International Journal of Computer Information Systems and Industrial Management Applications.
ISSN 2150-7988 Volume 3 (2011) pp. 912-923

The Impacts of Wayfinding Affordance on User Experience in Virtual Worlds

Gilok Choi

School of Library and Information Science, Pratt Institute
144, West 14th Street, New York NY 10011 USA
gchoi58@pratt.edu

Abstract: **With rapidly changing advances in technology, VEs have gained much attention from both scholarly and practitioner communities. In spite of intense and widespread efforts, most VE-related research has focused on the technical aspects of applications. By contrast, the necessary theoretical framework needed to assess the quality of interfaces and designs has not yet been fully developed. This research, as a response to such challenges, investigates usability issues of VE interface and design. For this purpose, four different experimental conditions were set up and tested.**

The study results show that the design of wayfinding affordance has significant effects on users' perceptual experience as well as their task performance. Task performance was significantly better where affordance cues were provided independently from the VE interfaces. In addition, the study indicates that the fixed and, therefore, stable interfaces provides a better sense of presence whereas manipulative and customizable interfaces offers a greater level of playfulness. The research findings also point out that the design of 3D interfaces has a greater impact on non-expert users than on expert users.

Keywords: Virtual Worlds, wayfinding, usability, presence, playfulness, user experience

I. Introduction

With rapidly changing advances in technology, Virtual Environments (VEs) have gained much attention from both scholarly and practitioner communities. A three-dimensional VE is a computer representation of a real or an imaginary space through which and in which users can navigate and dynamically interact with objects in real time [15].

Since the introduction of VEs, the advancement of technology has been dramatic and the application of Human Computer Interaction (HCI) knowledge has helped to improve VE interface and usability [3]. However, concepts and interactions associated with VEs are considerably different from those of traditional two-dimensional applications, and therefore new environments for VEs cannot rely solely on principles and guidelines developed for standard two-dimensional user interfaces [37].

Because there are few comprehensive and systematic approaches with regard to the design of new VE applications, it is critical to address the challenges posed by the development of many new systems and to create a theoretical basis for the design of VE interfaces [38]. The current study therefore seeks to address some of these issues by investigating the effects of wayfinding affordance design on users' task performance and perceptual experience in 3D desktop VEs.

This research focuses particularly on three-dimensional VEs in a two-dimensional desktop application. Although the majority of current industry applications are represented with desktop VEs, not many studies have investigated VEs in a desktop environment [31]. Desktop VEs offer new possibilities and challenges for innovative user interfaces that can be realized only when VEs are balanced against the usability challenges from which most current three-dimensional VE systems suffer [19].

II. Background

A. Improving usability with wayfinding affordance

People move through real-world environments for the purpose of reaching a destination or simply to explore. When this common task is transferred to a virtual world, complications and difficulties arise due to the absence of real world constraints such as gravity, the sense of time flow and realistic motion cues [14].

Navigation in VEs refers to "the task of moving the viewpoint within a 3D space" [4]. According to Bowman et al. [5], there are two major reasons that navigation in VEs has emerged as one of the most critical issues in VE research. First, navigation is the most universal and common interaction task in 3D user interfaces. Second, it often supports other tasks and this secondary nature of the task increases the need for usability [5].

Navigation consists of both cognitive and motor components, and the cognitive part of navigation is called wayfinding [5]. Wayfinding in VEs is more difficult to support than in the real world because VEs lack many of the real world physical cues and affordances [14]. For this reason, wayfinding has been one of the major challenges in the design and development of

VE systems [11]. Without effective means of moving through VEs, it is not possible for users to maximize their performance and experience.

One potential approach for addressing this problem is the enhancement of cognitive or perceptual affordances: that is, the addition of perceptual cues to virtual spaces [5]. The challenges in designing three-dimensional VE applications are, therefore, to identify principled rules governing users' experience with perceptual cues in virtual space.

Among various types of perceptual cues, maps are the most frequently and efficiently used affordance cues in VEs [8]. Maps are invaluable tools for wayfinding because they help users obtain survey knowledge directly that would otherwise require extensive navigation effort [12]. The integration of maps into VEs offers numerous possibilities for developing new forms of maps and map use that can utilize the unique characteristics of VE features, such as user-map interactivity, user-environment immersion and varying information intensity in the display [20]. However, the use of maps requires repeated switches between the egocentric and exocentric perspectives as well as mental rotations that, in turn, require significant mental efforts and, for that reason, are difficult to perform [8]. Maps in VEs can be presented in two different ways. One is as a separate GUI from a 3D world, referred to in this study as *detached affordance cues (DAC)*, and the other is as an inclusive element of the 3D environment referred to here as *embedded affordance cues (EAC).*

As detached affordance cues, maps can be rendered separately from internal objects in virtual spaces: that is, maps can be presented next to or on top of a 3D world as a separate layer [3]. The design of the map as a detached affordance cue facilitates active seeking of information [1]. Although artificial, this feature allows users to explore the environment more actively [1]. On most desktop-based 3D user interfaces, detached affordance cues have become popular because users can take advantage of those cues whenever they need to [5]. An interesting aspect of detached maps is that if detached cues are critical for users to make sense of an interface, it seems likely that users will recognize maps as a real part of the environment [1]. In a sense, affordance cues function as an augmented reality system [1]. However, the main shortcoming of this approach is that users need to switch between two different GUI modes [5]. Detached maps also fill a large portion of the display and, thus, block other objects and the environment [5].

As an alternative, maps can be implemented as part of the VE interface. This approach offers the most natural way of presenting affordance cues without blocking or limiting the users' visual fields. The main problem of this approach, however, is that it may affect the effectiveness of maps. In other words, maps as *embedded affordance cues* are not always visible and, therefore, users must remember the locations of maps and move to them, when necessary.

B. Perceptual Experience

1) Presence

One of the potential characteristics of future interfaces is compelling illusion that invites users to feel a sense of embodiment and presence in a computer-simulated environment [2]. There exists a clear distinction between users' perception that they are within (or interacting with) a virtually structured environment and their perception that the display is a mere projection of a three-dimensional model [41]. According to Riva [29, pp.89], "the soul of virtual reality (VR) is a perceptual experience, that enables users to feel that they are 'being there' in the virtual world."

