

GROUNDING THE INNOVATION OF FUTURE TECHNOLOGIES

Antti Oulasvirta

Helsinki Institute for Information Technology, Finland

Abstract: *Mobile and ubiquitous technologies can potentially change the role of information and communication technology in human lives. Empirical, human-centered approaches are emerging as an alternative to technology-driven approaches in the innovation of these technologies. Three necessary empirical stages, intertwined with analytical ones and with each informing and grounding the succeeding stages, are analyzed. First, needfinding is utilized to discover societal and individual demands for technology. Second, observational and experimental studies examine the social and cognitive preconditions for interaction. From these two steps, a hypothesis is formulated regarding how technology will change existing practices. Finally, this hypothesis, embodied in the design of a prototype, is tested in a field trial. Four design cases illustrate the value of empirical grounding.*

Keywords: *user-centered design, mobile human-computer interaction, ubiquitous computing, technology innovation, design process, user studies.*

GROUNDING THE INNOVATION OF FUTURE TECHNOLOGIES

Recent advances in hardware and software technologies have led many to believe that we are on the edge of a shift regarding the current information technology frame. Processors, memories, wireless networking, sensors, actuators, power, packing and integration, optoelectronics, and biomaterials have seen rapid increase in efficiency with simultaneous decreases in size. Moore's law (see Schaller, 1997) on the capacity of microchips doubling every 18 months and growing in order of magnitude every 5 years has been more or less accurate for the last 3 decades. Similarly, fixed network transfer capacity is growing in order of magnitude every 3 years, wireless network transfer capacity every 5 to 10 years, and mass storage every 3 years. Significant progress in power consumption is less likely, however. Innovations and breakthroughs in distributed operating environments, ad hoc networking, middleware, and platform technologies have recently begun to add to the software side of the vision. Innovations in input and output technologies are shaping the way as well.

(M. Mäntylä, personal communication, January 5, 2004; Satyanarayanan, 2001; Tennenhouse, 2000; Weiser, 1991).

From a human perspective, these mobile, personal, and ubiquitous technologies are transforming the nature of interaction with computers. Most researchers accept that human-computer interaction (HCI) is shifting from stationary desktop computers towards interaction that takes place in rich use situations “beyond the desktop.” The ubiquitous computing enterprise envisions a world with thousands of computers per user embedded within their everyday environment (Weiser, 1991). The vision builds on the idea that computers adapt to the surrounding use situation, the context. What context concretely entails has important implications for the design of interaction and the user experience. Initially, context was mostly synonymous with location, but was soon extended to cover other aspects as well. For example, wearable computing (Mann, 1996) looks at wearable personal computers able to help us remember and capture our everyday experiences through video and sound recording of our daily contexts. Tangible bits (Ishii & Ullmer, 1997) examines context not as something that had to be reacted to, but as the user’s surroundings that could be augmented with tangible (i.e., “graspable”) computers and as ambient media that display digital information using distraction-free output channels. Context has been a thorny issue in the past, and the debate still continues.

In many other respects as well, the research is currently in an anomalous state. New concepts and new approaches are introduced frequently, and there seems to be no consensus for what and how the new technologies are going to be used, or how to develop them rigorously. To mention a few controversies, some claim that the new era of interaction is going to be more physical, engaging, and tangible, whereas others want future computers to be ambient, disappearing, or even invisible. Some proposals seek to provide resources for spontaneous user-initiated action, whereas some think it should be proactive—anticipating events and acting autonomously without user intervention. Moreover, the tenet “access to information anywhere, any time” has been criticized, and a more relaxed, asynchronous interaction style that leaves more room for reflective cognition has been called for. One might ask if controversy and the richness of approaches is a natural element of progress or an indication of diverged research efforts that cannot systematically tackle the fundamental interaction problems in future human-computer interaction. One situation hinting that the latter might be true is that there are few if any mass consumer products featuring context-aware computing, even after almost 15 years of research (For details, see Oulasvirta, 2004a; Oulasvirta & Salovaara, 2004).

This unfortunate situation stems partly from the lack of empirical work that would help innovators to *ground* their ideas. The design of technological artifacts is essentially a cognitive activity that can be characterized as problem-solving activities undertaken by individuals (Simon, 1969). “In essence, artifacts are implicit psychological hypotheses that are tested through subsequent empirical evaluation” (Ball & Ormerod, 2000, p. 148). Since the 1990s, it has been increasingly clear that the artifactualized hypotheses must be grounded in knowledge about the user, about her practices and about the use contexts (Ehn, 1988; Wixon, Holtzblatt, & Knox, 1990). Designers, therefore, need to assess how technological artifacts can support and transform the understandings about users’ practices. This knowledge can be informative (providing useful research findings), predictive (providing tools to model user behavior), or prescriptive (providing advice regarding how to design or evaluate) (Rogers, 2004). Moreover, hypotheses must be explicated, verbalized, and communicated in

the social practices constituting design processes. Without explication and proper formulation, hypotheses cannot be confirmed, tested, confronted, questioned, or rejected by additional, novel evidence. Put briefly, grounding is as an activity in the design process that explicates hypotheses based on factual, testable knowledge about users' needs and behaviors and use contexts, which results in better design choices.

According to a recent review of mobile HCI research methods, most research is driven by technological motives rather than user-centered principles (Kjeldskov & Graham, 2003). An underlying, albeit false, presumption among technology-driven researchers is that the main problem in research is a technological one, of constructing the apparatus. This is understandable, as in technological breakthroughs such as the invention of the ubiquitous computer the lead researchers tend to be technologists who often lack education in behavioral or social sciences. However, the relevant interaction phenomena are so complex, multidimensional, and dynamic that empirical grounding—that is, truly understanding the needs and uses of technology by users—is necessary.

