From Everyday Objects to Computational Devices: Understanding the Science behind Ubiquitous Computing Interface Design

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Computing is moving away from the desktop, permeating into everyday objects and the environments around us. Many researchers in ubiquitous computing are excited about the potential to profoundly change the way we live by revolutionizing how we interact with these objects and the information they convey. Despite the excitement, there are few successful applications. While this could easily be attributed to the immaturity of the research area, it is also a manifestation of a larger problem—the lack of coherent methods, processes or tools that assist designers in thinking about pertinent issues as they explore potential ideas and create new systems. This paper explores some of the issues and challenges that differentiate ubiquitous computing from the norm. They are organized according to the major design stages—early design, community factors, system design as well as usage factors; in order to help guide designers as they go through the rigors of creating new systems. Through a study, this paper delves into how some of these issues can manifest themselves in the systems created.

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1. INTRODUCTION

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Given the proliferation of smaller and low bandwidth computing devices, advances in wireless communications, and the increasing commercial interest as industry explores more ways to generate profit from their communication infrastructural investments, Weiser's vision [Weiser, 1991, 1993] of calm and ubiquitous computing seems attainable. Ubiquitous computing is an emerging model of computer science and human-computer interaction in which the communication of and interaction with information is integrated into objects in the environment. Common examples of ubiquitous computing devices include large video displays in public places (like those in Times Square in New York City or in Shibuya in Tokyo), wearable technology, and handheld computers. Within research communities, active pioneers in the field of ubiquitous computing include Hiroshii Ishii and his Tangible Media group at MIT (e.g., [Ishii & Ullmer, 1997]) and Gregory Abowd and his Future Computing Environments group at Georgia Tech (e.g., [Abowd & Mynatt, 2000]). Companies like Nokia and Intel focus both research and development efforts on ubiquitous computing research and products. The ACM has sponsored a ubiquitous computing conference since 2001 (see ubicomp.org for details).

When the proliferation of ubiquitous computing devices comes to pass, computing shall move beyond the confines of isolated tool usage, shifting from the largely sedentary and solitary desktop platform towards a pervasive penetration of the environment around us. Emphasis shall shift from interaction between an individual and a single device to a profusion of networked mobile and embedded computing devices that individuals and groups employ across a variety of settings—creating new forms of information display and interaction. A good understanding of the issues at play is important because it will help interface designers to successfully build on the work of those who have come before us, while evaluating ubiquitous computing technology in its proper context and understanding its impact—a prerequisite for progress in any research area.

Although social implications of these technologies are generally acknowledged, they are rarely given full consideration. Partly, this might be due to the lack significant deployments of the technology that work long enough to enable designers to study some of the social, cultural and organizational changes that may arise [Norman, 1999] or the lack of studies that explore effects of the key elements of ubiquitous computing systems. It could also be that the methods that used to create these new systems do not allow adequate engagement of potential end-users, enabling greater appreciation their needs. As individuals have increasing access to on-the-go information, both through devices that they carry with them and devices integrated in the environment, questions arise as to whether researchers will be able to effectively use the information [Lally et al, 2007].

This paper explores two related issues critical for the successful design and deployment of ubiquitous computing technology. The particular questions explored in this work are:

- As research transcends from desktop to ubiquitous computing paradigms, how must classic interface design processes change to helping designers to envision and design "better" systems?
- As computing artifacts get embedded into everyday objects, creating a new breed of interfaces, will people be able to understand the information that they convey? What are some of the factors likely to influence their adoption and use? How can these factors be captured and used in a design process?

The remainder of the paper reviews the issues that compound the challenge of enhancing everyday objects with computing technologies, organizing them into their respective design stages. The stages represent a process that can be followed in designing ubiquitous computing interfaces, highlighting key issues that must be addressed in the design process. Necessary with any process are units of information that must be exchanged as a designer moves from stage to stage. As a demonstration, this paper presents a human-computer interaction user study that investigates some of raised issues by using everyday objects as system interfaces that convey various types of information in ordinary scenarios, toward exemplifying the knowledge needed in design. Finally, this paper puts its findings in perspective and outlines future work.