While VEs brought the issue of presence to the forefront of research in recent years, the illusion of presence is actually a product of all media [2]. Steuer claims what differentiates VEs from other media is the level of presence that influences the creation of presence as an explicit design goal as well as a leading indicator of VE usability [36]. According to Biocca [2], when users feel presence, they no longer view themselves as mere observers but rather see themselves as actual participants in events happening on the computer screen. Interface principles and usability guidelines has established a distinction between users and information environments, thereby creating a boundary around the computer and its information but presence in VEs removes this boundary, thus making the interface transparent [6]. The VE brings about a perspective shift, a transformation that allows users to move from the feeling of simply viewing a picture to that of being in a place, a transition from observation to experience, from being an external user to an internal participant, from the sense of just interfacing with a display to actually inhabiting an environment [21].

It has been suggested that users might perceive desktop VEs as less immersive than HMDs. However, Weiderhold et al. [44] found that changes in users' heart rates were not significantly different between HMD and PC interfaces in a study where users accessed simulated plane flights. A study by Tichon and Banks [39] also found that the degree of presence did not lead to differences between a semi-immersive screen and a desktop VE.

The importance of presence is often realized in the context of its potential relationship with performance. The results of many evaluations show that the greater the level of presence in VE productions, the better the performance [47]. A strong sense of being there also facilitates learning and increases the efficiency of training in the real world [7]. In general, when individuals interact with an environment, they gain personal, direct, tacit, non-reflective and even unconscious types of first-person experience [46]. In many cases, VEs can be a valuable substitute for real world experience by providing a first-person perspective and allowing for interactive, engaging activities that include a higher sense of presence [8]. In addition, the natural interaction in VEs reduces the unnecessary cognitive load [45]. In immersive VEs, interaction with technology becomes very natural, thus enabling users to focus cognitive resources on learning the content material rather than on attending to the interfaces [18]. In learning situations, the concentration of cognitive resources motivates and enables users to be more deeply involved in the educational materials [28].

Researchers believe that the positive relationship between presence and performance is constructed in certain situations. Held and Durlach [17] suggest that presence enhances performance when the tasks are wide-ranging, complex and uncertain because those situations ask users to extend their adaptive sensory-motor and problem solving skills to another physical environment. Future research should, therefore, seek to uncover when, and under what conditions, presence is a benefit or a detriment to performance and what is contributed by the sense of presence [3].

2) Playfulness

The most prominent psychological impact of presence is playfulness [26]. Playfulness is a subjective experience characterized by perceptions of pleasure and involvement [4]. It is "the ability to fool around, to spin out 'what if' scenarios" [24, pp.114]. In terms of user interactions with computers, playfulness is described as a situation-specific individual characteristic or tendency to interact spontaneously, inventively and imaginatively with computers [43].

Traditionally, playfulness has been studied from three main perspectives [43]; playfulness as a trait or a relatively-enduring characteristic of an individual [25]; play as an opposition to work [22] and, thus, a potential social influence during training; and playfulness as a temporary state [13]. One of the key findings of previous studies is that playfulness in computer interaction is a function of both individual trait(s) and psychological states(s) [48].

The term *trait* refers to individual predispositions to behave consistently over time across situations [23] whereas the term *state* is cued by the nature of the situation [34]. Playfulness as a state can be influenced by a situation, such as the technology being used or the challenge in interacting with the computer [48]. The state of playfulness is specifically conceptualized as *flow*.

The term *flow* is a psychological state of consciousness in which an individual feels happy, motivated and cognitively efficient and, therefore, totally satisfied beyond a sense of having fun, when actively engaged in an intrinsically rewarding activity [9]. Flow, therefore, has an important emotional component that denotes an intrinsic enjoyment of the task or activity in and of itself [48]. For this reason, flow is often called an *optimal experience* or *autotelic enjoyment*, as self-reinforcing and the highest level of well-being [10].

Flow is a multi-dimensional concept that incorporates diverse features of individual experience. The central properties of flow include a sense of pleasure, enjoyment, curiosity, complete involvement or engagement in an activity, attention focus, intrinsic interest, and volition [42].

Flow is different from the more passive concept of pleasure. Whereas pleasure is based on genetically encoded drives for survival that do not require much conscious effort (e.g., eating behavior), flow involves an active use of skills that entails enjoyment and growth [27].

Fixed **Movable**

Detached

Figure 1. Fixed Detached Affordance Cues (FDAC)

Figure 2. Switchable Detached Affordance Cues (SDAC)

Embedded

Figure 3. Fixed Embedded Affordance Cues (FEAC)

Figure 4. Portable Embedded Affordance Cues (PEAC)

Flow is also associated with situational interaction [32]. Situating conditions for computer interaction facilitates users' engagement and participation and is more likely to be achieved in spontaneous, informal and non-sequential characteristics of context-based presentation [32].

Similar to presence, the impact of playfulness is extensive, including increased user satisfaction [48], increased learning [42], time distortion [32], changes in attitudes and behavior [16], increased curiosity [42], intrinsic interest [42], positive subjective experience [18], enhanced creativity as well as more openness to possibilities offered by information technologies [40].

III. Research Questions

The questions that guided the research are the following:

1. What are the effects of wayfinding affordance design on the wayfinding task performance?
2. What are the effects of wayfinding affordance design on users' perceptual experience, particularly in terms of presence and playfulness?
3. What is the relationship between users' perceptual experience and wayfinding task performance?
4. What is the relationship between presence and playfulness? Are these two experiences interdependent?

IV. Methodology

A. Participants

Thirty-two participants were recruited at the University of Texas at Austin and from online community websites. Participants received a compensation for $15.

B. Experimental Design

The study employed a controlled experiment with within-participant factorial design. It is generally thought that the within-subject repeated measure is appropriate to examine VE interaction because this method minimizes participants' individual differences such as personality, ability and experience in using computers and VEs [4].

The participants were asked to accomplish four sets of comparable tasks in two sessions of trials with four different conditions. The experimental conditions were manipulated by the display of maps and signs that showed participants' locations and orientations on virtual university campuses.

Affordance cues were presented in one of two ways; one is as a separate GUI from the 3D world and the other is as an inclusive element of 3D VEs. Besides location of affordance cues, this study considered the visibility of cues. The combination of location and visibility of affordance cues resulted in four different affordance conditions; the Switchable Detached Affordance Cues (SDAC) condition, the Fixed Detached Affordance Cues (FDAC) condition, the Portable Embedded Affordance Cues (PEAC) condition, and the Fixed Embedded Affordance Cues (FEAC) condition. Figure 1-4 show those four wayfinding affordance conditions.

