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Ubiquitous Computing Capabilities and User-System Interaction Readiness:

An Activity Perspective

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Abstract

Based on mobile computing technologies, ubiquitous systems enable people to access information anywhere and anytime. In addition to the capability of interactivity concerning inquiry processing based on user input through interfaces, ubiquitous systems may offer contextualization and personalization dealing with information filtering based on task contexts and user preferences, which help relieve user effort on the move. This study investigates how different combinations of these major ubiquitous computing capabilities affect user behavior. Using the unifying framework of Activity Theory, it conceptualizes user-system interaction as a tool-mediated activity, the different aspects of which are facilitated by interactivity, personalization and contextualization. It is hypothesized that such capabilities shape user experiences including sense of control, perceived understanding and motive fulfillment, which lead to how ready people are to interact with ubiquitous systems. The results from an experiment support the hypothesized relationships, and suggest that different capabilities interact with each other in their effects. The findings yield insights on how to take a systematic and balanced approach of ubiquitous system design to enhance user experiences.

Keywords: Ubiquitous Computing; Activity Theory; Interactivity; Personalization; Contextualization; User-System Interaction.

Ubiquitous Computing Capabilities and User-System Interaction Readiness:

An Activity Perspective

The advance of information and communication technology (e.g. cloud computing, wireless sensing) enables ubiquitous computing for users to access information services anywhere and anytime through mobile devices such as smart phones (Poslad, 2009; Li, Xu and Zhao, 2015; Xia et al., 2014). Though the detailed implementation varies from one system to another, there are some common design considerations, such as interactivity and personalization. They are related to the capabilities of a system that make it functional and effective: interactivity allows it to accept user input and respond with output (Burgoon et al., 2000), and personalization let it adapt the communication to user preferences (Thongpapanl and Ashraf, 2011). More noticeably, the emerging trend of context-aware computing allows a system to utilize contextualization for catering to users' needs with information processing relevant to their environment (Dey, 2001).

Despite the tremendous potential, the failure rate of such applications remains high, and a major reason is the insufficient consideration of user experience and requirement in system design (MobiThinking, 2013; Dwivedi et al., 2015; Ogara and Koh, 2014). What developers consider a good design may turn out unappealing to users. For example, some context-aware systems notify users of things available nearby when they come across some "points of interest" (e.g. restaurants), and such location-based services actually annoy many users (Zhou, 2015). Thus, the question "what kind of ubiquitous systems would people like to use?" is worth investigating for researchers and practitioners.

The way that people use a ubiquitous system depends on the capabilities it offers. For example, personalization does not require users to always indicate individual preferences. In different ways, interactivity, personalization and contextualization influence user experiences. Though they intend to enhance user experiences, actual effects are not always as expected. In addition, these capabilities interact with each other in their effects on user behavior. For instance, combining contextualization and interactivity by letting users make inquiries rather than passively receive information is more appealing to people (Sun, 2003; Goh, Lee and Razikin, 2015).

Previous studies have provided insights on how a single capability – interactivity (e.g. Burgoon et al., 2000), personalization (e.g. Thongpapanl and Ashraf, 2011) or contextualization (e.g. Barkhuus and Dey, 2003) – may affect user experiences. The implementation of a ubiquitous system, however, usually endows it with multiple capabilities. It is important to study their effects in a systematic way due to possible interactions. Yet these general design features are rarely considered in relation to one another, as manifested by stand-alone definitions of interactivity, personalization and contextualization (c.f. McMillan and Hwang, 2002; Greenberg, 2001; Riechen, 2000).

First of all, this study examines how the combinational use of ubiquitous computing capabilities in system design may affect user acceptance based on the understanding of their different roles in facilitating user-system interaction. For empirical evidence, it further develops a research model and conducts a factorial experiment to test the hypothesized relationships. Such a systematic investigation helps address the issues of concept vagueness and effect uncertainty among different capabilities. The findings may yield insights on how to take a holistic and balanced approach in the design of ubiquitous systems to enhance user experiences.

Research Background

Human-computer interaction (HCI) research deals with "the design, implementation and evaluation of interactive systems in the context of the user's task and work" (Dix et al., 1998, p.3). Existing studies of user behavior in this stream examine certain user experiences in interacting with various systems, such as interaction involvement (Burgoon et al., 2000). The understanding provides insight on how to improve the implementation of systems, especially interface design (Shneiderman, 1998). Due to the main focus on design, few HCI studies move on to address the question of how these experiences shape people's attitude towards using the systems. It is such an attitude – formed on the basis of user experiences with a system – that connects the previous use and future use of the system at the individual level (Jasperson, Carter and Zmud, 2005). Technology acceptance research in the information systems (IS) field, on the other hand, focuses on user attitude to address how likely an individual is to use a certain system but did not include system design into analysis (c.f. Venkatesh et al., 2003). Based on the notion that HCI research and IS research can shed light on each other for a better understanding of user behavior (Zhang et al., 2002), this study investigates how major ubiquitous computing capabilities affect user behavior together.

Rooted in social psychological theories such as Theory of Reasoned Action (Fishbein and Ajzen, 1975), technology acceptance theories examine user behavior in the unit of an action between a subject user and an object system. The behavioral outcome – intention to use a system – depends mostly on the cognitive evaluations of it, such as perceived usefulness and perceived ease-of-use in the well-known Technology Acceptance Model (Davis, 1989). Such evaluative perceptions hardly reflect specific experiences that users have in interacting with a system to capture the effects of particular ubiquitous computing capabilities on the continuous use. Thus, researchers called for a paradigmatic shift in the theoretical perspective of system artefacts and user behavior (Bagozzi, 2007).