2. ISSUES AND CHALLENGES OF UBIQUITOUS COMPUTING

Weiser articulated the notion of ubiquitous computing by envisioning a time in the future when people and environments would be augmented with computational resources providing appropriate information and services when and where desired [Weiser, 1991; Weiser, 1993]. He predicted the large increases in the number of personal devices of varying sizes that has come to pass, with the proliferation of smaller and low bandwidth computing devices stimulated in part by advances in wireless communications. He heralded that, in order for these systems to achieve their true potential, they would have to be

"invisible"—stay out of the way of the user's task and draw no attention to themselves. Applications are emerging that leverage these devices and infrastructure, portentous of new ways of interaction inspired by the widespread access to information and computational capabilities available [Abowd & Mynatt, 2000].
There are a number of unique inherent characteristics that differentiate ubiquitous computing from the current desktop paradigm, making the conventional human-computer interaction knowledge that researchers have built up over time inadequate.

Having done an extensive literature survey and identified the major characteristics, this research endeavor sought to organize this knowledge in a manner useful to a system designer going through the rigors of creating a new system. The intent is to enable the designer to think about each of these characteristics at an appropriate stage in the design process as a mechanism to address any design issues that may emerge. This work leverages Scholtz & Consolvo's [2004] evaluation framework for ubiquitous computing applications, relying on their ubiquitous computing evaluation areas (UEAs) to determine how to not only evaluate the design of ubiquitous computing systems as they recommend, but also design right from the earliest requirements gathering stages to final deployment. Many of the inherent characteristics for ubicomp that were identified are covered in some form in Scholtz & Consolvo's evaluation framework. All this has inspired a compression of these characteristics into four groups of factors that largely correspond to the major design stages as defined in Rosson & Carroll [2002] and other major textbooks: early design factors (requirements analysis), community factors (conceptual design), system design factors (system design) as well as usage factors (deployment and evaluation).
Early design factors relate to the things the user is willing to risk/spend to use the proposed system i.e. trust, attention [Scholtz & Consolvo, 2004]. The system should be able to support dynamic user goals and situations without the user actively reconfiguring the system to adapt to the changing conditions [Banavar & Bernstein, 2002]. Users often have difficulty judging how goals shift and what the impact of attentional shift may be [Avrahami, Fogarty, & Hudson, 2007]. Initial stages of requirement gathering gain in importance as the cost of technological development and deployment grow.

Community factors examine system impact on those around it—including people with little or no stake in the system, i.e. impact and side effects [Scholtz & Consolvo, 2004]. This will require thinking beyond human-device relationships to include system mediated human-human relationships and social awareness that emerges in the presence of the technology [Banavar & Bernstein, 2002; Grudin, 1994, 2002; Jessup & Robey, 2002; Bödker & Christiansen, 2006]. Awareness of context and infrastructure become of primary importance in the design of the technology, and must be accounted for in the design process.

System design factors explore the designer's conceptualization of the proposed system, how that conceptualization is realized, and how well the design model matches the user model i.e. interaction, conceptual models, invisibility [Scholtz & Consolvo, 2004]. It is fecessary to support device hetepggeneity and their resource constraints while accommodating multiple communication networks and their coverage limitatiofs [Banavar & Bernstein, 2002; Islam & Fayad, 2003]. Systems will need the ability to support multiple devices for most of the services they provide. Although this might result in limitations based on the capabilities of different devices, it shall allow members to use devices that they already own and minimize the new skills that they need to acquire before benefiting from a given system.

Usage factors guarantee certain performance and reliability levels needed by the user of the system i.e. application robustness [Scholtz & Consolvo, 2004]. Beyond these, researchers should begin to think about ethereal qualities like appeal, presence [Hallnäs & Redström, 2002], pleasure [Jordan, 2000], emotion [Norman, 2003], interruptability [Avrahami, Fogarty, & Hudson, 2007] and other facets of human nature that may have an influence on system adoption. Ubiquitous computing has the potential to fundamentally change the way people and organizations use computing to perform various tasks, but the utility of the resulting computing advancements cannot be evaluated without performing significant user studies on widely deployed systems that people use for substantial periods of time.
The four stages of design, extracted and combined from the evaluation-based work of Scholtz and Consolvo and the process-based work of Rosson and Carroll, represent a first step in identifying unique elements of a staged process for ubiquitous computing design. Introduction of ubiquitous computing technology within any environment is bound to have a more significant social effect, compared to conventional computing technology. What will be the effect on existing social behavior? Will researchers and practitioners end up with new organizational and social structures? There is a need to develop effective methods to test and evaluate the wide and often unpredictable range of usage scenarios enabled by the new possibilities. In addition, the ability to compare research outcomes and be able to build on the work

of those who have come before will be critical for progress in this research area [Scholtz & Consolvo, 2004].