This paper argues that innovation, development, and evaluation of design ideas cannot be based only on the designer's intuitions but must be grounded in users' actual needs and behaviors. We need to apply social and psychological sciences to understand how technology could qualify a positive change for the users (Oulasvirta, 2004a). The user-centered design tradition serves as a natural starting point for this agenda.

Having said that most innovation of future technologies is technology driven, it is important to see that an alternative approach is slowly emerging. Since the breakthrough years of 1996–97, increasingly more user-oriented researchers have embarked on studying the ubiquitous computer. Socially oriented researchers have started to emphasize the social context and issues in people's practices and everyday conduct. These approaches give special consideration to activities that people engage in and highlight their complex nature (Dourish, 2004). Activity-centered approaches emphasize turntaking in communication between the user and the applications (e.g., Fischer, 2001), and the knowledge of the situated and time-varying natures of the user's needs in daily life (e.g., Greenberg, 2001). This line of research highlights the difficulties that exist in computers making correct inferences about a user's tasks through impoverished sensor information data. Considerations of social issues in ubiquitous computing design include questions such as how to fit computational intelligence into people's routines in an unremarkable manner (e.g., Tolmie, Pycock, Diggins, MacLean & Karsenty, 2002) and how people's patterns of interaction with humans and computers change when computationally augmented artifacts are adopted for use.

Although these considerations raise important points, especially regarding the boundary or preconditions for the acceptance of ubiquitous computing (e.g., alignment of interaction to social practices; Tolmie et al., 2002), they are silent regarding how to innovate use purposes in the first place. Importantly, this gap in research has been recognized in several recent discussions. As another indicator of the turn in the research on future technologies, within the past 4 years or so, more and more stringent criteria have been imposed within HCI literature on publications introducing new mobile or ubiquitous interaction mechanisms. For example, field evaluation with representative users (not researchers themselves) is often required.

TOWARD AN EMPIRICAL FRAMEWORK FOR THE INNOVATION OF FUTURE TECHNOLOGIES

This paper sketches a framework for empirical grounding of innovation of future technologies. Inevitably, such empirical grounding restructures the processes of innovation, development, and evaluation. The value of such approach is justified and several illustrative example design cases are provided.

The foundation of this emerging framework is tied to the tradition of user-centered design in HCI. User-centered design (UCD) has conventionally embraced as its values (a) the role of human needs in directing innovation and design (A. Kankainen, 2003), (b) the importance of understanding users in their natural use contexts (Beyer & Holtzblatt, 1997), and (c) the goal of enhancing people's activities and tasks through technology. However, new directions are seen within UCD as well. Social computing (Schuler, 1994; for an application in ubiquitous computing, see Dryer, Eisbach, & Ark, 1999) emphasizes the embeddedness of technology within social context and also studies the social change it causes. The value-sensitive design approach (Friedman, 1996) adds to the previous ones by emphasizing the role of human values and morals in deciding which features of technology are relevant and worth pursuing in design (e.g., user autonomy).

Three fundamental empirical stages can be distinguished from, yet interweaved with, consequent and necessary analytical stages. They differ in terms of the objective of the research and methods, and the function of expected outcomes. First, empirical research is conducted to discover user needs related to future technologies. In the following analytical stage, user needs are analyzed and selected for further inspection while keeping in mind the capabilities of the intended class of technology. These studies are succeeded by the analytical stage of selecting the studied user groups and the parameters of the use situations. These decisions should be based on how representative or desirable the user group or the use situation is, but in practice issues are posed by access to groups (often the user group comprises easily accessible people, such as other researchers or students) and the limitations of technology.

Second, empirical studies are needed to understand and concretize the use situations related to the user needs. The understanding gathered at empirical stages one and two serves as the basis for articulating hypotheses regarding how technological intervention will introduce a change to the existing human practices. This analytical phase is followed by a one that translates this hypothesis into design and embodies it in a prototype. In the last empirical stage, the hypothesis is tested in a prototype intervention study. The hypothesis is either rejected or retained, the former leading to reformulation of the underlying user needs, and the latter to improving the design and again testing it in a field trial until satisfactory results are obtained.

In Jürgen Habermas' (1971) terms, all three empirical stages are only secondarily hermeneutic in regard to their interest of knowledge, but primarily technical. That is, instead of just describing or explaining user behavior, findings from empirical stages must enable counterfactual thinking—to entertain, predict, and simulate alternative behaviors mediated by technology.

From the perspective of design, three principles are endorsed. First, design is based on the understanding of the social and individual needs and qualities of the use situations. Second, design is an embodiment of a hypothesis regarding how technology will change social practices or communities. Third, design is evaluated by testing the hypothesis in the field.

The rest of the paper is organized according to the three empirical stages. Four design cases are provided to illustrate the ideas.

Stage I: Empirical Studies to Discover User Needs

The first empirical challenge is to discover and articulate what users' motivations and needs could be addressed by a new technology. That makes it much more challenging theoretically at the initial stage.

Corporations have traditionally used market research methods, such as surveys, to investigate needs. Surveys have worked well in quantifying customers' preferences but they cannot really help in discovering new needs that might not come from existing applications. In technologist-driven research, supposed needs are recognized in the personal lives of the researchers or adopted from previous research. In both cases, they do not necessarily generalize to the larger population. Moreover, in both cases, they are not articulated concretely enough to enable design choices.

Discovering motivational needs, *needfinding* for short, is useful for three main reasons. First, human need lasts longer than any specific solution. Second, needs are opportunities for design, not just guesses at the future. Innovation of use potential does not have to depend only on predicting future because a crucial part of that future already exists in the form of human needs. And third, human needs provide a "roadmap" for design (Patnaik & Becker, 1999).