In the FDAC condition, participants completed their tasks with a map and signs that were independent from the 3D virtual environment and fixed on the top left corner of the screen. In the SDAC condition, participants performed their tasks using a detached map. The SDAC condition used a map separate from the 3D VE, similar to that in the FDAC condition except that in the SDAC condition, users were able to control visibility and location of the map and signs. In other words, users could toggle maps on and off and move on a screen as desired.

In contrast, in the FEAC condition, participants carried out their tasks with maps and signs that were created as objects in the VE and that were fixed in certain locations. Finally, in the PEAC condition, participants accomplished their tasks with a built-in map and signs that moved as participants changed their location.

Table 1 shows four experimental conditions defined by visibility and location of cues. For two sets of sessions, two virtual university campuses (University 1, 2) were constructed with ActiveWorlds as shown in Figures 5 and 6.

The combinations of experimental conditions and university models for the two sets of sessions resulted in 48 different treatment cases. The order of universities and experimental conditions were counterbalanced to minimize participants' learning effects and reduce fatigue. Thirty-two participants were randomly assigned to one of 48 cases, systematically skipping 16 cases.

Visibility of Cues / **Location of Cues**	**Fixed**	**Movable**
Detached	FDAC (Fixed Detached Affordance Cues)	SDAC (Switchable Detached Affordance Cues)
Embedded	FEAC (Fixed Embedded Affordance Cues)	PEAC (Portable Embedded Affordance Cues)

Table 1. Experimental conditions defined by visibility and location of cues

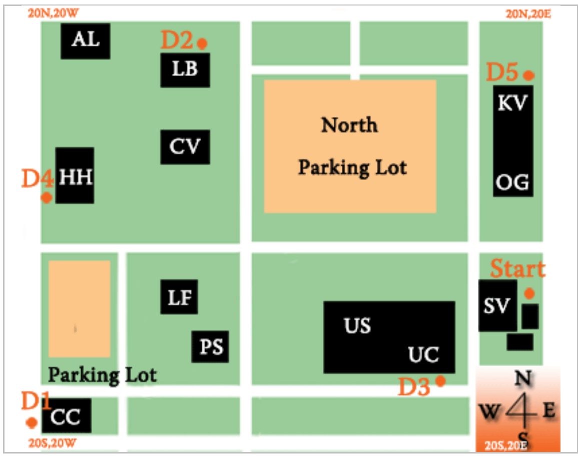

Figure 5. University model 1

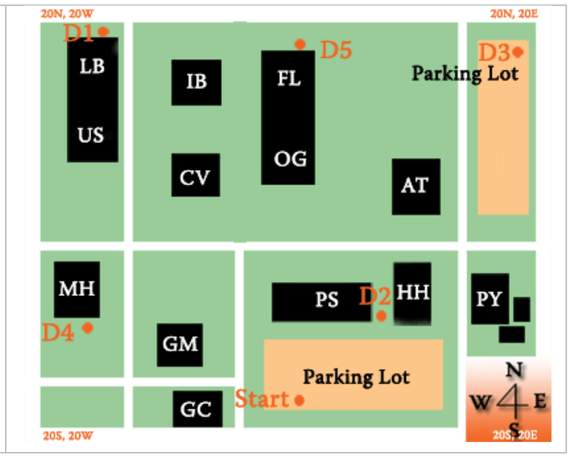

Figure 6. University model 2

C. Measurement

The experiment was conducted using a within-participant design with the type of wayfinding affordance cues as the main independent variable implemented with maps and signs that informed participants of their location and orientation on the virtual university campuses.

The dependent variables were presence, playfulness and task performance. Responses to the presence and playfulness questionnaire were recorded on a 1-to-7 Likert-type scale for which the higher score indicated higher reported presence and playfulness. The presence questionnaire was developed for this research based on Slater and colleagues [33], and Witmer and Singer [49].

The playfulness scores were evaluated with a questionnaire based on Skadberg and Kimmel [32]. To complement the Likert-type scale, an open-ended questionnaire with a short interview was given to participants at the end of the procedure.

Finally, the task performance was evaluated by task completion time, path that means the number of navigation steps taken by the participants, perceived task difficulty and user satisfaction with task performance. Task difficulty and satisfaction were rated on a 7-point Likert scale.

D. Equipment

Participants used keyboard arrow keys to move forward and backward a fixed distance on each key press and to turn left and right by a fixed angle on each key press. The viewpoint was fixed to "third-person," and visibility to 200 meters. The experiment was performed using a personal PC and a 17-inch monitor with 1042×768 displayed pixels and 24 bits color depth.

E. Procedure

After participants completed a consent form, and background questionnaire, a moderator explained the multi-part procedure for the session and the use of wayfinding aids followed by exploration phases. Then, participants were assigned randomly into one of the 4 experimental conditions. In the first condition, participants completed 3 sets of searching and object manipulation tasks to their satisfaction, and then answered a post-test questionnaire on their experience, including their perceived sense of presence and state of playfulness. Participants repeated this step three more times in different conditions on different university models with a 5-minute break.

F. Data Analysis

This study produced both quantitative and qualitative data for each type of wayfinding affordance design while performing their tasks. Analysis of Variance (ANOVA) repeated measure was performed for each of the dependent variables to identify the differences among four experimental conditions. Two-tailed correlation analysis was also conducted to examine the relationship among presence, playfulness and task performance. In order to identify the differences in performance and experience related to gender and VE expertise as well as computer literacy, independent sample t-tests were employed.

Qualitative data were also collected from both the exploratory tasks and the open-ended questionnaires to determine what subjective preferences for the four conditions and what specific thoughts and ideas participants had in comparing the four conditions. For the analysis of qualitative data, HyperResearch was used to identify commonalities and variances among participants.

V. Results

Thirty-two participants completed three sets of navigation and manipulation tasks in 3×2 (University Model 1) and 4×4 (University Model 2) block university environments. Task Performance was measured by task completion time, path, task difficulty and participants' satisfaction with task performance.

