-experience-battle

Beer, R. D. (1997). The dynamics of adaptive behavior: A research program. *Robotics and Autonomous Systems, 20*, 257–289.

Beer, R. D. (2008). The dynamics of brain-body-environment systems: A status report. In P. Calvo & A. Gomila (Eds.), *Handbook of cognitive science: An embodied approach* (pp. 99–120). Amsterdam: Elsevier.

Bittner, K., & Spence, K., & Jacobson, I. (2003). *Use case modeling.* Reading, MA, USA: Addison-Wesley.

Block, F., Haller, M., Gellersen, H., Gutwin, C., & Billinghurst, M. (2008). VoodooSketch: Extending interactive surfaces with adaptable interface palettes. In *Proceedings of the 2nd International Conference on Tangible and Embedded interaction* (pp. 55–58). New York: ACM.

Blomberg, J., Giacomi, J., Mosher, A., & Swenton-Wall, P. (1993). Ethnographic field methods and their relation to design. In D. Schuler & A. Namioka (Eds.), *Participatory design, principles and practices* (pp. 123–155). Hillsdale, NJ, USA: Erlbaum.

Bødker, S. (1991). *Through the interface: A human activity approach to user interface design*. Hillsdale, NJ, USA: Lawrence Erlbaum Associates.

Brooks, R. A. (1991). Intelligence without representation. *Artificial Intelligence, 47,* 139–159.

Brooks, R. A. (2002). *Flesh and machines*. New York: Pantheon Books.

Bruns, A. M., Keyson, D. V., & Hummels, C. C. M. (2008). Squeeze, rock and roll: Can tangible interaction with affective products produce stress reduction? In *Proceedings of the 2nd International Conference on Tangible and Embedded Interaction* (pp. 105–108). New York: ACM.

Buxton, B. (2007). *Sketching user experiences: Getting the design right and the right design.* San Francisco: Morgan Kaufmann.

Carroll, J. M. (1997). Human computer interaction: Psychology as a science of design. *International Journal of Human-Computer Studies, 46*, 501–522.

Carroll, J. M., Chin, G., Rosson, M. B., & Neale, D. C. (2000). The development of cooperation: Five years of participatory design in the virtual school. In D. Boyarski & W. Kellogg (Eds.), *Proceedings of DIS00: Designing Interactive Systems: Processes, Practices, Methods, & Techniques* (pp. 239–251). New York: Association for Computing Machinery.

Chiel, H. J., & Beer, R. D. (1997). The brain has a body: Adaptive behavior emerges from interactions of nervous system, body and environment. *Trends in Neurosciences, 20*, 553–557.

Clancey, W. J. (1997). *Situated cognition: On human knowledge and computer representation.* Cambridge, MA: Cambridge University Press.

Clark, A. (1997). *Being there: Putting brain, body and world together again.* Cambridge, MA, USA: MIT Press.

Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain.* New York: Putnam.

Dey, A. D., Ljungstrand, P., & Schmidt, A. (2001). Distributed and disappearing user interfaces in ubiquitous computing. In *CHI '01 Extended abstracts on human factors in computing systems* (pp. 487–488). New York: ACM.

Diaper, D., & Stanton, N. (2003). *The handbook of task. Analysis for human–computer interaction*. Mahwah, NJ, USA: Lawrence Erlbaum Associates.

van Dijk, J., Kerkhofs, R., van Rooij, I., & Haselager, W. F. G. (2008). Can there be such a thing as embodied embedded cognitive neuroscience? *Theory & Psychology, 13,* 297–316.

Djajadiningrat, J. P., Wensveen, S. A. G., Frens, J. W., & Overbeeke, C. J. (2004). Tangible products: Redressing the balance between appearance and action. *Personal and Ubiquitous Computing, 8,* 294–309.

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

Dreyfus, H. L. (1990). *Being-in-the-World: A commentary on Heidegger's* Being and Time*, Division I.* Cambridge, MA, USA: MIT Press.

Dreyfus, H., & Dreyfus, S. (1990). Making a mind versus modeling the brain: Artificial intelligence at a branch point. In M. Boden (Ed.), *The philosophy of artificial intelligence* (pp. 309–333). Oxford, UK: Oxford University Press.

Fodor, J. (1983). *The modularity of mind.* Cambridge, MA, USA: MIT Press.

Gibson, J. J. (1979). *The ecological approach to visual perception.* Boston: Houghton Mifflin.

Godfrey-Smith, P. (2002). Environmental complexity and the evolution of cognition. In R. J. Sternberg & J. Kaufman (Eds.), *The evolution of intelligence* (pp. 233–249). Hillsdale, NJ, USA: Lawrence Erlbaum.