One conceptual basis for needfinding in the future technology innovation context has been suggested by A. Kankainen (2003), who distinguished between two types of human needs: motivational needs and action needs. *Motivational needs* rationalize and motivate taking a certain action in a context. Motivational needs are experienced as emotional and behavioral potentials that are activated by particular situational incentives (see also Atkinson, 1982). For example, the social need of affiliation is activated by the incentive of having an opportunity to please others and gain their approval, which in turn causes the person to want to act in a certain way constituted by that situation, thus an *action need*. Furthermore, it is helpful to elaborate a distinction between two types of motivational needs: basic and quasi-needs. Any given user may harbor a multitude of *basic needs* related to a given HCI situation, some of which are related to regulating bodily homeostasis (physiological needs such as pain avoidance, thirst, hunger, and sex), some to providing psychological nutrients for growth and healthy development (organismic psychological needs such as self-determination, competence, and relatedness), and some preferring some aspects of the environment rather than others (social needs such as achievement, affiliation, intimacy, and power; e.g., Reeve, 2001). *Quasi-needs*, on the other hand, are more ephemeral, situationally induced wants that "create tense energy to engage in behavior capable of reducing the built-up tension" (Reeve, 2001, p. 151). They are not full-blown needs in the same sense as basic needs, but they do affect how we think, feel, and act. For example, the desire for an umbrella in the rain or for money at the store would be considered a quasi-need. Both basic and quasi-needs are instantiated in a given situation where the user eventually wants to perform a certain action that takes him/her closer to satisfying the motivational need.

Motivational needs provide a promising starting point for discovering design opportunities. Needfinding at the individual level can be complemented by looking at societal demands for technology (Oulasvirta, 2004a). In the following case, user needs related to

mobility are presented to illustrate how these needs are found and how they can direct the innovation of new concepts.

Example I: Personal, Social, and Cognitive Needs in Mobility

The aim of A. Kankainen and Oulasvirta (2002) was to discover motivational needs for mobility in public and semipublic urban areas. In order to gather rich data, focus groups, photodiary studies, interviews, and observation studies of 25 urbanites were conducted. The idea in triangulation (using many methods to study the same phenomenon) is to gather both third-person and first-person data to describe what, how, and why the person did something. Situations that participants consider problematic, such as where they fail, where they have to come up with workarounds, or where they are forced to deviate from routine action, provide the bases for discovering motivational needs. Over 1,300 travel episodes (descriptions of a person moving within a city in pursuit of a goal) were analyzed in this manner.

Three classes of needs related to mobility were found. The first class is personal needs. For example, when paying or sharing costs with other people in public places, participants expressed concerns about losing control over their money. And while moving, certain places often trigger memories and opinions that are considered worth preserving. Other needs in this category are finding silence or privacy in the middle of crowd, finding bargains, and expending time by seeking fun and exceptions.

The second class of needs relates to navigation or wayfinding, and these are cognitive in nature. Many participants expressed a need to know and optimize routes. For example, a participant got lost after returning home from picking flowers in an unfamiliar place. Similarly, journalists often received e-mail invitations to events in unknown locations around the city. Reaching the navigation goal in time is considered important, but equally important is having enough time for sidestepping (i.e., unplanned deviations from the planned route). Packing and carrying items received plenty of attention, as they are related to the need to anticipate and prepare for predicted events (e.g., taking an umbrella for a forecasted rain). Other needs are related the ability to combine several sites to one route, finding the shortest route, locating missing objects, and safety (avoiding potentially dangerous areas).

Third, a class of social needs was identified. For example, an amateur theatre group had to decide their new rehearsal schedule, but not all of the group members were present when the decision took place. However, it was decided that the absent members would be informed through a call ring. As it turned out, however, somebody had forgotten to call another, and some of the actors did not show up for the first rehearsal. This reflects a need for awareness of changes in shared schedules. Many situations were observed in which participants had a need to be continuously aware of social surroundings. They often expressed a need to be aware of acquaintances when moving in the city. Some participants also had a need to meet new likeminded people while expending extra time. When such a situation was realized, however, finding something to talk about was difficult. A similar need for discussion topics was also gathered in a situation in which three friends who were waiting in a café skimmed through a newspaper and discussed the headlines. Participants were also curious about events taking place in their environment, eager to share opinions with peers, and expressed needs to shop with a friend, to get an opinion from a friend about a product, or to delight others by dropping into a promising store and buying gifts.

Example II: Needs of Mobile Elderly People

Tiitta (2003) conducted a similar study to discover the needs of elderly people related to mobility and communication. The study revealed that needs for maintaining contacts with family (some participants even had learned to use e-mail and the Internet for this purpose) and with friends met before retirement. They also had more time and the curiosity to get to know their surroundings better and find new places, yet they were often afraid of getting lost or for their safety. They expressed doubt over changes in their environment and wanted to share these opinions, and spent considerable time monitoring their neighborhoods. Aesthetics and nature in the environment were also important. They are able to combine experiences with routine tasks, such as going with friends abroad to shop. While traveling, they reserved extra time to arrive early at the bus stop or station. They appreciated fast, reliable, and quiet transportation, where platforms were not slippery in winter. Traveling alone during the nighttime was considered unpleasant, and they were eager to share their experiences of unsafe areas, practices, or services.

Example III: EventTagger Prototype

The EventTagger prototype is presented here to illustrate how needfinding can inform innovation of product concepts and direct design choices. EventTagger was inspired by observations of and interviews with elderly people who have difficulties in remembering past events and objects (e.g., products), which indirectly hampers their ability for social sharing of experiences and their freedom for mobility. It was hypothesized that by supporting remembering and organizing everyday events elderly people's impaired memory abilities could be improved and their sharing of life events among peers supported. Empowering aging people in their everyday social-cognitive practices is also an important societal demand; it is needed to prevent early solitude and displacement.