3. USING EVERYDAY OBJECTS TO CONVEY INFORMATION—AN EXPERIMENT

The previous section introduced issues that must be considered at each of four stages of a design process for ubiquitous computing, inspired primarily by the ubiquitous computing evaluation framework of Scholtz and Consolvo [2004] and the user interface design process of Rosson and Carroll [2002]. Equally important in design is the units of knowledge that a designer must consider at each stage. That is, how can designers encapsulate and revisit their concerns throughout the design process? And more specific to ubiquitous computing, how can key interaction components be analyzed for inclusion, modification, or removal in an interface at each stage of design?

In reviewing the literature, many scenarios in which everyday objects have been enhanced with some form of computational power were encountered. It is apparent that many designers of these new systems take for granted that their creations are superior to the everyday objects that users normally interact with. They do not investigate whether embedding computational capabilities alters the way people perceive these objects or impinges on their everyday use. Would people knowingly use these enhanced objects and understand how to interact with them in accustomed settings? How would this alter ordinary use of the objects?

This work was inspired to explore what users thought of these new types of interfaces and the implications of some of the issues raised in the preceding sections. It is suggested that user interfaces as known today shall gradually disappear as computational devices get integrated into everyday objects and the environment around us. While this creates many opportunities for situated computing, it raises questions of whether people expect to find computational functionality in these objects or environments, let alone, be able to use them and understand the information that they convey. For an extended discussion of this study, please see prior publications [Ndiwalana, 2003; Ndiwalana, Chewar, Bussert, Somervell, & McCrickard, 2003].

While it is much harder to make interfaces invisible in the environment in the literal sense of the word, researchers have had more success at embedding them into everyday objects and exploring when and how they are used [Beigl, Gellersen, & Schmidt, 2001; Ishii & Ullmer, 1997; Terrell & McCrickard, 2006; Huang, Koster, & Borchers, 2008]. Most everyday objects are designed with specific functions in mind; this usually influences their design both in appearance and in the affordances that they embody. Computational power might be added in order to enhance the utility of a given object, or to give the object added functionality. In either case, researchers presumably would like to maintain their appearance as well as original functionality. While this provides flexibility to use the object either as a normal artifact or as an "invisible" computing interface, designers will inevitably have to contend with the tradeoffs created by this duality.

Ubiquitous computing is still cutting-edge technology that has not yet found its way into the mainstream population, a step vital for its success. Since awareness of its existence and potential is not well documented, it is relevant to explore this aspect and to probe at some of the inhibitive notions that they may have towards the technology. This will not only enable this work to do a better job at educating researchers about the possibilities, but it will also help researchers and designers to better address people's concerns, as both sides engage in a participatory design approach, enabling designers to come up with more relevant and marketable applications.

While this work makes contributions toward the creation and design of ubiquitous systems, the primary contribution is in the areas of human factors and human-computer interaction—emerging sub-disciplines of computer science that appear in most computer science educational curricula and for which there are many quality textbooks and graduate reading books (e.g., [Carroll, 2000; Rosson & Carroll, 2002; Jordan, 2000; Norman, 1999]). The experiment described in this paper is based on the methodology outlined in Rosson and Carroll [2002], and the selection of a sample size of 50 participants and the evaluation metrics are based on recommendations of Shadish, Cook, and Campbell [2002] toward ensuring reasonable validity of the correlation model.

3.1 Purpose of experiment

Specific questions to be answered with this study include:

Early Design (Requirements Analysis). Do people expect to find computational functionality in everyday objects? Will they trust these objects? Will they find them intrusive?
Community Impact (Conceptual Design). Will they understand how to use them and when?
System Design (Interaction Design). Will people understand the information conveyed by these interfaces, given that they are accustomed to using these objects in other ways?
Usage (Deployment and Evaluation). What are some of the factors that would influence people's decisions to adopt the use of some of these interfaces?

This work also wanted to determine whether, with the help of some examples, it was possible to stimulate participants to generate ideas that could be further explored for potential applications.