This study adopts Activity Theory, a theoretical framework introduced to the HCI field in 1990s (Bødker, 1991), to study the relationship between ubiquitous system design and user attitude. Such a relationship is likely to be indirect: design choices shape user experiences, which then lead to attitude formation. Traditionally, HCI research focuses on design-experience relationship, and technology acceptance research focuses on experience-attitude relationship. In an effort to reach a better understanding of how ubiquitous computing capabilities influence user behavior, this study adopts the premises and principles from both research streams with a unifying activity perspective.

Activity Theory was initially developed by the Russian psychologist Vygotsky in the 1920's and was later elaborated by his followers, especially Leont'ev (cf. Kuutti, 1996). Unlike most social psychological theories that take the singular human action as the unit of analysis, Activity Theory views human behavior as an evolving system of mediated relationships among subjects, objects and tools (Leont'ev, 1978). The unit of analysis is an activity comprising a series of actions – something a subject is conscious of doing with an immediate goal – that are organized by the common motive to transform an object into an outcome with the help of all kinds of tools (Vygotsky, 1978, 1981).

Conceptual Framework

According to Activity Theory, information systems are tools that people use to accomplish certain tasks (Christiansen, 1996). The object that a user transforms is not a system but the digitalized data it retrieves, processes and stores. Through the interaction with a system, a person wants to obtain the information pertinent to the task at hand (Cane and McCarthy, 2009).

Thus, the motive for an individual to use a system is to transform raw data into meaningful information for a certain purpose. This motive defines the behavioral settings of user-system interaction, which can be called task context. Figure 1 depicts the relationships in such a tool-mediated and context-embedded activity.

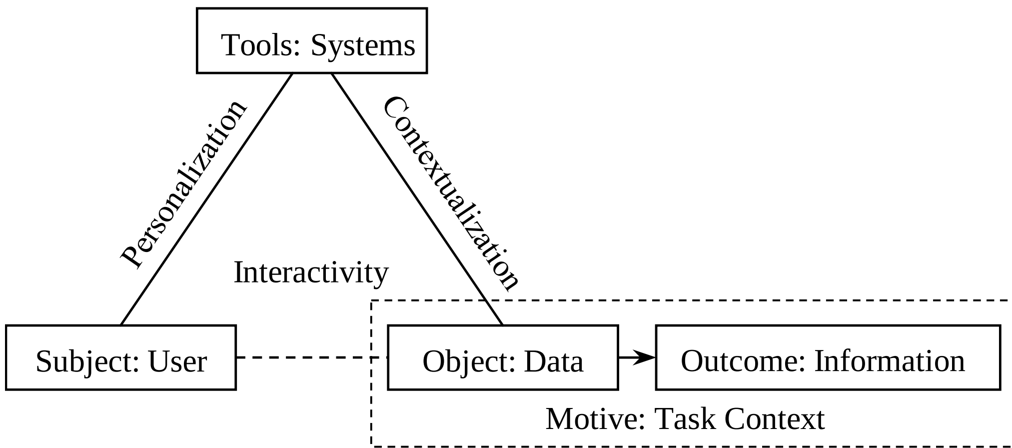


Figure 1. User-System Interaction and Ubiquitous Computing Capabilities

There is a mediated relationship between *user* and *data* through *system*. An individual cannot work on digitalized data without an information system, which is not a simple tool but a complex of software and hardware components. Compared with the action-based conceptualization, the activity perspective of user-system interaction examines user behavior in terms of the actions associated with relevant artefacts. To understand how ubiquitous computing capabilities shape user experiences, therefore, it is important to identify their roles in facilitating different actions in user-system interaction.

Interactivity deals with how a system facilitates users to specify input and receive output (Adiele, 2011). Abowd and Beale's (1991) interaction framework shows that input and output interfaces mediate the two-way communication between user and system. Based on Activity Theory, Bødker (1991) further indicates that such user interfaces give people the access to and control of data processing. Thus, interactivity bridges user-data gap through user interfaces that connect user-system and system-data relationships. Thus it is the fundamental design feature at the center of user-system-data triangle.

Personalization deals with how a system caters to user preferences regarding the ways of specifying input and receiving output (Gao, Liu and Wu, 2010). It is the communication rules – norms, procedures and customs regarding how to exchange information – that regulate such a two-way communication (Cushman and Pearce, 1977). A personalized system allows the customization of communication rules rather than making them the same for all users. Take the above-mentioned ubiquitous system to search for local points of interest for example, a personalized system may display results based on user preferences (e.g. distance, price). Thus, personalization is a design feature that directly affects user-system relationship.

Contextualization deals with how a system collects and utilizes contextual data to facilitate task undertaking for individual users (Abecker et al., 2000). For example, a ubiquitous system may detect where users are to narrow down the search results of local points of interest. Thus, contextualization is the design feature of a system to adapt data processing to real-time task context with the help of technologies (e.g. GPS and other sensor networks). A contextualized system does not just passively do what the users command, but actively engage in data processing to help people get meaningful information for the task at hand. Thus contextualization directly affects system-data relationship.

The triangular conceptualization of the relationships among user, data and system demonstrates how major ubiquitous computing capabilities including interactivity, personalization and contextualization facilitate different aspects of user-system interaction. From the perspective of users, interactivity allows them to specify exactly what kind of information they want to eventually get from a system, whereas personalization and contextualization help ease the effort with system-side pre-processing based on user preference and task relevance. The detailed design of a system such as interfaces, rules and procedures are based on capability choices. On one end, traditional systems require people to specify their needs in form of the input through user interfaces following pre-specified steps; on the other, location-based services utilize contextualization and personalization to obtain the output with minimal user involvement. To people on the move, the former approach may impose the effort beyond what they can handle, and the latter is based on the overreaching presumption that a computer system is able to know what they need in context.