EventTagger consists of a small button (see Figure 1), wirelessly connected to a handheld computer kept in a pocket, backpack or handbag. Upon pressing the button, EventTagger "tags the moment" by gathering all information available from the digital and physical environment, including a 15-second audio clip, current calendar of events, time, location (from GPS), and a list of other nearby system users. This information is saved to a log file that can be accessed and edited by the user on the device. The tagged information serves as a retrieval cue that helps the user to later do mental, episodic "time travel" by bringing to mind the to-be-remembered information.

EventTagger attempts to eliminate one important factor, namely poor memory for experiences, that causes isolation and immobility among elderly people. Other factors, of course, exist and they need to be addressed by other means. This case highlights that empirical groundwork provides design ideas that are better justified and motivated than those based on intuition. Needfinding is a promising method that can be used for eliciting design ideas in the early phase of development.

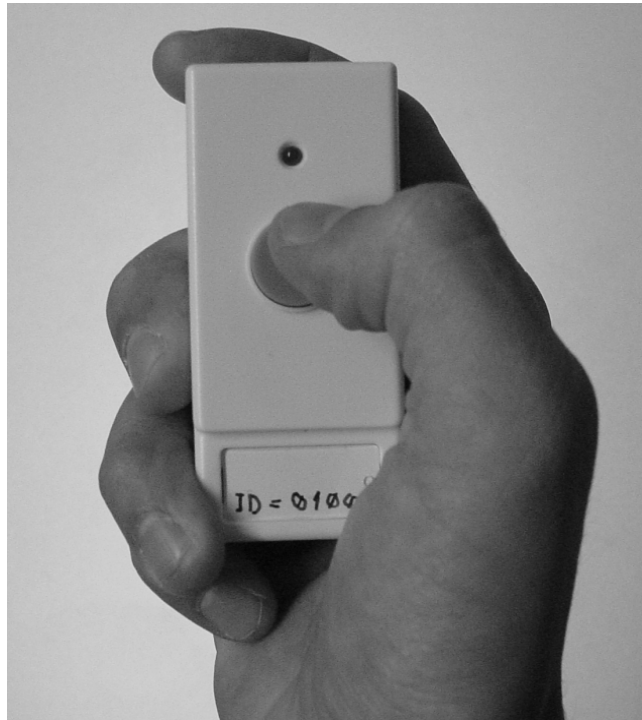


Figure 1. EventTagger is a wireless button that upon pressing sends a signal to the host PDA to gather and record all available context information into a log entry.

Stage II: Empirical Studies of Preconditions for Use

The second challenge is to try to understand the future use situation in which the new technology is going to intervene. The chief methods used include ethnographic (Tamminen, Oulasvirta, Toiskallio, & A. Kankainen, 2004), ethnomethodological (Kurvinen & Oulasvirta, 2004; Oulasvirta & Tamminen, 2004), and experimental (Oulasvirta, 2004b; Oulasvirta, Tamminen, Roto & Kuorelahti, 2005) studies of mobile behavior.

Example I: Mobile Resources and Restrictions

As an example, we present studies of mobility. Mobility poses a distinctive challenge to future technologies because mobile contexts differ from desktop contexts in many important ways. Internal factors such as task goals are different and external factors such as social resources and physical surroundings are dynamic and unpredictable. Indeed, when mobility-related phenomena in our mobility data were classified, several items were frequently cited: shopping, observing passers-by, selecting routes, ad hoc meetings, SMS messaging, relaxing, waiting, surprising and delighting others, arranging meetings, being late, remaining safe, acquiring information, collecting memories, and playing gags. These are in stark contrast to what is commonly attributed to desktop contexts.

Tamminen et al. (2004) conducted ethnographic studies to find distinctive (in comparison to static contexts), general (from the point of view of frequency), and useful (from the point of

view of design) socio-psychological aspects of mobile contexts. It was argued that these characteristics would be useful to understand regarding what restrictions and resources prevail in mobile use contexts.

The results show that mobility is socially structured around navigation. Situational acts are embedded within planned acts of navigation—dropping by, ad hoc meetings, and other forms of sidestepping are socially motivated and require flexibility from the plans related to navigation. Second, it was recognized that since mobile places are normally public, personal spaces must be actively constructed and claimed by socially recognizable acts (e.g., picking up a newspaper on the metro creates a personal space). Third, temporal tensions (fluctuations of importance of time in relation to space) were identified—waiting, for example—that pose radically different cognitive and social demands for behavior. Think about, for example, the cognitive and social restrictions to use imposed by a typical waiting place, a bus stop, and compare these to rushing through a city in a hurry. Fourth, it was observed that most problems in navigation were solved by utilizing social contacts and only rarely by using artifacts such as schedules, maps or the like. Aspects of multitasking were also identified, in particular how different cognitive and social restrictions for multitasking are posed at various stages in navigation (e.g., reaching the goal vs. calibrating speed in the beginning of the journey).

Social practices are always embedded in a socio-psychological framework that determines many aspects of use. The most important result of this research has been the simple, yet powerful concepts that make some of the obvious aspects of this framework visible to researchers. Personal spaces, temporal tensions, multitasking and so forth both restrict and enrich mobility and should be taken into consideration in the design of future technologies. In current research, we have investigated the possibility of conducting lighter, in situ ethnographic observations during concept innovation. The best benefit of this method, coined “bodystorming,” comes from the fact that many essential context factors that might be hidden or not explicated in observation documents are immediately observable in situ (Oulasvirta, Kurvinen & T. Kankainen, 2003).

Example II: CoffeeMug Prototype

This case illustrates how understanding the nature of distributed cognition in an editorial office helps in innovating functions and features of a design.