3.2 Brief outline of experiment

Participants are introduced to the notion of ubiquitous computing via a scenario-centric presentation using basic everyday objects imbued with some computational power to convey various types of information. Besides determining whether they understand the information, participants also compare these ubiquitous interfaces with desktop interfaces that display the same information allowing researchers to glean some insight as to how the two types of interfaces might differ.

Through a detailed survey, participants provide feedback relating to their impressions, rating the performance of each interface on a number of metrics and making comparisons between the ubiquitous and desktop interfaces. The interfaces inspire them to think of new ways to use the demonstrated ubiquitous technology to support current information needs that they may have or come up with new and different uses for them. Additionally, the survey solicits for other everyday objects that they think could be successfully implanted with computational capabilities to help convey information in the real world.

3.3 Hypotheses

The hypotheses for the study extricated from the questions above may seem to be obvious statements consistent with mainstream human-computer interaction thinking, however, based on the concerns raised by some researchers [Abowd & Mynatt, 2000; Hallnäs & Redström, 2002], they are important to verify for the ubiquitous design paradigm:
People prefer desktop over ubiquitous interfaces to display everyday information.
People will be more willing to start using ubiquitous interfaces if they perceive them as trustworthy and intuitive.
The effort required to understand information conveyed by the ubiquitous interfaces inhibits willingness to use.
People who have never heard of ubiquitous computing before will be less trusting of and want to be less dependent on ubiquitous computing systems, impacting their willingness to adopt ubiquitous interfaces.
The main themes within human-computer interaction drawn upon for the study are scenario-centric methods used to determine user needs and investigate predictors of user adoption of ubiquitous computing technology [Bødker & Buur, 2002; Hallnäs & Redström, 2002; Iacucci & Kuutti, 2002; Mikkonen, 2002; Strom, 2002].

3.4 Methodology

In this study, participants are introduced to the notion of ubiquitous computing with the help of basic everyday objects imbued with the ability to convey information through the level of power provided to them. The Real World Interface (RWI) toolkit [McCrickard, Bussert, & Wrighton, 2003] was used to extend the capabilities of three everyday objects. The toolkit provided a programming interface that allowed connection of the power input to any electrical device to a computer program, effectively letting any computer interface control the power to a real-world device. The infoLAMP uses the brightness of a light to convey information, the dataFAN uses wind speed from a fan, and the hapticCHAIR uses vibration from a cushion (see Figure 1).

Figure 1: Everyday objects that have been imbued with computational power to enable them to convey information using the Real World Interface Toolkit. From the left to right, they are the infoLAMP, the dataFAN and the hapticCHAIR.

The Real World Interface (RWI) toolkit abstracts a lot of the details allowing the designer to use the objects just as they would any typical interface widget [McCrickard et al., 2003]. The X10 transmission protocol, used to control power flow to these electrical devices, allows association of information sources with physical device properties such brightness levels, rotation speed or vibrations, which are adjusted in this case to depict varying information states.

Participants compare these ubiquitous interfaces with two desktop interfaces that display the same information: a simple number display counter and a progress indicator bar, allowing the analysis to reveal some insight as to how the two types of interfaces might differ.

3.4.1 User Population

In conducting this study, there is a focus on a population familiar with emerging technology that will more likely be at the forefront of ubiquitous computing early adoption. Therefore, participants are 50 undergraduate computer science students who received class credit for their time. There are 5 females and 45 males, who range in age from 19 to 31. Most of them reported being very familiar with computers (43/50), while the rest felt fairly familiar (7/50). They own a range of mobile computing devices that include laptops, cellular phones, Personal digital assistants (PDAs), miniature MP3 players, etc. In the pre-study questions, the majority indicated not having heard of the term “ubiquitous computing” before (34/50), while some (4/50) were not sure. Of those who had heard of the term (12/50), two were not sure of its meaning.

3.4.2 Experimental Session

Participants were studied in groups of eight, although each session was conducted in identical fashion. During an experimental session, participants are introduced to all of the interfaces. Everyday information is conveyed to the participants on the various devices within the context of a scenario that helped situate the interaction. The scenarios reflect a variety of information needs, and they include monitoring of three different types of information: 1) outdoor temperature, 2) online buddy status for instant messaging, and 3) progress in performing a timed task.

Scenario 1. In this scenario, participants were told to imagine themselves seated before a computer, engaged in an editing task. They were then asked to monitor outdoor temperature to determine changes over time with each of the five devices being tested.