The designs of most ubiquitous systems, therefore, strike a balance somewhere in between. How to combine different capabilities in an optimal manner demands a systematic investigation of their relationships and effects. Interactivity is the fundamental design feature related to the implementation of user interfaces that mediate user-data relationship. Contextualization provides further enhancement related to the employment of information technologies that converts from a reactive to a proactive system-data relationship. Personalization is another supplement from the customization of communication rules that enriches the traditionally uniform user-system relationship with diversified preferences.

Research Model

The major ubiquitous computing capabilities influence user behavior in different ways, as the research model illustrates in Figure 2. The outcome variable is user-system interaction readiness (USIR, simply "user readiness") that captures how prepared and willing an individual is to interact with an information system (Sun and Poole, 2010). Compared with the action-based construct of behavioral intention (i.e. whether or not to use a system), user readiness comprises the attitudinal dispositions toward the actions in a user-system interaction activity, including input willingness (IW), output receptivity (OR) and rule observance (RO). The behavioral consequence is design preference: an individual is likely to choose a design that he/she is ready to use. Unlike the other variables in the model, design preference is a categorical variable to capture the overt choice behavior, and its relationship with user readiness will be assessed differently from other linear relationships as indicated by the dotted line.

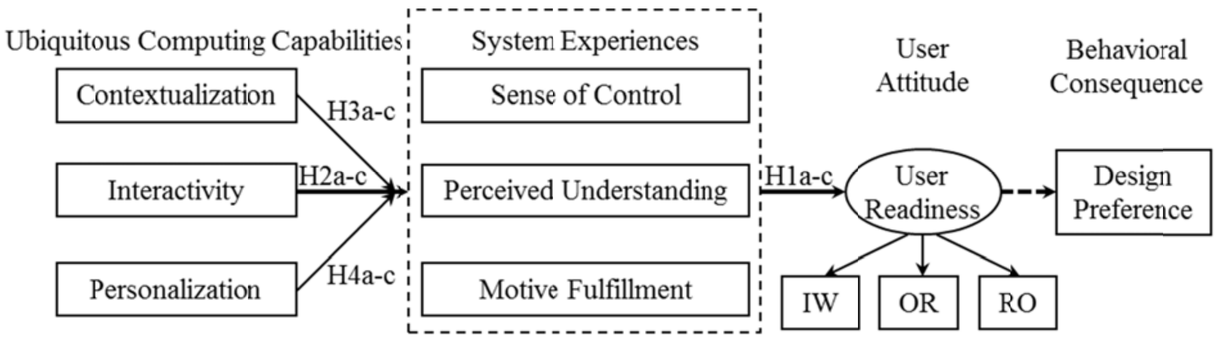


Figure 2. Research Model

User readiness is shaped by system experiences in terms of sense of control, motive fulfillment and perceived understanding that pertain to user input, system output and interaction procedure (Sun, 2012). Compared with commonly-used variables reflecting the properties of a system as the object in the action conceptualization such as perceived ease-of-use and perceived usefulness, these variables capture user experiences from the actions (i.e. specifying input, utilizing output, and following procedure) comprising the system-mediated and task-driven activity. Users may find a system easy to use and useful for some tasks but not the others, yet such “object properties” are supposed to remain stable. Sense of control and motive fulfilment, on the other hand, cover corresponding content domains but recognize that user experiences with a system are situated. Moreover, perceived understanding captures the process-aspect of experiences, which is largely ignored in technology acceptance research. Here are the research hypotheses to reconfirm the effects of system experiences on user readiness:

H1a: Sense of control has a positive effect on user readiness.

H1b: Perceived understanding has a positive effect on user readiness.

H1c: Motive fulfillment has a positive effect on user readiness.

System experiences related to control, understanding and fulfillment, in turn, are able to capture the effects of ubiquitous computing capabilities. Interactivity concerns user control, two-way communication and synchronicity (Guedj et al., 1980). Whereas two-way communication and synchronicity are the underlying requirements of this design feature, user control is particularly related to one's experience in communicative behavior (Brenders, 1987). Personalization, based on the premise that the coordination of perspectives in a dialogue contributes to mutual understanding (Foppa, 1995; Krauss et al., 1995), may let users feel that a system is able to understand them. Contextualization requires a system to adapt information processing to each task context. Because such a context defines user motive (Nardi, 1997; Suchman, 1987; Yaverbaum, 1988), contextualization is likely to enhance its fulfillment.

The effects of ubiquitous computing capabilities on system experiences, on the other hand, may exhibit a hierarchical structure. Interactivity directly affects how users interact with a system. A non-interactive system may just display all relevant records, but an interactive system allows people specify needs through user interfaces. Correspondingly, a ubiquitous system may simply list all local points of interest and leave the user to scroll through it, or allow users to narrow down the search with certain keywords (Wang, Hong, Xu, Zhang and Ling, 2014). Whereas interactivity directly facilitates user-system interaction, personalization and contextualization enrich the process. A personalized system tailors communication rules to user preferences, and a contextualized system adapts data processing to task contexts.

Thus, there are two levels of questions regarding the effects of ubiquitous computing capabilities on user behavior: 1) how different levels of interactivity make differences in user readiness; and 2) for an interactive system, how different levels of personalization and contextualization further influence user readiness? The first question concerns the necessity of interactivity to the formation of user readiness, and the second question concerns the sufficiency of personalization and contextualization to its enhancement. In the research model, therefore, interactivity has the primary effect, and personalization and contextualization have the secondary effects on user readiness through the mediation of system experiences.

As aforementioned, interactivity boosts sense of control by allowing users to specify information requirements. In addition, users are likely to get what they ask for and feel understood if a system gives timely and reasonable responses. Thus, interactivity enhances motive fulfillment and perceived understanding as well. This leads to the hypotheses below:

H2a: Interactivity has a positive effect on sense of control

H2b: Interactivity has a positive effect on motive fulfillment

H2c: Interactivity has a positive effect on perceived understanding.