The CoffeeMug prototype was inspired by participant observations conducted in an editorial office. The study uncovered a social practice of a editor-in-chief walking to the kitchen to fill his coffee mug and, on the way back, casually dropping by coworkers’ desks with the tacit purpose of delegating jobs and monitoring ongoing work. Often during the discussion, a need arose to view documents that were not readily available, and fetching them caused an interruption to the activity. The design goal was to support these short-term, spontaneous, face-to-face social practices by creating a fluent and invisible access to digital documents during journal editing activities.

CoffeeMug is a tangible container interface that provides a link between a physical object (here, a normal RF-ID tagged coffee mug, see Figure 2) and recently edited documents on a desktop computer. When the user takes the CoffeeMug upon leaving his or her workstation, recent documents are automatically uploaded to a server, and the documents can be selected for downloading to another computer if the owner authorizes this by scanning the mug by a reader.



Figure 2. CoffeeMug is a tangible container interface that can be used to provide access to owner's recently edited documents.

The instantaneous, portable, and tangible access to most recent documents provided by CoffeeMug is less disruptive and poses fewer cognitive demands than alternative workstation-based access methods (e.g., e-mail, intranet) because CoffeeMug users don't need to manage access rights, memorize what files to send to a colleague after a discussion, or anticipate what documents will be important in a future discussion. The empirical analysis showed that the design features that make the design better understood and better controlled, in this situation, are tangibility (for privacy and spontaneity of action), simplicity (does not tax cognitive resources), and transparency (the algorithm that decides which documents are selected is simple and predictable).

Stage III: Empirical Evaluation in the Field

Thus far, it has been argued that significant empirical effort has to be made in understanding the needs and preconditions that constitute use situations. These findings, then, are analyzed to formulate a hypothesis of why and how a design could change the practices and communities of users. Finally, I turn to the question of evaluating the design in such a hypothesis-testing framework. The two cases, InfoRadar and ContextPhone, illustrate that evaluation is built on a much firmer basis when it draws on this kind of explicated hypothesis rather than on an exploratory approach in which there is no clear criterion for selecting what outcome variables indicate a positive or negative change in behavior.

Example I: InfoRadar Prototype

It has been widely accepted that traditional usability testing is not suitable for evaluating context-aware services, as it neglects social issues, is too concerned with task-based issues such as performance, and is based on the (invalid) assumption that interaction should be as attention intensive as it is in the usability-testing situation. For evaluating a technological

hypothesis, it is possible to employ a method that could be called the *subtraction method*. Essentially, from observations or other data, we gather a baseline of behavior that is being subtracted from behavior indicated by a field study with an actual prototype. This leftover, or “added value,” indicates a change in practices that is then assessed. In the case of community building, one would be interested to see if a communication device would inspire communication among people who did not know each other beforehand (the result of the subtraction would be the additional, or previously absent, practices of communication), or if it created new forms of discussion among a well-integrated group.

InfoRadar is a location-aware messaging system implemented on a handheld computer (here, a Compaq IPAQ) and based on a positioning system, an electronic compass, and GPRS (see Figure 3). Participant observations and diary studies conducted as part of the InfoRadar investigation suggested that a location-aware communication system that aims to cater to mobile communication cannot be based on just one channel (e.g., location-based messages). Instead, it must include auxiliary channels that help users to both initiate and sustain communication. To this end, InfoRadar includes multiple synchronous and asynchronous and location-dependent and location-independent channels. It involves functionality to track and locate nearby associates, a social activity indicator, a voting system to raise awareness of communal issues, a capability for attaching digital pictures to messages to encourage other users to read messages, and a chat function to sustain communication in a location-independent and asynchronous manner.

InfoRadar was tested in two 3-week field trials (see Rantanen, Oulasvirta, Blom, Tiitta & Mäntylä, 2004). In the first study a group of participants who did not know each other in advance used InfoRadar in a shopping mall. The hypothesis was that by stimulating asynchronous discussion about location-related issues, InfoRadar could create new virtual friendships. This, indeed, was observed as some of the participants formed friendships that would not have emerged without InfoRadar. In this respect, InfoRadar succeeded in community building among strangers. In the second study a group of friends (normally telecommunicating only through SMS and phones) used InfoRadar. It was hypothesized that InfoRadar could enhance their community by supporting asynchronous location-triggered discussion (e.g., leaving comments and votes regarding shared sites). Indeed, InfoRadar was observed to inspire and sustain relatively long chains of discussion that were triggered by location. In this respect, InfoRadar succeeded in enhancing communication resources of an existing community.

Hypothesizing how technology transforms human practices is the key for evaluating designs. The idea in the subtraction method is simple, but it requires explicating a baseline and a hypothesis of how the design might introduce a change. Essentially, it is a step towards transforming the evaluation of future technology from exploratory studies to hypothesis testing.

Example II: ContextPhone Prototype

The idea of ContextPhone is based on the findings that many of mobile phone calls never reach the intended receiver and in about 70% of calls, people communicate their present location (e.g., “I’m at the train station”; see Arminen, 2003), a figure that is radically smaller (< 5 %) in landline calls. In addition, research has found that knowing the availability of friends, an awareness of friends’ present activities, communicating one’s own availability,



Figure 3. InfoRadar is a radar-like user interface to location-based messaging.

and reminders of contextual changes (e.g., somebody is going to a certain night club) were important communication needs for a close group of people dispersed in a wider urban area (A. Kankainen & Tiitta, 2003). Given these findings, an idea was surfaced to provide context information (i.e., cues regarding a friend's availability and interruptability) to reduce the number of failed communication attempts.