Haselager, W. F. G. (1997). *Cognitive science and folk psychology: The right frame of mind.* London: Sage.

Haselager, W. F. G. (2004). O mal estar do representacionismo: sete dores de cabeça da Ciência Cognitiva [The indisposition of representationalism: Seven headaches of cognitive science]. In A. Ferreira, M. E. Q. Gonzalez, & J. G. Coelho (Eds.), *Encontros com as Ciências Cognitivas* (Vol. 4; pp. 105–120). São Paulo, Brazil: Coleção Estudos Cognitivos.

Haselager, W. F. G., van Dijk, J., & van Rooij, I. (2008). A lazy brain? Embodied embedded cognition and cognitive neuroscience. In F. Calvo Garzón & T. Gomila, T (Eds.), *Handbook of embodied cognitive science: An embodied approach* (pp. 273–290). Amsterdam: Elsevier.

Heidegger, M. (1986). *Sein und Zeit* [Being and time]. Tübingen: Max Niemeyer Verlag. (Original work published in 1927)

Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed cognition: Toward a new foundation for human-computer interaction research. *ACM Transactions on Computer-Human Interaction, 7,* 174–196.

Hornecker, E., & Buur, J. (2006). Getting a grip on tangible interaction: A framework on physical space and social interaction. In R. Grinter, T. Rodden, P. Aoki, E. Cutrell, R. Jeffries, & G. Olson (Eds.), *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 437–446.). New York: ACM.

Hummels, C. C. M., & Overbeeke, C. J. (2008). E-scale: Unity of location and time, increasing bandwidth and enhancing physical learning does matter. In *Proceedings of the 2nd International Conference on Tangible and Embedded Interaction* (pp. 173–176). New York: ACM.

Hutchins, E. (1995). *Cognition in the wild.* Cambridge, MA, USA: MIT Press.

Ishii, H., Ratti, C., Piper, B., Wang, Y., Biderman, A., & Ben-Joseph, E. (2004). Bringing clay and sand into digital design: Continuous tangible user interfaces. *BT Technology Journal, 22,* 287–299.

Jacob, R. J., Ishii, H., Pangaro, G., & Patten, J. (2002). A tangible interface for organizing information using a grid. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: Changing Our World, Changing Ourselves* (pp. 339–346). New York: ACM Press.

Keijzer, F. (2001). *Representation and behavior.* Cambridge, MA, USA: MIT Press.

Keller, A. I. (2005). *For inspiration only: Designer interaction with informal collections of visual material* [Doctoral dissertation]. Delft, the Netherlands: Delft University.

Kelso, J. A. S. (1995). *Dynamic patterns: The self-organization of brain and behavior.* Cambridge, MA, USA: MIT Press.

Kirsh, D., & Maglio, P. (1994). On distinguishing epistemic from pragmatic action. *Cognitive Science, 18,* 513–549.

Landauer, T. (1995). *The trouble with computers: Usefulness, usability and productivity.* Cambridge, MA, USA: MIT Press.

Merleau-Ponty, M. (1962). *Phenomenology of perception.* New York: Routledge.

Moran, T. P., & Dourish, P. (2001). Introduction to this special issue on context-aware computing. *Human-Computer Interaction, 16,* 1–8.

Morville, P. (2008). User experience design. Retrieved March 2, 2009, from http://semanticstudios.com/publications/semantics/000029.php

Neth, H., Carlson, R. A., Gray, W. D., Kirlik, A., Kirsh, D., & Payne, S. J. (2007). Immediate interactive behavior: How embodied and embedded cognition uses and changes the world to achieve its goals. In D. S. McNamara & J. G. Trafton (Eds.), *Proceedings of the 29th Annual Conference of the Cognitive Science Society* (pp. 33–34). Nashville, TN, USA: Cognitive Science Society.

Newell, A., & Card, S. K. (1985). The prospects for psychological science in human-computer interaction. *Human-Computer Interaction, 1,* 209–242.

Newell, A., & Simon, H. A. (1972). *Human problem solving.* Englewood Cliffs, NJ, USA: Prentice Hall.

Nielsen, J. (1993). *Usability engineering.* San Francisco: Morgan Kaufmann.

Norman, D. A. (2002). *The design of everyday things.* New York: Basic Books. (Originally published as Norman, D. A. (1988). *The psychology of everyday things.* New York: Basic Books)

Procter, R., & Williams, R. (1992). HCI: Whose problem is it anyway? In J. A. Larson ´& C. Unger (Eds.), *Proceedings of the IFIP Tc2/Wg2.7 Working Conference on Engineering for Human-Computer Interaction* (pp. 385–396). Amsterdam: North-Holland Publishing Cooperation.