Compared with interactivity, contextualization affects system-data relationship by allowing a system to collect and utilize contextual data. For some location-based services that push information to users, this design feature deprives users of control because it is the system rather than the user that makes the judgment on the relevancy of information. However, if a system allows users to specify their needs, such as in the case of information requirement elicitation (Sun, 2003), users may feel in control of the interaction process as well as their situations. Therefore, contextualization is likely to enhance sense of control when the system is interactive. Because the information needs of users depend on their task contexts, an interactive system of higher-level contextualization should give more pertinent results. This not only facilitates motive fulfillment as aforementioned, but also displays an understanding of user situations. For an interactive system, therefore, the above discussion suggests the following:

H3a: Contextualization has a positive effect on sense of control.

H3b: Contextualization has a positive effect on motive fulfillment.

H3c: Contextualization has a positive effect on perceived understanding.

Personalization affects user-system relationship by allowing a system to customize communication rules. Like a contextualized system, a personalized system is supposed to provide information to users in the ways that they prefer, which leads to perceived understanding as aforementioned. In addition, motive fulfillment is likely to be enhanced as long as the system is also interactive. Unlike task contexts, however, user preferences are subjective, and therefore people are aware of them and can make their own choices at any moment. Even if the information about user preferences is "accurately" inferred or elicited at a point of time, they may change later (Schneider and Barnes, 2003). Because people usually do not want others to impose personal decisions on them, a system of higher-level personalization is more likely to make users feel they are losing control. As a result, personalization as a means of information automation is generally not welcomed by users (Karat et al., 2003; Nunes and Kambil, 2001). These considerations lead to mixed effects of personalization, based on the condition that a system is interactive:

H4a: Personalization has a negative effect on sense of control.

H4b: Personalization has a positive effect on perceived understanding.

H4c: Personalization has a positive effect on motive fulfillment.

Methodology

Experiment Design

To test the research framework, it is necessary to create experimental treatments that demonstrate to participants different levels interactivity, contextualization and personalization. Treatments should be as different as possible for the maximization of systematic variance and minimization of error variance (Kerlinger, 1986), and each design feature was arranged to have two levels: high (indicated by ‘1’) or low (indicated by ‘0’). For example, the treatment that is high on interactivity but low on contextualization and personalization is indicated by I1C0P0. As shown in Figure 3, there are eight possible combinations but only five of them connected with solid lines are relevant to the questions that this study aims to address.

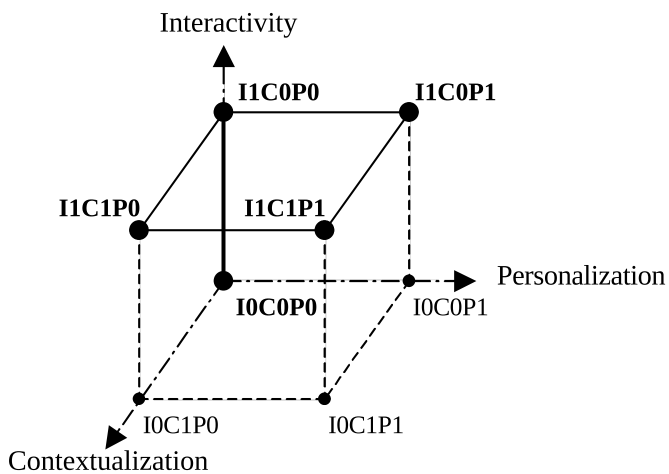


Figure 3. Experiment Treatments

To answer the first question whether interactivity is the necessary condition for users to be ready to interact with a system, subject responses can be compared between low-level interactivity and high-level interactivity in terms of treatments I0P0C0 and I1P0C0. Neither treatment is personalized or contextualized in order to filter out the noises from the two non-interactivity capabilities corresponding to the excluded treatments of I0C1P0, I0C0P1, and I0C1P1. If the result supports the necessity of interactivity to the formation of user readiness, the next step is to answer the second question whether contextualization and personalization enhance or weaken user readiness for interactive systems. Because of the likely interplay between these two capabilities (Chen and Pu, 2014), a two-by-two factorial design is used to test both main and interaction effects, leading to four treatments: I1C0P0, I1C1P0, I1C0P1, and I1C1P1.

A Web-based platform was developed to expose participants to different designs on a simulated smart phone, which creates an environment for demonstrating ubiquitous system features (Ogara and Koh, 2014). As illustrated by the screen shots in Figure 4, the designs varied in interactivity, personalization and contextualization. The laboratory scenario was that the participants tried to find a nearby nightclub in a downtown area to enjoy the music they like (e.g. rock, country and jazz etc.). The ubiquitous systems of different designs accessed the same database that contained the names, music types and locations of all the nightclubs in the area.

The implementation of five treatments is as follows: the system corresponding to the I0C0P0 treatment (not interactive, contextualized or personalized) lists all nightclubs in the city by alphabetic order; the system corresponding to the I1C0P0 treatment (interactive but not contextualized or personalized) allows a user to select a music type from a complete list first, and then gives relevant clubs in alphabetic order; the system corresponding to the I1C1P0 treatment (interactive and contextualized but not personalized) allows a user to select a music type from a complete list first, and then gives relevant clubs in order of distance from the user; the system corresponding to the I1C0P1 treatment (interactive and personalized but not contextualized) lets participants choose from a list of their favorite music types, and then gives relevant clubs in alphabetic order; and the system corresponding to the I1C1P1 treatment (interactive, contextualized and personalized) lets participants choose from a list of their preferred music types, and then lists the relevant nightclubs in proximity order.