The user interface consisted of the normal Nokia mobile phone contact book but with added contextual information about the entries. Context information included the current location (and time spent there) of the contact, an indicator of how recently the person has used the phone, and the current profile (audio and vibration alarms on/off). Consult Figure 4 for details on how these were implemented. One of the main design principles was to integrate the added functionalities into existing ones instead of making a separate application. This would be more familiar to the users. In addition, they would not have to learn new ways to use the phone, thereby decreasing technological disruption to social and communication practices. A second design principle was to make context communication automatic so that users would not have to initiate it. This was deemed important based on our studies of the cognitive and social resources people have while mobile. It was discovered that mobile people have just very limited (roughly speaking, about one third) attention capacities while mobile in comparison to desktop situations (Oulasvirta et al., 2005). Therefore, all unnecessary interaction steps were to be eliminated.

For the field study, the hypotheses were that (a) ContextPhone reduces the number of failed communication attempts and, more importantly, (b) Contextphone increases group awareness within the group that uses it. To test these hypotheses, we employed the ABA intervention methodology adopted from clinical psychology, which has three phases of investigation. In the A phase, we established a baseline of behavior with just the use of the

normal phone. In the B phase, the technological intervention was made using the enhanced phone. Then, in the last phase, the A situation was reintroduced, meaning the instrument of the baseline study (a normal mobile phone) was returned and the data measured again. Data analysis of this process provided the ability to assess, by comparing behavior in the A phases to the B phase, whether the changes in behavior during Phase B were technology-induced rather than arbitrary contingencies or regression towards the mean. This methodology, then, provides a better protection against threats to validity in very complex settings where researchers have poor control over nuisance variables.

In the study, a four-person single-parent family was provided with ContextPhones and instructed on their use. Participants' interactions with the phone, phone calls and SMSs within the family were logged for each week of the ABA process. Family members were interviewed separately after each of the 3-week phases. As the results are still under analysis, they are not presented here. For the purposes of this paper, however, the most important point in this case was to illustrate how the hypothesis-testing framework inspired us to adopt a more rigorous testing methodology than the prevailing exploratory field study methodology had to offer.



Figure 4. ContextPhone is a context/information-enhanced contact book for mobile phones. Next to each contact, the phone automatically updates information on how recently the phone has been manipulated by the person (the hand icon on the left), his/her current location (and time spent there), and phone profile (audio and vibration alarms on/off).

DISCUSSION

Even a brief inspection of scenarios proposed in key articles on interaction beyond the desktop reveals a need for discovering useful design ideas. Consider, for example, two key scenarios underlying a research project (Satyanarayanan, 2001): a video projector that warms up proactively before the presenter comes to the room (saving 30 seconds) or an agent that prevents an audience from seeing a confidential PowerPoint slide that was accidentally left in a presentation (saving the one click needed to skip to next slide). Despite the fact that the development of technological potentials and enablers is necessary, it must not do so in a manner overlooking the real users and the actual uses. Innovating design ideas that are useful and usable, however, requires effort. In innovating and developing socially relevant design ideas it is necessary to justify the ideas through observations from the field, instead of from intuition. Empirical studies not only help to innovate design ideas and derive functionality and interaction features but also to identify preconditions for uses, such as the recently debated issues of privacy and trust that are increasingly more important for the future technologies. Most importantly, empirical studies are needed to explicate and justify a hypothesis about how a design is going to be useful for the users, and this hypothesis can be operationalized and tested in a field study.

The empirical framework sketched in this paper is however largely an idealization. In the circumstances of modern HCI research where time and other resource constraints loom behind every effort, one or more of the three empirical stages are almost always compromised, which of course subjects research to several threats at the end design. When needfinding is not conducted, or the underlying needs are not articulated, it is easy to err in design, for two main reasons. First, choosing one feature or function over another in the design stage requires a choice in which the use purpose is assumed. Second, in operationalizing the evaluation of the system, the whole trial should be informed by the intended purpose. Often, if this is not the case, the study is beset by several serious threats to validity and to the usefulness of its outcomes. Three of these problems are worth mentioning here: the study situation may not reflect the actual use; the methods and selected dependent variables may not be tuned to be sensitive to signals of how well the technology suits user needs; or, finally, there may be no possibilities for the experiment to *fail* to show support for the technology (for example, no baseline for comparing if the technology has improved previous practices).

One should have no illusions, however, that needfinding is being established as a mature methodology. First, the notion of user need is inflated by the panoply of definitions and uses seen in the HCI literature, not to mention that the notion is under debate in psychology. Second, to make things worse, there is almost no linkage between the use of the needfinding notion in HCI and in modern psychology, which means that no common, shared typology exists in HCI for speaking about the kinds of needs relevant in interaction. It has been mainly cognitive psychology that has had an impact in modern HCI, whereas other branches of psychology have lagged behind. Modern psychology, with its emphasis on motivation, personality, and emotion, has distinguished and sophisticated concepts to describe cognitive structures intrinsic in behavior, such as goals, strivings, tasks, projects, scripts, strategies, current concerns, life narratives, and so on (McAdams, 1996). As categorizations of user data are inherently laden with the preconceptions of the researcher, ensuring that they are based on sound, scientific theories is of high importance for future research. Third, a user need is a

mentalist entity, which means that attributing these needs to users is not a straightforward process, and therefore must include inferences on latent variables based on observations of behavior. Nevertheless, needs are generally carelessly postulated based on scanty evidence and without proper triangulation, without proper testing of the hypothesis by collecting evidence from multiple sources by multiple methods. Fourth, the notion of user need is almost entirely individualistic, and emergent needs that pertain to groups and organizations of users cannot be addressed. However, despite the shortcomings and obvious need for further conceptual work, one must not underestimate the value of the concept in guiding the design process.