Scenario 2. Like in scenario 1, they performed a similar primary task. However, they were asked to use the devices being tested to monitor online buddy status of someone they are interested in communicating with via instant messaging.

Scenario 3. In the final scenario, the primary task changed, requiring participants to imagine themselves engaged in a timed online examination. They were then asked to monitor their progress in relation to the amount of time that had passed using each of the five devices.

Detailed feedback is collected via a questionnaire, which consists of four subsections and 154 questions in total. After each scenario demonstration, participants provided feedback by completing a section of the questionnaire. The questions in the questionnaire involved rating the performance of each interface, as well as comparing them on a number of metrics that include: learnability or ease of learning, intuitiveness or easy of use with no prior explanation, interruptiveness and simplicity of effort required to understand the information conveyed. Participants conveyed their answers on a 5-point Likert scale. The first three sections are similar, and are used to collect feedback for each of the scenarios, while the fourth section is general and probes experience in all three scenarios. Each section consists of 46 questions and is repeated for all three scenarios. Table 1 shows a typical beginning portion for the first three sections, with the results from scenario 2 for each of the devices that were tested [Ndiwalana, 2003].

Participants conclude the study session with a general section consisting of 10 questions that asks for their thoughts on a variety of social aspects pertinent to ubiquitous computing [Abowd & Mynatt, 2000; Jessup & Robey, 2002] and inspires them to think of new ways to use these interfaces. Of specific interest were feelings about their current and possible information needs that should be supported, as well as better interface designs that would convey this information. Participants were free to ask questions at any time during the session, which normally lasted for about one hour.

Table 13: Some of the typical questions from the beginning portion of the first three sections of the questionnaire that help rate the performance of each of the tested devices in each of the scenarios. Average results from scenario 2 are shown. Average ratings (on a 5-point scale) and standard deviations are shown.

	Typical question in the first part of section 1, 2 & 3	infoLAMP	dataFAN	hapticCHAIR	counter	indicator
a)	easy to learn to use in this scenario	4.78, +/-.65	4.38, +/-.90	4.32, +/- .91	4.52, +/- .65	4.62, +/-.67
b)	easy to understand the information conveyed in this scenario	4.78, +/-.68	4.28, +/-.93	4.40, +/-.86	4.56, +/-.61	4.58, +/-.73
c)	interruptive to the current task that I am doing	2.65, +/-1.25	3.20, +/-1.21	3.86, +/-1.28	2.16, +/-1.22	2.28, +/-1.34
d)	easy to use with no prior explanation	4.30, +/-1.02	3.82, +/-1.03	3.90, +/-1.18	4.20, +/-1.01	4.32, +/-.94
e)	I would use it in real life in this scenario	3.50, +/-1.22	2.18, +/-.86	1.94, +/-1.02	3.16, +/-1.23	3.41, +/-1.21
f)	I would you use it in the same way that it was demonstrated	4.04, +/-1.17	3.13, +/-1.31	2.69, +/-1.40	3.61, +/-1.24	3.92, +/-1.11

3.5 Results

The first hypothesis was generally supported, although ubiquitous interfaces showed promise in specific situations. Based on the questionnaire results for all three scenarios, 63% of responses exhibited preference for desktop interfaces, while 21% showed preference for ubiquitous interfaces, and 16% were unsure, as indicated in Table 2. However, focusing on monitoring online buddy status (scenario 2) 22 of the 50 participants expressed preference for the infoLAMP, favoring the ubiquitous device over other interface choices. User comments elaborated on this finding, recognizing preference for peripheral information delivery: "not having to focus on the desktop," "provides information you need," "you don't have to read it or look at it." Preference for ubiquitous interfaces was weak in all of the other scenarios.

Table 14: Number of participants indicating preference for each device (infoLAMP, dataFAN, hapticCHAIR) type in each scenario (1, 2, 3). The totals and overall percentages in parentheses for all the participants for each device are shown at the bottom.

response / Scenario	infoLAMP	dataFAN	hapticCHAIR
1	9	36	5
2	16	24	10
3	6	35	9
totals	31 (21%)	95 (63%)	24 (16%)

responses for each (% total of whole group)

To probe the second hypothesis, the data were filtered to include only the 27 participants who indicated "sufficient trust to be able to use" ubiquitous computing systems. Of these, further filtering identified cases where participants agreed that a ubiquitous computing device was "easy to use with no prior explanation." This sample consisted of trusting participants that found the particular ubiquitous computing device to be intuitive in use. Qualifying sample sizes and the percentage of these cases where the participant was willing to start using that particular device is shown in Table 3. Had hypothesis 2 held, the percentages in the table would approach 100%. Surprisingly, only the infoLAMP in scenario 2 showed a (weak) correlation between trust and intuitiveness as a predictor for willingness to adopt.