A. Task performance

1) Task completion time

The mean wayfinding task completion time was 509.66 (SD = 249.28). As presented in Table 2, The mean difference between the detached conditions and the embedded conditions was significant $F(1, 63) = 16.67$, $p < .001$, showing that the participants completed their tasks faster, using the detached

Condition		Minimum	Maximum	Mean (sec.)		SD (sec.)	
DAC	**FDAC**	169	830	393.09	446.28	120.08	195.91
	SDAC	186	1089	499.47		240.29	
EAC	**PEAC**	116	1345	512.41	573.03	273.92	280.57
	FEAC	281	1207	633.66		278.14	

Table 2. Task completion time in four wayfinding affordance conditions

conditions (FDAC, SDAC). The mean completion time was greatest in the FEAC condition with 633.66 (SD = 278.14) whereas it was smallest in the FDAC condition with 393.09 (SD = 120.08), indicating that the difference was more than 240 seconds.

In order to examine the effects of wayfinding affordance design on task completion time, ANOVA repeated measure was performed and the results revealed there were significant differences among the four conditions, $F(3, 93) = 12.77$, $p < .001$.

The subsequent pairwise comparisons yielded 121.25 (SD=.39.00), 134.19 (SD=30.80) and 240.56 (SD=44.10) mean differences for FEAC-PEAC, FEAC-SDAC and FEAC-FDAC that were all significant at the .01 level. The results suggest that participants were significantly slower in the FEAC condition than in other conditions. There were also significant mean differences of 119.31 (SD=44.86) and 106.38 (SD=39.30) for the FDAC-PEAC and the FDAC-SDAC at the .01 level and .05 level, indicating that participants in the FDAC condition were faster than other two conditions.

As part of the study, the 32 participants were divided into 2 groups of 16 each for the purpose of identifying difference among those who completed their tasks faster and those who were slower. The difference between fast and slow participants was greatest in the FEAC condition with 361.56 and least in the FDAC condition with 124.56. This indicates that the performance of the “slow” participants was not that different from that of the “fast” participants in the FDAC condition, implying that the FDAC condition was more favorable to the “slow” participants.

Regarding the difference between the “experienced” and the “non-experienced” participants, those participants who had previous experience with 3D virtual environments did significantly better than those who had no prior experience in all conditions, except in the FDAC condition. Table 3 shows that “non-experienced” participants in the FDAC condition completed their tasks in a comparatively shorter time than in other conditions, suggesting that the FDAC condition was more favorable to “non-experienced” participants. Table 3 also indicates that the differences among the “non-experienced” participants were much greater than among the “experienced” participants across the four different conditions, implying that the design of wayfinding affordance has more significant effects on “non-experienced” participants.

2) Path

Path refers to the number of steps that participants took in order to perform their tasks. As summarized in Table 4, The mean difference between the detached conditions and the embedded conditions was significant $F(1, 63) = 12.40$, $p < .01$, showing that the participants took significantly more steps in the embedded conditions (PEAC, FEAC). The mean was highest in the FEAC condition with 20.91 (SD = 5.89) whereas it was lowest in the FDAC condition with 16.03 (SD = 2.79).

ANOVA repeated measure was performed in order to examine the differences among the four wayfinding affordance conditions and the results revealed a significant effect of wayfinding affordance design on the number of steps taken by participants, $F(3, 93) = 9.99$, $p < .001$.

The subsequent pairwise comparisons indicated significant differences among the following conditions: FEAC-PEAC, FEAC-SDAC, and FEAC-FDAC. The results suggested that participants in the FEAC took significantly more steps than those in other conditions.

Condition	Participant Type	N	Mean	SD	Mean Diff	T	P
FEAC	Experienced	23	541.91	217.48	327.00	3.48	<.01
	Non-Experienced	9	868.11	289.26			
PEAC	Experienced	23	434.39	208.23	277.39	2.34	<.05
	Non-Experienced	9	711.78	330.60			
SDAC	Experienced	23	396.78	158.54	365.11	5.28	<.001
	Non-Experienced	9	761.89	216.42			
FDAC	Experienced	23	384.96	136.87	28.93	.60	
	Non-Experienced	9	413.89	60.66			

Table 3. T-test results between the “experienced” and the “non-experienced” participants in the four wayfinding affordance conditions regarding task completion time

Condition		Minimum	Maximum	Mean (sec.)		SD (sec.)	
DAC	FDAC	12	22	16.03	16.63	2.79	3.75
	SDAC	12	33	17.22		4.49	
EAC	PEAC	12	31	17.31	19.11	5.16	5.78
	FEAC	12	34	20.91		5.89	

Table 4. Path in the four wayfinding affordance conditions

The differences between the "fast" and the "slow" participants were significant in the SDAC (t=2.73) and PEAC (t=2.44) at the .05 level. The results suggest that the "fast" participants took a significantly smaller number of steps to complete their tasks in the SDAC and the PEAC.
However, there was no significant difference in the FDAC and the FEAC conditions, indicating that the performance of the "slow" participants was not very different from that of the "fast" participants in these two conditions.

3) Satisfaction

The mean satisfaction score was 5.02 (SD = 1.59) on a 7-point scale, indicating that participants were satisfied with their overall task performance.
When the difference between the detached and the embedded conditions were considered, significant mean difference F (1, 63) = 6.16, p < .05 was found, suggesting that the participants were more satisfied with their task performance in the detached conditions (FDAC, SDAC).
When each of the scores was considered, the mean satisfaction score was highest in the FDAC condition with 5.41 (SD =1.62) whereas it was lowest in the FEAC condition with 4.31 (SD =1.80).
ANOVA repeated measure test was performed in order to examine the differences among the four wayfinding affordance conditions and the results revealed a significant effect of wayfinding affordance design on participants' satisfaction with their task performance, F (3, 93) = 5.95, p < .01.
The subsequent pairwise comparisons indicated significant differences between the following conditions at the .01 level as shown in Table 5: FEAC-PEAC, FEAC-SDAC, and FEAC-FDAC. The results show that participants in the FEAC condition reported significantly lower satisfaction score than those in the other conditions.

4) Task difficulty

The overall mean difficulty score was 3.38 (SD = 1.47) on a 7-point scale. When the difference between detached and embedded conditions was considered, there was significant mean difference, F (1, 63) = 17.58, p < .01, demonstrating that the participants felt more difficulty in the embedded conditions (PEAC, FEAC).
The results of the ANOVA repeated measure revealed significant differences in difficulty scores among the four conditions F (3, 93) = 13.57, p < .001 and the subsequent pairwise comparisons also showed significant differences among the following conditions at the .01 level: FEAC-PEAC, FEAC-SDAC, and FEAC-FDAC. The results indicated a significant effect of wayfinding affordance design on task difficulty.
Regarding the difference between the "experienced" and the "non-experienced" participants, those who did not have previous experience with 3D virtual environments reported significantly higher difficulty score in the embedded conditions (FEAC, PEAC) and the results were significant at the .05 level.
However, there was no difference found in the difficulty scores between the "experienced" and the "non-experienced" participants in the two detached conditions (SDAC, FDAC). This means that the "non-experienced" participants felt comparatively more difficulty in the embedded conditions than in the detached conditions.