Randall, D., Hughes, J., & Shapiro, D. (1991, July). Systems development, the fourth dimension: Perspectives on the social organization of work. Paper presented at the Policy Issues in Systems and Software Development workshop of the SPRU CICT Conference, Brighton, UK.

van Rooij, I. (2008). The tractable cognition thesis. *Cognitive Science, 32,* 939–984.

Schuler, D., & Namioka, A. (Eds.). (1993). *Participatory design: Principles and practices.* Hillsdale, NJ, USA: Lawrence Erlbaum Associates.

Sharp, H., Rogers, Y., & Preece, J. J. (2007). *Interaction design: Beyond human–computer interaction.* New York: John Wiley.

Skarda, C. A., & Freeman,W. J. (1987). How brains make chaos to make sense of the world. *The Behavioral and Brain Sciences, 10,* 161–195.

Steen, M. (2008). High-tech meets end-user. In D. Jemielniak & J. Kociatkiewicz (Eds.), *Management practices in high tech environments* (pp. 75–93). Hershey, PA: IGI Global.

Steen, M., van Eijk, de Koning, N., & Reitsema, E. (2009). A we-centric telecom service for police officers to support communication. In J. Filipe, J. Cordeiro, & J. Cardoso (Eds.), *Lecture Notes in Business Information Processing* (Vol. 12; pp. 357–365). Berlin, Germany: Springer.

Streefkerk, J. W., van Esch-Bussemakers, M. P., & Neerincx, M. A. (2008). Field evaluation of a mobile location-based notification system for police officers. In *Proceedings of the 10th international Conference on Human Computer interaction with Mobile Devices and Services* (pp. 101–108). New York: ACM.

Suchman, L. A. (2007). *Human machine reconfigurations: Plans and situated actions* (2nd ed.). Cambridge UK: Cambridge University Press.

Suri, J. F., & IDEO. (2005). *Thoughtless acts? Observations on intuitive design*. San Francisco: Chronicle Books.

Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action.* Cambridge. MA, USA: MIT Press.

Ullmer, B., & Ishii, H. (2000). Emerging frameworks for tangible user interfaces. *IBM Systems Journal, 39,* 915–931.

Underkoffler, J., & Ishii, H. (1998). Illuminating light: An optical design tool with a luminous-tangible interface. In C. Karat, A. Lund, J. Coutaz, & J. Karat (Eds.), *Conference on Human Factors in Computing Systems* (pp. 542–549). New York: ACM Press/Addison-Wesley Publishing Co.

Varela, F. J., Thompson, E., & Rosch, E. (1991). *The embodied mind*. Cambridge, MA, USA: MIT.

Verbeek, P. P. (2005). *What things do: Philosophical reflections on technology, agency, and design.* University Park, PA, USA: Penn State University Press.

von Uexkull, J. (1934). A stroll through the worlds of animals and men. In C. Schiller (Ed.), *Instinctive behavior: The development of modern concept* (pp. 65–80). New York: International Press.

Wakkary, R., & Maestri, L. (2007). The resourcefulness of everyday design. In *Proceedings of the 6th ACM SIGCHI Conference on Creativity & Cognition* (pp. 163–172). New York: ACM.

Weiser, M. (1994). The world is not a desktop. *interactions*, *1*, 7–8.

Wensveen, S. A. G. (2005). *A tangibility approach to affective interaction* [Doctoral dissertation]. Delft, the Netherlands: Delft University.

Wilson, R. A., & Clark. A. (2008). How to situate cognition: Letting nature take its course. In M. Aydede & P. Robbins (Eds.), *The Cambridge handbook of situated cognition.* Cambridge, UK: Cambridge University Press.

Winograd, T., & Flores, F. (1986). *Understanding computers and cognition: A new foundation for design.* Reading, MA, USA: Addison-Wesley.

Ziemke, T., & Sharkey, N. E. (2001). A stroll through the worlds of robots and animals: Applying Jakob von Uexküll's theory of meaning to adaptive robots and artificial life. *Semiotica*, *134*, 653–694.

Author's Note

The author wants to thank Pim Haselager for discussions and helpful comments on earlier drafts of this paper, especially regarding the writings of Heidegger.

All correspondence should be addressed to

Jelle van Dijk
Research Centre for Product Development
Utrecht University of Applied Sciences
PO Box 182, 3500 AD Utrecht,
The Netherlands
Jelle.vandijk@hu.nl

Human Technology: An Interdisciplinary Journal on Humans in ICT Environments
ISSN 1795-6889
www.humantechnology.jyu.fi