By failing to investigate the preconditions for use, the first iteration with full prototypes is almost certain to be unsuccessful. HCI in a world of ubiquitous and mobile computers is plagued by interaction problems that have only recently become known to HCI, and large areas of the territory still remain uncharted. Recent research has begun to identify and explicate reoccurring problems, some of which include the absence of needed resources (cognitive, computational, social, physical, artifactual), the suitability of user interface for mobility, the acceptability of the manifestation of the computer in the intended use context (e.g., agent-like representations vs. direct manipulation interfaces in smart home applications), the fit for multitasking and management over multiple contexts (e.g., especially interleaving of tasks, rapid task-switching, and interruptability features), leaving room for both situated and planful action (planful opportunism), alignment with social and organizational practices, usability in a multidevice and multiterminal ecology, the responsibility sharing between proactive computer agents and humans, and the support for accountability over unequal communication platforms. Most of these contentions are germane to many future technologies, and they must be tackled carefully to minimize the need for costly iteration with prototypes.

Finally, failing to conduct empirical evaluation of a technology is obviously disadvantageous. As has been known for decades in Computer Supported Cooperative Work, domestication, appropriation, and repurposing of technology are complex processes that are almost impossible to be foreseen by researchers. Moreover, the evolution of social and individual practices with and through new technologies is difficult to capture in the circumstances of a typical field trial because of insufficient resources, difficulties in reaching critical mass, etc. Nevertheless, as it is exactly these processes that determine the success of a technology, addressing them, at least in the limited way field trials allow for, is essential. Yet, while striving to make the currently idealized hypothesis-testing framework a reality, we all must face the realities of day-to-day research. Often, we are unable to operationalize a hypothesis in a manner that allows for exhaustive testing of the dependent variables, or we are unable to leave enough space for spotting potentially interesting phenomena that are not related to the initial hypotheses. Moreover, in investigating the transformation of human behavior due to new technology, simple comparisons such as the one presented in the case of ContextPhone may not suffice in actually informing design at a practical level. Simply noting that an introduced technology is better than nothing helps little in actually improving the design. On the other hand, adding more comparison conditions is obviously costly.

Taken together, empirical grounding throughout the design process is an important step forward from the prevailing attitude where researchers so easily fail to elicit anything meaningful from the numerous (and often arbitrary) outcome variables in an exploratory study with prototypes. As we have argued, empirical work has the potential to guide and structure the whole process of innovation, development, and evaluation. Furthermore, it

provides a natural union between the analytical and constructive approaches toward technology development, which are too often seen as mutually exclusive rather than complementary.

It goes without saying that the empirical framework loosely sketched here needs more work. The associated concepts and methods need to be crafted and elaborated. However, an even more pressing objective for the more immediate future would be to effectively communicate the idea to technologists, designers, and other practitioners. We need to educate and guide developers in utilizing the results and in employing the methodology. Furthermore, keeping in mind the complex and elusive nature of the studied phenomena, another challenge will be to conduct such studies that provide convincing yet concrete information from the field to inform developers in decision making. An implication is that we need to clarify the ideas and go beyond the fuzziness of the theoretical concepts. Aiming for clarity and communicability is obviously necessary to ensure impact in decision making in organizational settings. Ultimately, focusing holistically on the human role early in technology development pays off in the quality of end products.

REFERENCES

- Arminen, I. (2003, September). Location: a socially dynamic property—a study of location telling in mobile phone calls. In L. Haddon, E. Mante-Meijer, B. Sapio, K-H. Kommenon, L. Fortunati, and A. Kant (Eds.), *The Good, the Bad and the Irrelevant: The User and the Future of Information and Communication Technologies*, Proceedings of the The Good, The Bad and The Irrelevant Conference, Helsinki, Finland.
- Atkinson, J. W. (1982). Old and new conceptions of how expected consequences influence actions. In N. T. Feather (Ed.), *Expectations and Actions: Expectancy-Value Models in Psychology* (pp. 17-52). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Ball, L. J., & Ormerod, T.C. (2000). Putting ethnography to work: the case for a cognitive ethnography of design. *International Journal of Human-Computer Studies*, 53, 147-168.
- Beyer, H., & Holtzblatt, K. (1997). *Contextual design: Defining customer-centered systems*. San Francisco: Morgan Kaufman.
- Dourish, P. (2004). What we talk about when we talk about context. *Personal and Ubiquitous Computing*, 8, 19–30.
- Dryer, D. C., Eisbach, C., & Ark, W.S. (1999). At what cost pervasive? A social computing view of mobile computing systems. *IBM Pervasive Computing*, 38, 652-676.
- Ehn, P. (1988). *Work-oriented design of computer artifacts*. Stockholm, Sweden: Arbetlivscentrum.
- Fischer, G. (2001). Articulating the task at hand and making information relevant to it. *Human-Computer Interaction*, 16, 243–256.
- Friedman, B. (1996). Value-sensitive design. *interactions*, 3(6), 16-23.
- Greenberg, S. (2001). Context as a dynamic construct. *Human-Computer Interaction*, 16, 257–268.
- Habermas, J. (1971). *Knowledge and Human Interests*. Boston: Beacon Press.
- Ishii, H. & Ullmer, B. (1997). Tangible bits: Towards seamless interfaces between people, bits and atoms. *Proceedings of the SIGCHI [Special Interest Group on Computer-Human Interaction] Conference on Human Factors in Computing Systems* (pp. 234–241). New York: ACM Press.
- Kankainen, A. (2003). UCPCD - User-centred product concept design. *Proceedings of DUX2003 [Designing User Experience]* (pp. 1-13). New York: ACM Press.
- Kankainen, A., & Oulasvirta, A. (2002). Design ideas for everyday mobile ubiquitous computing based on qualitative user data. *Proceedings of 7th ERCIM [The European Research Consortium for Informatics*