B. Perceptual Experience

Perceptual experience was measured by two concepts: presence and playfulness. This research found that the design of wayfinding affordance had statistically significant effects on participants' perceptual experiences, although the effects were not as great as those of task performance.

1) Presence

The overall average of presence score was 4.58 (SD = 1.10) on a 7-point Likert-type scale and there were significantly more participants who felt presence than those who did not (X^2 = 6.13 p < .05). This means that desktop virtual environments provided some degree of presence to the participants.
When looked at from the perspective of overall average, the participants in the fixed conditions had presence scores that were slightly higher than those for the movable conditions and the mean difference was fairly close to significant, F (1, 63) = .52, p = .065, showing that the participants tended to more presence in the fixed conditions (FDAC, FEAC) than in the movable conditions (SDAC, PEAC).
When each condition of the presence scores was compared, the mean presence score was highest in the FDAC with 4.91 (SD = 1.17) whereas it was lowest in the PEAC with 4.39 (SD = 1.10).

Condition		Minimum	Maximum	Mean (sec.)		SD (sec.)	
DAC	FDAC	2	7	5.41	5.28	1.62	1.39
	SDAC	3	7	5.16		1.11	
EAC	PEAC	2	7	5.22	4.77	1.58	1.74
	FEAC	1	7	4.31		1.80	

Table 5. Participants' Satisfaction with Task Performance

Paired Comparisons	FEAC	SDAC	PEAC	FDAC

FEAC	·	N.S.	N.S.	*
SDAC		·	N.S.	*
PEAC			·	*
FDAC				·

Table 6. Pairwise comparison of the four conditions with regard to presence (*: p < .05)

In order to identify the differences in presence scores among the four wayfinding conditions, ANOVA repeated measure test was performed and the results yielded the significant effects regarding wayfinding affordance design on presence, F (3, 93) = .2.97, p < .05.

The subsequent pairwise comparisons yielded differences for the FDAC-PEAC and the FDAC-FEAC at the .05 level and for FDAC-PEAC at the .01 level. The results suggest that the FDAC condition provided a significantly higher presence experience for the participants. The results of pairwise comparisons are presented in Table 6.

Regarding the difference between the "experienced" and the "non-experienced" participants, those who had previous experience with 3D virtual environments reported higher presence scores in the detached conditions (FDAC, SDAC). In contrast, participants without prior experience reported that they felt more presence in the embedded conditions (PEAC, FEAC). However, an independent sample t-test did not reveal any statistical difference between the "experience" and the "non-experienced" participants.

In terms of task-speed, the "fast" participants reported higher presence scores in the moveable conditions (PEAC, SDAC) whereas the "slow" participants tended to feel more presence in the fixed conditions (FEAC, FDAC). However, the difference between the movable conditions and the fixed conditions were not statistically significant.

2) *Playfulness*

Playfulness is a subjective experience characterized by perceptions of pleasure and involvement [42]. The overall average of score was 4.66 (SD = 1.04) on a 7-point Likert-type scale and there were significantly more participants who felt playfulness than those who did not (X^2 = 6.13 p < .05).

When viewed from the perspective of an overall average, the participants in the detached conditions reported playfulness scores that were slightly higher than those for the embedded conditions, F (1, 63) = 6.58, p < .05, showing that the desktop virtual environments provided more playfulness to participants in the detached conditions (FDAC, SDAC).

When each condition of the playfulness scores was compared, the mean playfulness score was highest in the FDAC with 4.89 (SD = 1.06) whereas it was lowest in the FEAC with 4.44 (SD = 1.15). In order to identify the difference in playfulness scores among four conditions, ANOVA repeated measure was performed and the results showed that the effect of wayfinding affordance design on playfulness approached statistical significance, F (3, 93) = .2.60, p = .057.

The subsequent pariwise comparisons yielded differences for the FDAC-PEAC and the FDAC-FEAC at the .05 level as presented in Table 7. The results suggest that the FDAC condition provided significantly higher flow experience than the two embedded conditions (PEAC, FEAC).

C. Correlation among presence, playfulness and task performance

Pearson correlation coefficients indicate that presence and playfulness scores were significantly correlated with each other, across all four conditions (*r* = .797, p < .01 in FEAC, *r* = .734, p < .01 in PEAC, *r* = .732, p < .01 in SDAC, *r* = .796, and p < .01 in FDAC). This means that participants who reported feeling a greater sense of presence also reported feeling more playfulness. However, the results of correlation analysis revealed that task performance was not directly related to presence or playfulness.

D. Participants' subjective preferences

In order to understand participants' subjective preferences for and thoughts about the four experimental conditions, post-test questionnaires and an interview were conducted.

With regard to the Fixed Embedded Affordance Cues (FEAC) condition, participants mentioned that they had more chances to explore and appreciate the worlds and objects, such as sculptures, buildings and trees, rather than to focus only on tasks that led to their next destination. Participants also stated that the FEAC condition provided visually more appealing and perceptually more engaging environments. In addition, participants pointed out that the FEAC condition was most similar to the real world and such a realistic environment allowed participants to perform exciting and challenging tasks.

However, other participants pointed out that it was more difficult to accomplish wayfinding tasks in the FEAC condition because they felt easily disoriented and oftentimes became lost without necessary affordance cues at hand. Participants also stated that they attempted to memorize next destinations and routes while performing their tasks, and sometimes they were forced to guess their current location and orientation.

Paired Comparisons	**FEAC**	**SDAC**	**PEAC**	**FDAC**
FEAC	·	N.S.	N.S.	*
SDAC		·	N.S.	N.S.
PEAC			·	*
FDAC				·

Table 7. Pairwise comparison of the four wayfinding affordance conditions with regard to playfulness (*: p < .05)

In contrast to the FEAC condition, the participants reported that the advantages of the Portable Embedded Affordance Cues (PEAC) condition were its ability to support wayfinding task performance. Participants stated that wayfinding cues in the PEAC condition were more convenient to reference because those cues were always with them. The participants also pointed out that the location and visibility of affordance cues enabled them to complete their tasks easily by helping them to focus on their physical movements and destinations. However, participants who did not like this condition claimed that affordance cues in the PEAC condition blocked and limited their visual field and eventually interfered with their attention and perceptual experience.