Table 15: Number of participants indicating sufficient trust to use each device in each scenario. In parentheses is the percent of those participants who indicated a willingness to adopt the device.

Device / Scenario	infoLAMP	dataFAN	hapticCHAIR
1	16 (19%)	14 (36%)	10 (0%)
2	24 (75%)	17 (12%)	20 (10%)
3	19 (16%)	12 (0%)	16 (50%)

filtered sample size (% willing to adopt)

The third hypothesis assessed the effort required to understand the information conveyed in terms of three factors—responses on questions related to learnability, intuitiveness, and interruptiveness. With each device, patterns related to these responses and the outcome of the willingness-to-adopt question were explored. For instance, in 62 of the 68 occurrences that participants indicated negative responses to both learnability and intuitiveness, they were also unwilling to adopt. Likewise, two or more unfavorable responses in the effort-required factors are a strong predictor of not being willing to adopt (108/114 occurrences). However, it is surprising that when we compare the predicted unwillingness to adopt versus the actual unwillingness to adopt, it was found that the third hypothesis is a weak predictor and dependent on the scenarios. In scenarios 1 and 3, the factors predicted 57/123 and 54/130 cases of unwillingness to adopt, while scenario 2 predicted only 6/108 cases. The results are depicted in Table 4 below.

Table 16: Ratio of predicted unwillingness to adopt based on hypothesis 3 criteria versus actual unwillingness to adopt. Note that Scenarios 1 and 3 exhibit much better prediction success, although this hypothesis is not supported by any scenarios.

Device / Scenario	infoLAMP	dataFAN	hapticCHAIR	Total
1	12/40	14/36	31/47	57/123 (46%)
2	1/18	3/46	2/44	6/108 (6%)
3	17/42	24/50	13/38	54/130 (42%)

For the fourth hypothesis, the data were filtered to include only the 34 participants who indicated having not "heard of the term ubiquitous computing." From the sample, 28 did "sufficiently trust" ubiquitous computing systems to be able to use them and 6 did not exhibit agreement that they trust these systems. Of the 28 who sufficiently trusted ubiquitous computing systems to be able to use them, 17 were worried about becoming fully dependent on the reliable operation of ubiquitous computing technology and 11 were not. Of the 6 who did not sufficiently trust, 4 did not mind dependency, while 2 did. Figure 2 depicts how user samples are distributed between these conditions. The only group that directly meets the conditions of hypothesis 4 is indicated with a dashed outline. If Hypothesis 4 had been supported, the participants would not have indicated willingness to use any of the ubiquitous computing devices. However, both agreed that they would want to use multiple ubiquitous computing devices—evidence contrary to hypothesis 4. Notable is that other subgroups had lower percentages of willingness to adopt.