- and Mathematics] *Workshop on User Interfaces for All* (pp. 458-464). Berlin, Germany: Springer-Verlag.
- Kankainen, A., & Tiitta, S. (2003). Exploring everyday needs of teenagers related to context-aware mobile services. *Proceedings of HFT [Human Factors in Telecommunications] 2003* (pp. 19-26). Berlin, Germany: Fraunhofer Institute.
- Kjeldskov, J., & Graham, C. (2003). A review of mobile HCI research methods. In L. Chittaro (Ed.), *Proceedings of Mobile HCI 2003* (pp. 317-335). Berlin, Germany: Springer-Verlag.
- Kurvinen, E., & Oulasvirta, A. (2004). Towards socially aware pervasive computing: a turntaking approach. *Proceedings of the 2nd International IEEE [The Institute of Electrical and Electronics Engineers] Conference on Pervasive Computing and Communications* (pp. 346-351). Los Alamitos, CA: IEEE Computer Society.
- Mann, S. (1996). "Smart clothing": Wearable multimedia computing and "personal imaging" to restore the technological balance between people and their environments. *Proceedings of the Fourth ACM [Association for Computing Machinery] International Conference on Multimedia* (pp. 163-174). New York: ACM Press.
- McAdams, D. (1996). Personality, modernity, and the storied self. *Psychological Inquiry*, 7, 295-321.
- Oulasvirta, A. (2004a). Finding new uses for context-aware technologies: The humanistic research strategy. *Proceedings of the SIGCHI [Special Interest Group on Computer-Human Interaction] Conference on Human Factors in Computing Systems* (pp. 247-254). New York: ACM Press
- Oulasvirta, A. (2004b) *Human-computer interaction in mobile context: a cognitive resources perspective*. Unpublished licentiate thesis, University of Helsinki, Finland.
- Oulasvirta, A., Kurvinen, E., & Kankainen, T. (2003). Understanding contexts by being there: case studies in bodystorming. *Personal and Ubiquitous Computing*, 7, 125-134.
- Oulasvirta, A., & Salovaara, A. (2004). A cognitive meta-analysis of design approaches to interruptions in intelligent environments. *Proceedings of the SIGCHI [Special Interest Group on Computer-Human Interaction] Conference on Human Factors in Computing Systems* (pp. 1155-1158). New York: ACM Press.
- Oulasvirta, A., & Tamminen, S. (2004, April). Temporal tensions in human-computer interaction. Paper presented at the CHI2004 [Special Interest Group on Computer-Human Interaction Conference on Human Factors in Computing Systems] *Workshop on Temporal Aspects of Work*, Vienna, Austria.
- Oulasvirta, A., Tamminen, S., Roto, V., & Kuorelahti, J. (2005). Interaction in 4-second bursts: The fragmented nature of attention in mobile HCI. *Proceedings of the SIGCHI [Special Interest Group on Computer-Human Interaction] Conference on Human Factors in Computing Systems* (pp. 919-928). New York: ACM Press.
- Patnaik, D., & Becker, R. (1999, Spring). Needfinding: the why and how of uncovering people's needs. *Design Management Journal*, 10(2), 37-43.
- Rantanen, M., Oulasvirta, A., Blom, J., Tiitta, S., & Mäntylä, M. (2004). Group and public messaging in mobile context. *Proceedings of the Third Nordic conference on Human-computer interaction 2004 (NordiCHI'04; pp. 131-140)*. New York: ACM Press
- Reeve, J. (2001). *Understanding Motivation and Emotion* (3rd ed.). Fort Worth, TX: Harcourt.
- Rogers, Y. (2004). New theoretical approaches for HCI. *Annual Review of Information Sciences and Technology*, 38, 87-143.
- Satyanarayanan, M. (2001, August). Pervasive computing: vision and challenges. *IEEE Personal Communications*, August 2001, 10-17.
- Schaller, R. R. (1997). Moore's law: past, present and future. *IEEE Spectrum*, 34(6), 52-59.
- Schuler, D. (1994). Social computing. *Communications of the ACM*, 37(1), 28-29.
- Simon, H. (1969). *The Sciences of the Artificial*. Cambridge, MA; MIT Press.
- Tamminen, S., Oulasvirta, A., Toiskallio, K., & Kankainen, A. (2004). Understanding mobile contexts. *Personal and Ubiquitous Computing*, 8, 135-143.
- Tennenhouse, D. (2000). Proactive computing. *Communications of the ACM*, 43(5), 43-50.

- Tiitta, S. (2003). Identifying elderly people's needs for communication and mobility. In J. Clarkson, R. Coleman, S. Keates, & C. Lebbon (Eds.) *Proceedings of Include 2003* (pp. 266-271). London: Springer-Verlag.
- Tolmie, P., Pycock, J., Diggins, T., MacLean, A., & Karsenty, A. (2002). Unremarkable computing. *Proceedings of the SIGCHI [Special Interest Group on Computer-Human Interaction] Conference on Human Factors in Computing Systems* (pp. 399-406), New York: ACM Press.
- Weiser, M. (1991). The computer for the 21st century. *Scientific American*, 265(3), 66-75.
- Wixon, D., Holtzblatt, K., & Knox, S. (1990). Contextual design: An emergent view of system design. *Proceedings of SIGCHI [Special Interest Group on Computer-Human Interaction] Conference on Human Factors in Computing Systems* (pp. 329-336), New York: ACM Press.

Author's Note

I am indebted to Jan Blom, Giolio Jacucci, Anu Kankainen, Esko Kurvinen, Martti Mäntylä, Pertti Saariluoma, and Antti Salovaara for fruitful discussions on the development of HCI methodology. I gratefully acknowledge funding from the Academy of Finland.

All correspondence should be addressed to:

Antti Oulasvirta
Helsinki Institute for Information Technology
P.O. Box 9800
FI-02015 TKK, Finland
oulasvir@hiit.fi

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