Figure 4. Simulated Ubiquitous System Designs

At the beginning of a session, participants indicated their music preferences by selecting up to three of their favorite music types from 10 options. Then they used all five systems in a random order to complete the task. Before interacting with each system, a participant selected or was randomly assigned a location on the city map. Based on user input, a system generated a list of nightclubs and displayed them in hyperlinks. A participant clicked a link to view how far the place is and the type of music featured, and decided whether to confirm the selection or go back to the previous step(s) and search again. After a participant made a confirmation, a score was automatically calculated indicating his/her performance by taking into account how close the club was to the person, whether the club was of the person's favorite music type, and how quickly the person found the club information. After using each system, participants answered the questions of user readiness and system experiences.

A pilot study was conducted for manipulation checks. Forty-three students from an undergraduate class participated. They were asked to follow the experiment instructions and none of them indicated any difficulty in using the systems or answering questions. On average, the entire procedure took about 25 minutes. At the end, the participants were given a description of each treatment and asked the extent to which they agreed that its implementation was consistent with the description on seven-point Likert scales (from 1-strongly disagree to 7-strongly agree). As Table 1 shows, the 25th percentile is equal to or greater than the neutral point of four for all treatments, indicating the participants' perceptions of the treatments were in line with the intended operationalization.

Table 1. Manipulation Checks

	I0C0P0	I1C0P0	I1C1P0	I1C0P1	I1C0P1
Mean (Std. Dev.)	4.95(1.29)	4.91(0.87)	5.26(1.43)	4.98(1.14)	5.63(1.25)
25th Percentile	4.00	4.00	5.00	4.00	5.00
50th Percentile	5.00	5.00	5.00	5.00	6.00
75th Percentile	6.00	5.00	6.00	6.00	7.00

Subjects

The target population for this study is people who are likely to use ubiquitous systems. College students are found to be early adopters of such applications on smartphones (Kim, Chun and Lee, 2014). Thus the subject pool in this study comprised the college students who took a computer literacy course from a southwest university in U.S.A. Participation was voluntary and subjects were given extra credit for agreeing to participate in the study. In all, there were 106 participants and they had a good mixture of academic backgrounds and computer skills. In the experiment of repeated-measure design, each of them answered the same set of questions for five treatments, resulting in a sample size of 530 at the within-subject level.

Measurement

The dependent variable, user readiness, was measured with the short version of information system interaction readiness instrument developed and validated to study user system choice behavior (Sun and Poole, 2010). There were cognitive, affective and behavioral items that measured each of the three factors including input willingness, output receptivity and rule observance.

Sense of control was measured with three items adapted from Ajzen and Madden’s (1986) Perceived Behavioral Control scale. Perceived understanding was adapted from Cahn and Shulman’s (1984) Perceived Understanding Instrument, including two Likert items for Perceived Being Understood and Perceived Being Misunderstood, respectively, and one item asking how much a subject feels that a system generally understood him/her during the interaction. Motive fulfillment was measured objectively with the previously-mentioned performance score automatically calculated in terms of how quickly a participant found a nearby club that featured his/her favorite music types.

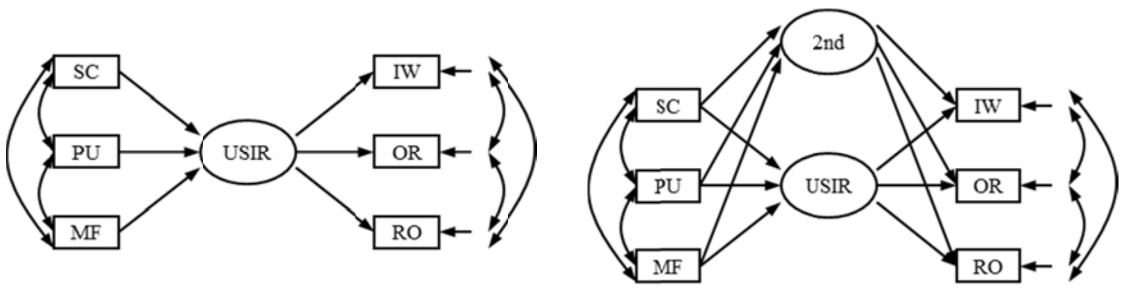
Results

First, reliability coefficients and descriptive statistics were obtained for all the measures as shown in Table 2. The reliability of the measures was assessed by taking the average of coefficient alphas across the five treatments. All coefficient alphas were above 0.7, indicating the internal consistency of responses to the measures was acceptable. This justified the calculation of index score for each one-dimensional construct by taking the average of its item scores. The mean index scores showed that sense of control, perceived understanding, motive fulfillment and user readiness factors varied significantly across different treatments. On average, the scores for the I0C0P0 treatment (not interactive, contextualized or personalized) were the lowest, and the scores for the I1C1P1 treatment (interactive, contextualized and personalized) were the highest. This result indicated that the treatment manipulation had expected effects as interactivity, contextualization and personalization were supposed to enhance system experiences and user readiness in general.