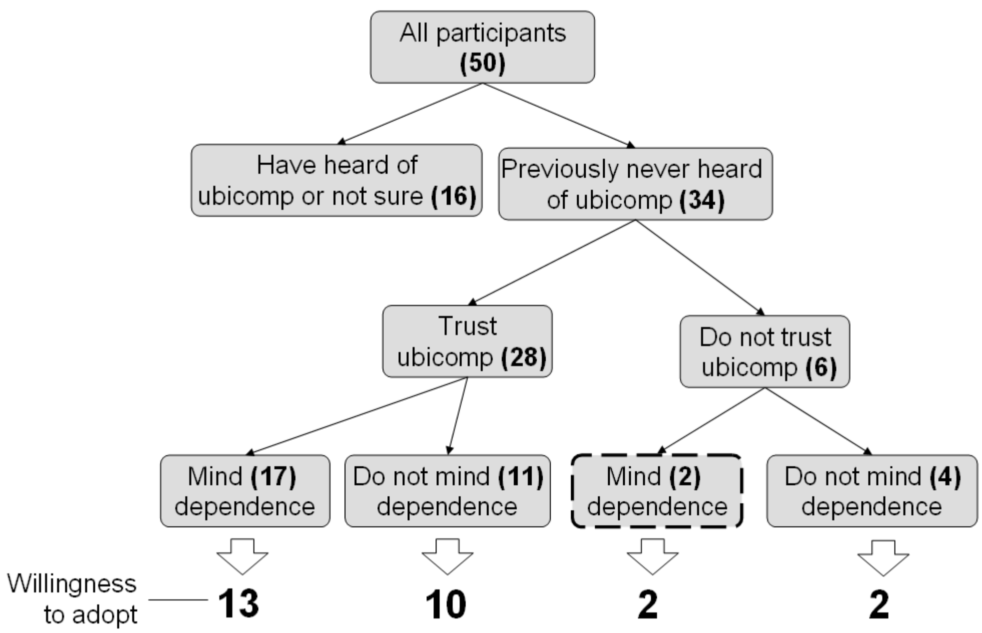

Figure 2: User samples distributed between hypothesis 4 conditions. The group with the dashed outline indicates the only participants who met the hypothesis conditions. The hypothesis implies that these participants would not have been willing to adopt any of the ubiquitous computing devices.

3.6. Discussion

The user survey provided introspection into the attitudes and tendencies of the target population toward the use of ubiquitous devices. Many of the results seemingly contradicted suggestions within existing literature. It was expected that many of the usability notions from mainstream human-computer interaction would be reflected more in the participant responses. However, this was not the case.

The preference for desktop interfaces over ubiquitous devices in hypothesis 1 might be explained by the fact that most participants have previously used desktop interfaces to keep track of similar information. However, this does not explain the unexpectedly strong preference for the infoLAMP in scenario 2. This may relate to the kind of information being conveyed in that scenario—unlike the ratio values conveyed in the other two scenarios, scenario 2 depicted binary categorical buddy statuses. While this implies successful information mapping for the infoLAMP, the result has deeper implications due to the lack of preference for the counter interface which has a rather similar information mapping. This highlights the importance of paying attention to system design factors during interaction design.

Factoring in the participant comments, the infoLAMP was truly appreciated for its ability to liberate information delivery from the desktop platform and blend in with the user's environment—this exemplifies success of a ubiquitous computing system.

Although hypotheses 2, 3 and 4 seem to be obvious extensions of human-computer interaction thought, it is most interesting that they do not hold true for predicting acceptance of ubiquitous computing systems. In other words, trustworthy, intuitive, easy to use devices were not readily accepted by users that frequently use computers, personal digital assistants, and other electronic gadgets. Perhaps this finding highlights the importance of identifying good application areas for ubiquitous computing systems, understandable given their potentially intrusive nature (particularly the haptic devices). This suggests the ubiquitous computing paradigm must not be measured in terms of the traditional; usability metrics, but must focus on other features of use as well—as also noted by other researchers [Abowd & Mynatt, 2000; Hallnäs & Redström, 2002; Huang, Koster, & Borchers, 2008].

Based on the experience in conducting this user survey, it was found that using scenarios to get feedback from potential users is an excellent and inexpensive way that can be used to generate and prioritize conceptual ideas for new ubicomp systems or applications, in addition to focusing the actual contexts of use. While the existing literature suggested benefits of this approach, it was uncertain from these accounts whether it would be suitable for probing barriers to ubiquitous computing adoption. Likewise, there were hesitations with using the prototypes to demonstrate features, fearing that users would not be able to fully appreciate the potential of computationally enhanced everyday objects integrated within the actual context of use. Neither of these initial apprehensions materialized in the study. Realizing this provides excitement about the rapid prototyping features of systems such as the Real World Interfaces (RWI) toolkit described by McCrickard [2003] and their potential to augment textual scenario descriptions as tools for use in the scenario-based design of ubiquitous computing systems and applications. The combination can enable designers to develop functional models of real-life use of new products and to present design ideas to the users, which could otherwise be difficult or expensive to prototype or simulate.

While many people might not have heard of ubiquitous computing before, they do not seem to have a hard time transitioning from the traditional user interface to ubiquitous interfaces, at least those embedded in everyday objects like the ones used in this experiment. While this is encouraging, it is worthwhile to note that people did not use these interfaces for more than an hour in the context of this study.