Finally, participants stated that detached conditions, that is, the Fixed Detached Affordance Cues (FDAC) and the Switchable Detached Affordance Cues (SDAC) conditions, were more efficient and easier to use because the orientation and location information was immediately available by way of affordance cues and, therefore, participants did not have to remember environmental settings. Participants mentioned that these conditions were like having a map in their pockets to refer to when necessary. Another interesting finding about detached conditions is that even though few participants actually used the switching and moving functions in the SDAC condition, the majority of participants reported that the SDAC condition was more preferable than the FDAC condition and more user-friendly because it was more flexible and customizable in terms of visibility and location of affordance cues.

VI. Conclusion

The overall research findings indicate that the design of wayfinding affordance has significant effects on users' perceptual experience as well as their task performance. Task performance was significantly better where affordance cues were provided independently from the VE interfaces (FDAC, SDAC). With regard to perceptual experience, the fixed and, therefore, stable interfaces (FEAC, FDAC) provided a better sense of presence whereas the manipulative interfaces (PEAC, SDAC) offered a greater playfulness.

A. The effects of wayfinding affordance design on task performance

With regard to task completion time, the wayfinding affordance showed significant effects, favoring the Detached Affordance Cues (FDAC, SDAC) where the wayfinding affordance cues were provided separately from the 3D environments.

In general, fast participants showed superior abilities in map-reading, encoding environmental information and setting-up strategies to move through virtual space. However, the research findings suggest that participants' expertise played more significant roles in certain design conditions; that is, when wayfinidng cues were not always visible so that participants had to remember all the necessary environmental details. Actually, the performance of the "slow" participants was more significantly different from that of the "fast" participants in the embedded conditions, thus implying that these conditions were comparatively favorable to the expert users.

With regard to the difference between the "experienced" and "non-experienced" participants, experience participants performed significantly better in all conditions, except in the FDAC condition. Another interesting point is that in all four conditions, the performance of "experienced" participants was comparatively stable whereas the performance of the "non-experienced" participants changed substantially from condition to condition. This finding implies that the wayfinding affordance design has more significant effects on "non-experienced" participants.

The overall study results also provided strong evidence that the design of wayfinding cues significantly affected path. The research demonstrated that the participants took considerably more steps in the embedded conditions. However, the differences among the other three conditions (FDAC, PEAC and SDAC) were not great, suggesting that the location or visibility of wayfinding cues did not make significant differences to path as long as those cues were available to the participants. When the path of the "fast" and "slow" participants was compared, only the PEAC condition showed a difference, suggesting that the "slow" participants took a relatively more steps to accomplish their tasks when wayfinding cues were located in the center of the screen and, for that reason, interfered with their interaction with the 3D virtual environments.

Concerning satisfaction and task difficulty, the overall study results provided evidence that the design of wayfinding cues affected participants' satisfaction with their task performance and task difficulty, in favor of the detached affordance cues (FDAC, SDAC) conditions. As expected from the results regarding task completion time and path, participants' satisfaction and difficulty scores were significantly different in the FEAC condition compared to those of other conditions.

B. The effects of wayfinding affordance design on perceptual experience

Perceptual experience was measured in terms of two concepts: presence and playfulness. This research found that the design of wayfinding affordance had statistically significant effects on participants' perceptual experience although the effects were not as great as those related to task performance.

The study results indicate that desktop virtual environments provided some degree of presence to the participants. This finding is important because a controversy exists about whether users feel presence in desktop virtual environments. This research supports the argument that participants do, in fact, feel a sense of presence in non-immersive desktop virtual environments. Interestingly, the "non-experienced" participants reported slightly higher presence scores than the "experienced" participants although the difference was not substantially significant. Previous studies pointed out that when users are unfamiliar with VE systems, their lack of familiarity is likely to discourage their sense of presence [12]. However, the results from this study show that once the "non-experienced" participants felt comfortable manipulating VEs, they felt more presence perhaps due to heightened curiosity and inquisitiveness about using new technology.

When viewed from the perspective of overall presence average, participants in the fixed conditions had slightly higher presence scores than those in the movable conditions. It is noteworthy that the difference regarding presence scores appeared between the fixed (FDAC, FEAC) and movable (SDAC, PEAC) conditions. In the movable conditions, the wayfinding cues were always available and, it is assumed, positively affected participants' wayfinding task performance. However, these movable wayfinding cues were obviously artificial and the low presence scores may be due to the participants' awareness of interface. In contrast, the wayfinding cues in the FEAC condition were created as an object in the environment and, therefore, may have appeared to be more natural. Even though the wayfinding cues in the FEAC condition provided a poor environment for wayfinding task performance, it may have seemed to provide more immersive environments.

Another important point of these findings is that the participants' sense of presence was greater in the FEAC condition than in the SDAC and PEAC conditions, even though the participants' task performance was not as great as that in the FEAC condition. In other words, participants in the FEAC condition had a significantly more difficulties completing their wayfinding tasks but their presence scores were surprisingly high, thus implying that users' task performance was not directly related to their perceptual experience.

Concerning playfulness, the research found that desktop virtual environments provided some degree of playfulness for the participants. The overall results of this study also revealed that the design of the cues had significant effects on playfulness in favor of the detached condition, especially the FDAC condition. It is noteworthy that the concepts of presence and playfulness measure slightly different aspects of users' experience in virtual environments. For presence, the fixed conditions (FEAC, PEAC) provided a more favorable environment. However, for playfulness, the detached conditions (FDAC, SDAC) were preferable. This suggests that participants felt a greater sense of emotional pleasure and freedom in the detached conditions but that they felt a greater sense of cognitive presence or immersion in the fixed conditions.

C. The relationship among task performance, presence and playfulness

The importance of perceptual experience is often highlighted in the context of its potential relationship with performance. The results of this study, however, did not explicitly show a relationship between any of the perceptual experiences and wayfinding task performance, thus indicating that wayfinding task performance was not significantly related to the participants' sense of presence or playfulness.

The overall presence scores were higher in the fixed conditions whereas the participants' task performance was better in the detached conditions. These findings suggest that participants might feel a higher degree of presence even though they did not perform their wayfinding tasks well in certain environments. Actually, participants showed higher presence scores in the FEAC condition even though they took a substantially longer amount of time and were required to take more steps to finish their tasks. With regard to playfulness, the participants reported higher playfulness scores in the detached conditions where they accomplished their tasks in a significantly shorter amount of time that required fewer steps. However, correlation analysis did not show any direct relationship between playfulness scores and participants' task performance.