Table 2. Reliability Coefficients and Descriptive Statistics

	α	I0C0P0	I1C0P0	I1C1P0	I1C0P1	I1C1P1
Sense of Control	.79	2.38 (.77)	5.08 (.72)	6.07 (.67)	4.48 (.77)	6.05 (.69)
Perceived Understanding	.84	2.46 (.74)	4.40 (.91)	6.03 (.68)	5.18 (.73)	6.11 (.70)
Motive Fulfillment	N/A	2.00 (.68)	3.84 (.79)	6.15 (.68)	4.45 (.71)	6.70 (.42)
Input Willingness	.79	2.63 (.75)	4.58 (.83)	5.84 (.72)	4.72 (.72)	5.87 (.75)
Output Receptivity	.78	2.44 (.71)	4.57 (.81)	6.01 (.67)	4.84 (.68)	6.13 (.62)
Rule Observance	.78	2.31 (.73)	4.45 (.82)	5.88 (.70)	4.64 (.76)	5.91 (.75)

To test the research hypotheses of how ubiquitous computing capabilities influence user readiness through the mediation of relevant experiences, a two-step strategy was employed. The first step examines whether most of the variation in user readiness factors is explained by sense of control, perceived understanding and motive fulfillment. If the results support that they are indeed the major antecedents of user readiness, the next step will test the effects of ubiquitous computing capabilities on these system experiences. The first-order multiple-indicators/multiple-causes (MIMIC) model in Figure 5 depicts statistically sense of control (SC), perceived understanding (PU) and motive fulfillment (MF) lead to the formation of user-system interaction readiness (USIR), which has three indicators: input willingness (IW), output receptivity (OR) and rule observance (RO).



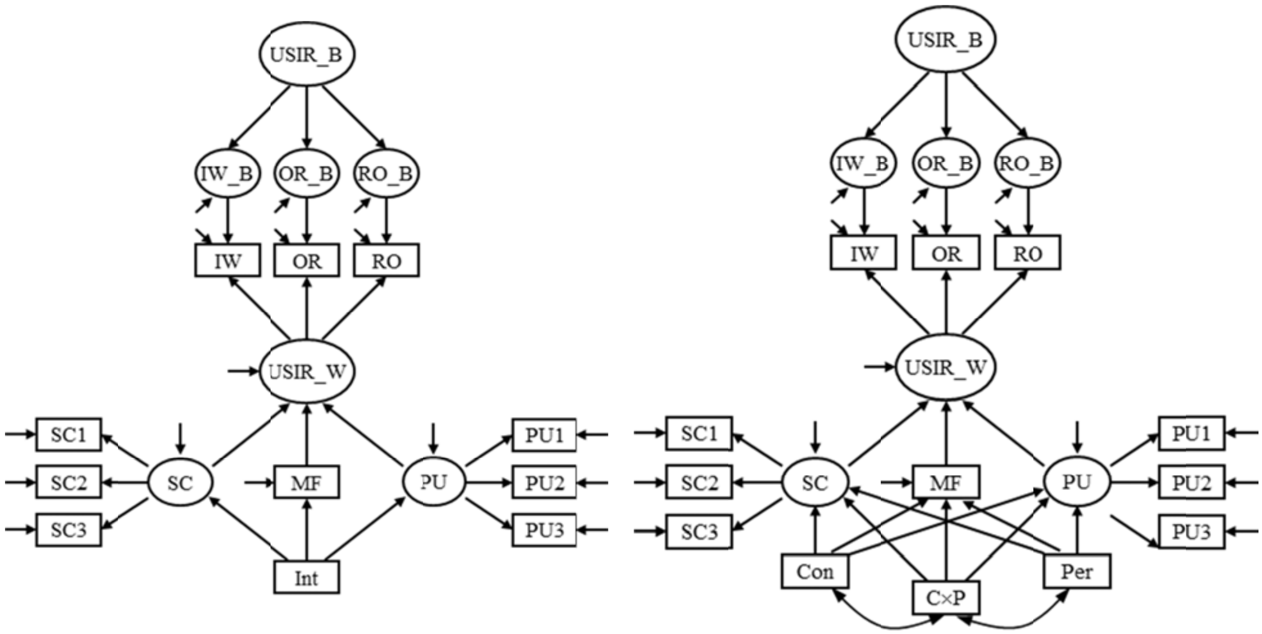
First-Order Model Second-Order Model

Figure 5. MIMIC Model of User Readiness

A multi-group analysis (N = 106) across five different treatments yielded an acceptable goodness-of-fit (χ^2/df = 1.74; RMSEA= .038; CFI = .992). The MIMIC model is equivalent to a first-order canonical correlation function, and its significance can be accurately tested with structural equation modeling (Fan, 1997). The chi-square difference test between the MIMIC model and the null model (in which the paths to and from the latent variable USIR were constrained to be zeros) indicated that the first-order canonical correlation function was highly significant ($\Delta df = 25$, $\Delta\chi^2 = 475.59$, p-value < 0.001). Also, the result of traditional canonical correlation analysis was obtained using SPSS: the canonical correlation coefficient was 0.95, and 86.7% of the variance of user readiness factors – IW, OR and RO – was explained by SC, PU and MF through the first-order canonical function. Because most shared variance between two sets of variables was explained, the second-order model did not improve the model fit significantly ($\Delta df = 25$, $\Delta\chi^2 = 33.56$, p-value = 0.12). These results suggest that sense of control, perceived understanding and motive fulfillment are the major antecedents of user readiness.

Then the hypothesized mediated relationships between ubiquitous computing capabilities and user readiness were tested. Because the study adopted repeated-measure (or within-subject) design, the appropriate statistical method for hypothesis testing should account for the variances at both between-subject level and within-subject level in order to minimize the error variance. For the analysis involving such hierarchical structure as well as mediated relationships and latent constructs, the multi-level structural equation modelling (SEM) method is appropriate (Goldstein and McDonald, 1988).

Figure 6 shows the two structural models tested: one for testing the primary effects of interactivity (Int) and the other for testing the secondary effects of personalization (Per), contextualization (Con) and their interaction term (CxP). In these models, user-system interaction readiness at the within-subject level (USIR_W) were indicated by input willingness (IW), output receptivity (OR) and rule observance (RO), and their shared variances across different treatments were accounted by the latent indicators (IW_B, OR_B and RO_B) of user-system interaction readiness at the between-subject level (USIR_B). Both sense of control (SC) and perceived understanding (PU) had three indicators corresponding to their measurement items. Objectively measured, motive fulfillment (MF) is a single-item variable.