Owing to the nature of ubiquitous computing, using different objects within the environment to present the same kind of information is going to be the norm. In this study, it is clearly apparent that different objects are only good at conveying certain types of information, given their properties. This accentuates the need to better understand the system design and usage factors because we do not yet have any universal metaphor or framework within which interface design or interaction decisions can be made, just as the current computing paradigm has the desktop metaphor and its embodiment in GUIs (graphical user interfaces) and WIMP (windows, icons, menus and pointing devices).

Ubiquitous computing interfaces can be preferred over desktop interfaces in certain situations. Although this might sound trivial, it is an indication that people are willing to make the transition from the currently predominant desktop paradigm to the ubiquitous computing. Paying attention to the community impact of ubiquitous computing systems can help discern situations where ubiquitous computing will be successful. This is important given that people will interact with more complex environments than the isolated computer systems or interfaces that we use today. While there is not yet an accepted approach on how to create usable computer systems even within the current desktop paradigm, there are many factors in the quagmire.

4. CONCLUSIONS AND FUTURE WORK

Research in ubiquitous computing presents a new set of challenges that differentiate it from most of the other computing challenges. Eminent among these is the need to support dynamic user goals as well as usage situations, which are entwined in a complex social environment. Besides compelling this work to reconsider many of the basic things currently taken for granted, like how users should interact with a system, this work contended with how to design new systems and user interfaces that support mobility, as opposed to sedentary use; systems that are "invisible" as opposed to being in users' faces all the time; systems that support different multiple devices as opposed to a single device; systems that allow multimodal interaction and support implicit interaction, as opposed to always having to wait for or rely on the user to directly provide input.

The ultimate ambition of ubiquitous computing technology is to be able to serve users anywhere, at anytime. However, taking into account the dynamic nature of user needs and usage situations, this is a non trivial undertaking. In essence, it is a fundamental change that requires rethinking many of the conventional answers and processes that currently guide the creation of interactive systems. Designers will have to consider early design factors which relate to the things that users are willing to compromise in order to use ubiquitous computing systems. They need to take into account community factors that impact the use of these systems and how they perturb various relationships that people have built up over time. Thinking about system design factors that characterize ubiquitous computing during interaction design will help create successful user interaction experiences, while paying attention to usage factors during deployment and evaluation will enable designers to accurately validate the user experience.

The study explored the use of computationally enhanced everyday objects to convey different types of information and the ability of users to understand it. By focusing on young males with backgrounds in technology fields, the study targeted the "early adopters" who are most likely to use emerging technologies like ubiquitous devices. It is notable that, even for this population, there were reservations about when and whether the types of applications used in this study would be adopted. Certainly possible next steps are to extend these results by looking at other devices, other situations, and other user populations—using more controlled empirical testing and more public free-form testing, when appropriate—as exemplified by the Huang, Koster, and Borchers [2008] field observations of current, public large information displays.

An aspect that emerged in the study and that is beginning to receive attention in HCI literature is the notion that successful design of everyday objects used as computational interfaces requires designers to think beyond the common notion of HCI usability. Although this is a complex area, which we might not be able to understand until much more research, researchers are already scratching the surface by to exploring aspects like presence [Hallnäs & Redström, 2002], pleasure [Jordan, 2000], emotion [Norman, 2003], and other facets of human nature. Of course, either the interface or the user could be the channel of these phenomena, and the usage context (other devices, people, activities, and the environment) may play a role too.

Design methods like scenario-based design can be successfully used to design ubiquitous computing technologies that respond to needs that most users will find relevant. The power of scenario-based design lies in the fact that scenarios or "descriptions of people using technology" enable the discussion and analysis of how technology could reshape people's lives [Carroll, 2000; Carroll & Rosson, 2002; Rosson & Carroll, 2002]. Related to scenarios, claims isolate a specific piece of knowledge about a device, along with its upsides and downsides [Rosson & Carroll, 2002; Wahid & McCrickard, 2006].

Our ongoing work seeks to augment the scenario-based design process to make it more relevant to the design of ubiquitous computing systems [Ndiwalana, 2003] as well as engaging users in a participatory design process that enables the designer to more easily incorporate the interaction outcomes back into the design process [Ndiwalana et al., 2004]. This work seeks to capture design knowledge in a claims library that could be used by designers to leverage the work of others [Payne et al., 2003; Branham et al., 2007; Wahid & McCrickard, 2006]. By capturing and sharing the design work of others, the emerging field of ubiquitous computing can move from one of unbridled innovation to one of scientific progress.

5. REFERENCES

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