In looking at the relationship between presence and playfulness, the Pearson correlation analysis revealed that those two concepts were significantly related to each other, across all four conditions. However, it is noteworthy that participants showed higher presence scores in the fixed conditions (FDAC, FEAC) than in the movable conditions (PEAC, SDAC) whereas they reported higher playfulness scores in the detached conditions (FDAC, SDAC) than in the embedded conditions (FEAC, PEAC). These findings imply that although playfulness and presence are closely related, these concepts measure two different aspects of users' experience in virtual environments.

VII. Implications of the Study

One of the most important aspects of user interaction in virtual environments is wayfinding. Many users in 3D virtual environments experience difficulties in keeping track of their current locations and orientation while they are traversing virtual environments and, as a result, users spend considerable time and effort in figuring out spatial information [5]. Therefore, the design of VEs should consider appropriate wayfinding affordance cues, and those cues should be carefully presented to users to minimize wayfinding complexity [35].

Regarding task performance, the detached conditions (FDAC, SDAC) were more favorable for all users – but the FDAC condition was especially preferable for novices. Therefore, when designers of virtual environments need to support users' wayfinding task performance, it may be advisable to provide affordance cues that are independent of the 3D environment – as in the FDAC condition. The reason seems to be that in the FDAC condition, cues are more stable and immediately available so that users can move about quickly without giving much thought to their next destination.

With regard to perceptual experience, even though playfulness and presence are related, it is assumed that those concepts measure two slightly different aspects of users' experience in virtual environments. Therefore, when designers of virtual environments want to support users' sense of presence, the fixed conditions (FDAC, FEAC) appear to be preferable. Especially for "expert" users who have more experience and better strategies to manipulate VE interfaces, the FEAC condition would be a better option. By contrast, when playfulness or entertainment aspects are the goal of the design, the detached conditions (FDAC, SDAC) may be preferable. In those conditions, the wayfinding cues are always visible, easy to access and, therefore, may offer users more cognitive resources to explore the environment and enjoy their tasks.

As indicated in this study, the FEAC condition significantly lowered the efficiency of participants' wayfinding performance in terms of task completion time, path, satisfaction with task performance and the sense of task difficulties. However, today's most popular Desktop Virtual Environments, including numerous 3D games and Multi-User Virtual Environments (MUVEs) rely very much upon wayfinding affordance cues that are presented as fixed embedded forms. If a 3D Virtual Environment is an example of future interfaces, and in order to realize the great potential that exists for these types of VE software, it is therefore very important to take more scientifically oriented approaches for designing wayfinding affordance cues, considering users' overall task performance and perceptual experience.

In this study, the focus was centered on wayfinding affordance cues that are based on maps and signs. Only limited attention has been devoted to other forms of wayfinding cues as well as relationships between these cues and users' particular characteristics. According to Ruddle, Payne and Jones [30], there was a significant wayfinding cue type effect when users move through VEs but only little empirical data have been reported about the effects of wayfinding cues on users' performance and experience in VEs [30]. It is therefore critical that further research investigates the effectiveness of various affordance cues and to optimize the designs of VEs.

References

[1] S. Adams, "Information behavior and meaning-making in virtual play spaces: A case study," Ph.D. dissertation, Dept. School of Inform., Univ. Texas, Austin, 2006

[2] F. Biocca (2005, July 25). *The cyborg's dilemma: Progressive embodiment in virtual environments,*[Online]. Available: http://jcmc.indiana.edu/vol3/issue2/biocca2.html

[3] W. Barfield et al., "Presence and performance within virtual environments," in *Virtual environments and advanced interface design,* W. Barfield and T. Furness, Ed., New York: Oxford Univ. Press, 1995, pp. 473-513.

[4] D. Bowman et al., "A survey of usability evaluation in virtual environments: Classification and comparison of methods", *Presence,* vol. 11, no. 4, pp. 404-424, 2002.

[5] D. Bowman et al., *3D User Interfaces: Theory and Practice,* Boston: Addison-Wesley, 2004.

[6] M. Bricken, "Virtual worlds: No interface to design," Human Interface Technology Laboratory, Univ. of Washington, Seattle, WA, Tech. Rep. R-90-2, 1990.

[7] A. S. Carlin et al., "Virtual reality and tactile augmentation in the treatment of spider phobia: A case report," *Behavior Research and Therapy*, vol. *35*, pp. 153-158, 1997.

[8] L. Chittaro and S. Burigat, "3D location-pointing as navigation aid in virtual environments," in AVI Advanced Visual Interfaces Conf., Gallipoli, Italy, 2004, pp. 267-274.

[9] M. Csikszentmihalyi, *Flow: the Psychology of Optimal Experience*, New York, NY: Harper and Row, 1990.

[10] M. Csikszentmihalyi and M. Wong, "The situational and personal correlates of happiness; a cross-national comparison," in *Subjective well being: an interdisciplinary perspective*, F. Strack et al., Ed., Toronto: Pergammon Press, 1991, pp. 193-212.

[11] R. Darken R and J. Sibert, "Wayfinding strategies and behaviors in large virtual worlds," in CHI, Vancouver, Canada, 1996, pp. 142-149.

[12] J. Edwards and C. Hand, "MaPS: Movement and planning support for navigation in an immersive VRML browser", in Symp. on Virtual reality modeling language, 1997, pp. 65-73.

[13] S. R. Ellis, *Why people play*. Englewood Cliffs, NJ: Prentice Hall, 1973.

[14] T. Elvins, "Virtually lost in virtual worlds-wayfinding without a cognitive map", *Computer Graphics*, vol. 31, no. 3, pp. 5-17, Aug. 1997.

[15] T. Furness and W. Barfield, "Introduction to virtual environments and advanced interface design," in *Virtual Environments and Advanced Interface Design*, W. Barfield and T. Furness, Ed., New York, NY: Oxford Univ.Press, 1995, pp. 3-13.

[16] J. A. Ghani and S. P. Deshpande, "Task characteristics and the experience of optimal flow in human-computer interaction." *J. of Psychology*, vol. 128, no. 4, pp. 381-391, 1994.

[17] R. Held and N. Durlach, "Telepresence, time delay and adaptation", NASA conf. publication 10032, 1992.