Interactivity Contextualization and Personalization

Figure 6. Multi-level Structural Models

The multilevel structure models were simultaneously fit to the pooled within-subject and scaled between-subject correlation matrices obtained with Muthén's (1989, 1994) maximum-likelihood (MUML) method. The fit indices (Model 1: $\chi^2/df = 1.417$, RMSEA= .063, CFI = .992; Model 2: $\chi^2/df = 3.574$; RMSEA= .090; CFI = .970) indicated that the goodness-of-fit was acceptable for both models. Parameter estimates were given in Table 3. Consistent with the previous canonical correlation analysis, sense of control (SC), perceived understanding (PU) and motive fulfillment (MF) had positive effects on user readiness at the within-subject level (USIR_W) for both models. Thus these system experiences lead to the formation of user readiness, supporting hypotheses H1a-c. For the first model, interactivity had positive effects on SC, PU and MF, supporting hypotheses H2a-c. For the second model assuming the system is interactive, contextualization had positive effects on SC, PU and MF, which supported hypotheses H3a-c. Personalization, however, had positive effects on PU and MF but a negative effect on SC, which supported hypotheses H4a-c that personalization has mixed effects. In addition, the interaction term (CxP) had a positive effect on SC, a negative effect on PU, and non-significant effect on MF.

Table 3. Parameter Estimates for Structural Models

Level	Variable	Path	Model 1	Model 2
Within	Readiness-Within (USIR_W)	USIR_W ---> IW	1.000 (.947)	1.000 (.914)
		USIR_W ---> OR	1.086 (.979)	1.119 (.952)
		USIR_W ---> RO	1.094 (.980)	1.105 (.939)
	Sense of Control (SC)	SC ---> SC1	1.000 (.950)	1.000 (.854)
		SC ---> SC2	.946 (.950)	1.183 (.906)
		SC ---> SC3	.903 (.966)	1.085 (.858)
	Perceived Understanding (PU)	PU ---> PU1	1.000 (.955)	1.000 (.902)
		PU ---> PU2	1.067 (.949)	.982 (.889)
		PU ---> PU3	.955 (.954)	.927 (.887)
	System Experiences	SC ---> USIR_W (H1a)	.229 (.328)	.337 (.350)
		PU ---> USIR_W (H1b)	.472 (.495)	.347 (.430)
		MF ---> USIR_W (H1c)	.210 (.205)	.168 (.312)
	Interactivity (Int)	Int ---> SC (H2a)	2.841 (.953)	/
		Int ---> PU (H2b)	1.935 (.888)	/
		Int ---> MF (H2c)	1.846 (.911)	/
	Contextualization (Con)	Con ---> SC (H3a)	/	.914 (.637)
		Con ---> PU (H3b)	/	1.685 (.983)
		Con ---> MF (H3c)	/	2.301 (.898)
	Personalization (Per)	Per ---> SC (H4a)	/	-.548 (-.382)
		Per ---> PU (H4b)	/	.797 (.465)
		Per ---> MF (H4c)	/	.606 (.236)
	Contextualization x Personalization (CxP)	CxP ---> SC	/	.512 (.309)
		CxP ---> PU	/	-.733 (-.370)
		CxP ---> MF	/	$-.049^{ns}$ (-.016)
Between	Readiness-Between (USIR_B)	USIR_B ---> IW_B	1.000 (.916)	1.000 (.790)
		USIR_B ---> OR_B	1.668 (1.052)	.944 (.837)
		USIR_B ---> RO_B	1.363 (.767)	1.174 (.916)

Note: Standard estimates were given in parentheses. All estimates except the one with the superscript of “ns” were significant at 0.001 level.

SEM is able to test mediating effects in a straightforward way (Brown, 1997; Mackenzie, 2001). The direct paths from ubiquitous computing capabilities to user readiness at the within-subject level (USIR_W) were added to the structure models to test whether sense of control, perceived understanding and motive fulfillment were really the mediators. Consistent with the hypothesized mediated relationships, all the direct paths added to the models were not significant (Int->USIR: p-value = .662; Con->USIR: p-value = .118; Per->USIR: p-value = .745; CxP->USIR: p-value =.397).

At the end of the experiment, each participant indicated which design he/she liked the most. There were five choices, making it hard to predict the multi-way (as opposed to binary) categorical variable statistically. Thus the relationship between user readiness and design preference was assessed in a more descriptive manner. Out of 106 participants, 66 (62.26%) and 37 (34.91%) chose the designs that correspond to their highest and second highest user readiness scores respectively. For the 37 participants, their highest and second highest scores were quite close as the average and standard deviation of score differences were 0.32 and 0.26 respectively on a seven-level Likert scale. This supported that user readiness makes a difference in design preference.

Conclusion and Implications

Based on Activity Theory, this study investigated how ubiquitous computing capabilities in terms of interactivity, personalization and contextualization affect user behavior. It conceptualized user-system interaction as a tool-mediated and context-embedded activity to transform raw data into meaningful information. Such a perspective provides the insights on the relationships among user, system and task. Based on such an understanding, a research model hypothesizes that ubiquitous computing capabilities influence user-system interaction readiness through the mediation of system experiences including sense of control, perceived understanding and motive fulfillment. The results suggest that interactivity is necessary for the formation of user readiness toward ubiquitous systems, and for interactive systems, contextualization enhances user readiness but personalization has mixed effects.

The main limitation of this study is related to the laboratory nature of the experiment used to test the research model. Compared with studies carried out in real world, laboratory studies are capable of giving the researcher a great deal of control. However, experiment treatments are typically simplified to enhance the effect size and they may not be very realistic. Unlike the dichotomous treatments (i.e. high vs. low) of interactivity, personalization and contextualization in this study, real systems vary in degrees regarding these capabilities. The use of student sample also places a limitation on the generalizability of results. Thus, the results obtained from laboratory studies involving student subjects are more appropriate for testing theoretical relationships than answering practical questions (e.g. evaluation of an actual system design) (Peterson, 2001). Future studies on the effects of ubiquitous computing capabilities on user behavior may require that field studies be conducted in actual task settings with real ubiquitous systems. One challenge in doing so is how to assess and control their differences in terms of interactivity, personalization and contextualization. An evaluation scheme of ubiquitous computing capabilities, therefore, needs to be developed before such studies can be conducted.

Despite the limitations, there are several theoretical and practical implications. First of all, the activity perspective helps define major ubiquitous computing capabilities in terms of how they facilitate different aspects of user-system interaction. Compared with the action-based frameworks (e.g. Technology Acceptance Model and Theory of Reasoned Action), this perspective does not treat an ubiquitous system as an object, but rather a complex tool comprising user interfaces, communication rules and information technologies. These artefacts, implemented in different ways, endow ubiquitous systems with different capabilities in terms of interactivity, personalization and contextualization. By incorporating system characteristics into analysis, the activity perspective helps break the black-boxed and abstracted notation of "information system" (Sun and Bhattacherjee, 2014).

In theorizing how ubiquitous computing capabilities influence user attitudes, this study includes relevant user experiences in interacting with ubiquitous systems as the mediators between two. Unlike simple causal theorizing, such a systematic deliberation on the multi-layer relationships taps the differences caused by system design on user behavior. Thus, the model provides a meaningful explanation of why people prefer to interact with some systems rather than others due to the differences in their designs. Simple causal theorizing based on user summary evaluations, on the other hand, may tap only secondary effects, rather than the real effects caused by ubiquitous computing capabilities. For instance, in some studies users are asked to judge the action of using a system as generally favorable or unfavorable and report their attitudes accordingly. Though this type of causal relationships can be found to be highly statistically significant, it does not provide much insight into what specific experiences that people have in using particular systems and how such experiences lead to their attitudes toward using the systems for similar purposes later.

Beyond the extant research focus on one capability at a time, the systematic investigation of interactivity, contextualization and personalization reveals how they interact with each other in shaping user experiences. In contrast to traditional systems, ubiquitous systems feature context-aware computing, which by itself deprives user control (Barkhuus and Dey, 2003), as in the case of location-based services. Yet this study shows that contextualization actually strengthens people's sense of control when interactivity is present so that they can decide when and where to get what information. To users, therefore, it is fine for a system to filter relevant information based on their environment as long as they initiate the process and have the final say.

Whereas contextualization can be regarded objectivity-oriented pertaining to real-time situations, personalization is rather subjectivity-oriented in dealing with users' current preferences in mind that a system presumes to know based on their previous indications and activities. The gap explains why personalization almost always weakens sense-of-control. Nevertheless, the negative effect of personalization can be mitigated by the co-implementation of contextualization as indicated by their positive interaction effect (i.e. CxP ---> SC in Table 3), which suggests that the effect of personalization becomes less negative when contextualization is present. Together with interactivity, both capabilities are also conducive to perceived understanding and motive fulfillment (their negative interaction effects in Table 3 are largely due to the law of diminishing marginal utility, like 1+1<2), leading to overall user readiness enhancement.

For practitioners, the systematic examination of the relationship between ubiquitous computing capabilities and user readiness may help them improve the design and implementation of ubiquitous systems in order to attract and retain users. First of all, the instrument and framework validated in this study provides the means to evaluate different system designs. Based on user responses, developers can assess the implementation of user interfaces, communication rules and information technologies that lead to different levels of interactivity, personalization and contextualization. In particular, they can measure user readiness and relevant system experiences including sense of control, perceived understanding and motive fulfillment. If the score of user readiness is somewhat low due to the relatively negative responses on one or more of system experiences, developers can find out which aspects of design need to be improved. For example, if users perceive lack of understanding from a design, the design may be insufficient in personalization and the developers can improve relevant communication rules to provide more tailored information to user preferences.

The results suggest that ubiquitous computing capabilities are not independent from each other in influencing user behavior. Thus, developers need to take the impacts of all of them into account and try to strike the balance. If a system in the above example is redesigned to be highly personalized for its users but they exhibit even lower readiness, the developers can check whether the design leads to lower sense of control. If so, the developers may revise the communication rules of the system to make them less obtrusive to the users, redesign the interface to give users more choices, and/or implement real-time information technologies to adapt to user current situations. After these improvements, the developers can further check whether they have expected effects on user behavior by measuring user readiness and system experiences again. Through this evolutionary and user-centered approach, developers can make sure that the final design would lead to a system that people like to use.

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Appendix: Measurement Items

User-System Interaction Readiness

<u>Input Willingness</u>

I have positive feelings toward the design of user interfaces.

I think the interfaces are appropriately designed for user input.

The interfaces make me hesitant to specify what I want.

<u>Output Receptivity</u>

I feel bad about how the results are generated and displayed.

I believe the output is given for my benefit.

I am receptive to the information given by the system.

<u>Rule Observance</u>

I like the way of interacting with the system.

I doubt that the logic of interaction process is reasonable.

I am inclined to follow the implicit rules in interacting with the system.

Perceived Understanding

The system seemed to understand what I was trying to do.

I found that the system did not comprehend my need at all.

How much do you believe that the system generally understood you?

Sense of Control

It was mostly up to me whether or not I got what I was looking for.

There was very little I could do with the system to find the information I need.

How much control did you have over the process?