[18] G. Hoffman et al., "Virtual chess: Meaning enhances users' sense of presence in virtual environments," *International Journal of Human-Computer Interaction*, vol. 10, pp. 251-263, 1998.

[19] C. Johnson, "On the problems of validating desktop VR," in *People and Computers XIIII*, H. Johnson et al., Ed., London: Springer, 1998, pp. 327-338.

[20] D. Jürgen and O. Kersting, "Dynamic 3D maps as visual interfaces for spatiotemporal data," *Proc. of the 8th ACM Int. Symp. on Advances in Geographic Information Systems*, 2000, pp.115-120.

[21] R. Lauria, "Virtual reality: An empirical-metaphysical testbed," *Journal of Computer Mediated Communication*, vol. 3, no. 2, 1997.

[22] B. Kabanoff, "Work and nonwork: A review of models, methods and findings," *Psychological Bulletin*, vol. 88, no. 1, pp. 60-77, 1980.

[23] D. T. Kenrick and D.C. Funder, D. C., "Profiting from controversy: Lessons from the person-situation debate." *American Psychologist,* vol. 43, no. 10, pp. 23-34, 1988.

[24] B. Laurel, *Computers as theater*. Reading, MA: Addison-Wesley, 1991.

[25] J. N. Lieberman, *Playfulness*. NY: Academic Press, 1977.

[26] M. Lombard and T. Ditton (1997), "At the heart of it all: The concept of presence," *Journal of Computer-Mediated Communication*, vol. 3, no. 2, 1997.

[27] F. Massimini et al., "Flow and biocultural evolution," in *Optimal experience: Psychological Studies of Flow in Consciousness,* M. Csikszentmihalyi and I. Csikszentmihalyi, Ed., Cambridge, UK: Cambridge Univ. Press, pp. 60-81, 1988.

[28] R. Moreno and R. Mayer, "Learning science in virtual reality multimedia environments: Role of methods and media". *J. of Educational Psychology,* vol. 94, no. 3, pp. 598-610, 2002.

[29] G. Riva, "From technology to communication: Psycho-social issues in developing virtual environment". *J of Vis Languages and Computing,* vol. 10, no. 1, pp. 87-97, Feb. 1999.

[30] R. Ruddle, S. Payne and D. Jones, "The effects of maps on navigation and search strategies in very large-scale virtual environments," *J. of Experimental Psychology Appl,* vol. 5, no. 1, pp. 54-75, March 1999.

[31] H. Sayers, "Desktop virtual environments: A study of navigation and age," *Interact with Computers*, vol. 16, no. 5, pp. 939-956, Oct. 2004.

[32] Y. Skadberg and J. Kimmel, "Visitors' flow experience while browsing a web site: Its measurement, contributing factors and consequences," *Computers in Hum Behav,* vol. 20, no. 3, pp. 403-422, May 2004.

[33] M. Slater et al., "The influence of body movement on subjectiv22e presence in virtual environments," *Hum Factors*, vol. 40, no. 3, pp. 469-177, Sept. 1998.

[34] D. Spielberger, *Manual for the State-Trait Anxiety Inventory (Form Y).* Palo Alto, CA: Consulting Psychologist Press. 1970.

[35] K. Stanney et al., "Human factors issues in virtual environments: A review of the literature," *Presence*, vol. 7, no. 4, pp. 327-351, Aug. 1998.

[36] J. Steuer, (1995). "Defining virtual reality: Dimensions determining telepresence," in *Communication in the age of virtual reality*, F. Biocca and Levy M., Ed., NJ: Lawrence Erlbaum, pp 33-56

[37] A. Sutcliffe and B. Gault, "Heuristic evaluation of virtual reality applications," *Interact with Computers*, vol. 16, no. 4, pp. 831-849, Aug. 2004.

[38] A. Sutcliffe A and K. Kaur, "Evaluating the usability of virtual reality user interfaces," *Behavior & Inform., Technology*, vol. 19, no. 6, pp. 415-426, 2008

[39] J. Tichon and J. Banks, "Virtual reality exposure therapy: 150-degree screen to desktop PC", *CyberPsychology & Behavior*, vol. *9*, no. 4, pp. 480-488, 2006.

[40] K. Trevino and J. Webster, "Flow in computer-mediated communication: Electronic mail and voice mail evaluation and impacts", *Commun. Research*,vol. 19, no. 5, pp. 539-573, 1992

[41] J. Wann and M. Mon-Williams, "What does virtual reality need? Human factors issues in the design of three-dimensional computer environments," *International J of Hum Computer Stud*, vol. 44, no. 6, pp. 829-847, June 1996.

[42] J. Webster et al.,"The dimensionality and correlates of flow in human-computer interactions," *Computer in Hum Behavior* , vol. 9, no. 4, pp. 411-426, Winter 1993.

[43]J. Webster and J. Martocchio, "Microcomputer playfulness: Development of a measure with workplace implications", *MIS Quarterly*, vol. 16, no. 2, pp. 201-226, 1992.

[44] K. Weiderhold, R. Davis and D. Weiderhold, "The effects of immersiveness on psychology" in *Virtual environments in clinical psychology and neuroscience*, G. Riva, B. Wiederhold and E. Molinari, Ed., Amsterdam: IOS Press, 1998, pp. 52-60.

[45] D. Wetzel, P. Radtke, and H. Stern, *Instructional Effectiveness of Video Media*, Hillsdale, NJ: Erlbaum, 1994.

[46] W. Winn. (2005, February 23). *A Conceptual Basis for Educational Applications of Virtual Reality* (R-93-9). [Online]. Available: http://www.psywww.com/psyrelig/psyrelpr.htm.

[47] B. Witmer and M. Singer, "Measuring presence in virtual environments: A presence questionnaire," *Presence*, vol. 7, No. 3, pp. 225-240, June 1998.

[48]A. Woszczynski et al., "Exploring the theoretical foundations of playfulness in computer interactions," *Computers in Hum Behavior*, vol. 18, no. 4, pp. 369-388, July 2002.

Author Biographies

Gilok Choi was born in Seoul, Korea in Oct. 10, 1970. She received a Bachelor of Arts degree in Journalism and Broadcasting from Ewha University in Seoul, Korea in 1993 and a Master of Arts degree in Communications from the same university in 1997. Then, she received PH.D degree in Information Studies from the University of Texas at Austin in 2008. Her research area include HCI, usability, interface design and information architecture.