Understanding User Interaction Problems with Wireless Connection via Research through Design

A thesis submitted for the degree of Doctor of Philosophy

by

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Abstract

People frequently have problems making multiple devices work together. In this thesis, I use the Research-through-Design approach to understand the issues and propose solutions.

Through an iterative series of investigations, the problems people have with the connection of multiple devices has been examined, including usability issues, difficulties with the sequential connection procedure, and difficulties performing an action. I found non-expert users to have difficulties with interpreting and evaluating the devices' interaction status regarding the sequence of the connection procedure. When an evaluation problem occurs, they have problems dealing with the required sequence or diagnosing the error in their interactions. The problem understanding was examined from additional cases.

The comprehension of the problems allowed me to generate design implications and propose a design solution. I proposed two implications with which to solve the stated problem. I suggested helping users evaluate device interaction and reduce unnecessary user interactions. A design framework was suggested as a solution by providing diagrammatic representations of system interaction and signals revealing device status. I then assessed the suggested solutions using paper prototypes, and demonstrated their effectiveness. The improved interfaces helped users evaluate device connection status so they may determine how to proceed with sequential interaction.

With the Research-through-Design approach constructing knowledge by integrating theories and hypothesis, I found the feature of user-multiple device interaction in which a user is required to manage the interaction between the devices. A single device cannot aid the user interaction. In the dissertation, I proposed a desirable state of user interaction, which is achieved by two devices revealing connection states together so that a user can earn a useful system image.

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Chapter 1. Introduction

1.1 Research motivation and background

More and more products around us are being used in a system of two or more devices to provide expanded functions and convenience. Wireless connection provides even greater convenience in our lives. For example, an MP3 player plays songs by connecting to a car's Bluetooth stereo system; a smartphone connected to a printer can quickly provide a printed picture; a radio frequency identification (RFID) tag embedded in a card provides easy and safe access to a building by working with a card reader instead of a security guard.

Although these wirelessly connected multiple-device systems provide various functional benefits, such conveniences cannot always be readily enjoyed because of difficulties that users face when trying to operate the devices together. This thesis is motivated by a personal experience in which I failed to use a device properly.

During an early experience with the Tube (i.e., the underground railway system in London), I bought an *Oyster card*, an electronic payment card for London transportation that makes use of RFID technology. If I pay expenses electronically by touching my Oyster card on the reader at a station, then I can pass the gate and take the Tube. After I had used this approach to travel on the Tube a few times, a machine at the gate in a small station prevented me from passing through. While I tried several times to make my Oyster card work with the reading machine in the unfamiliar hallway, I repeatedly received unfriendly "fail" messages. In the midst of a sea of busy people, I was in a panic; I did not know what had happened and could not determine the problem. There was no one to help me.

A review that criticized the Bluetooth wizardry of a luxury bike made me recall the embarrassing and stupid experience when I could not find out how to make the RFID card and a machine work. The reviewer of a BMW bike reported that he could not successfully get the bike's Bluetooth accessories to work together (Furchogott, 2011). Even the luxury bike company has problems with providing users with usable devices.

Difficulties concerning interactions between multiple devices have been reported by other sources. For example, Woo and Lim (2009) reported that, among eight participants, no one in their study succeeded in pairing an MP3 player and a pair of

headphones. Ayatsuka and Rekimoto (2005) demonstrated cumbersome interaction for connecting a PC and a projector. On the Internet and in magazines—such as articles by DesMarais (2013) or Lynn (2012), we can find lots of troubleshooting guidance for connecting wireless devices.

Researchers insisted that the difficulties of handling device connections seemed to make users hesitant to adopt new technologies (Edward et al., 2011; Newman et al., 2008). Through a usage scenario, Chong and Gellersen (2012) emphasized that the enjoyment of combined devices is ruined by troubles that users face when trying to make them work together. Therefore, the problems that non-expert users face when handling multiple wireless device connections are an important interaction challenge that requires urgent resolution.

Research into device associations has continuously proposed various techniques that reduce the human burden of dealing with wireless device connection in the human-computer interaction (HCI) area. Although spontaneous, natural, and intuitive device connections have been pursued by a wide range of techniques (Rekimoto et al., 2003; Iwasaki et al., 2003; Hinckley, 2003; Lucero et al., 2012; Woo & Lim, 2009 and so on), the way in which to provide desirable user interaction remains an open question (Chong & Gellersen, 2011).

While researchers have pointed out the importance of studying user experiences and improving user interaction (Bly et. al., 2006; Edwards et al., 2011; Poole et al., 2008; Shehan & Edwards, 2006), there are not many studies that provide useful findings and implications for designing these systems. Thoughtful understanding of user interactions and a reasoned vision of desirable states that designers can reference are still lacking.

1.2 Study purpose and objectives

In order to improve the user interaction of connecting devices, interaction design research needs to construct knowledge to help designers understand features of the user-system interaction, interpret the user difficulties, and envision a desirable state of user interaction. This thesis seeks to frame user interaction problems that relate to the process of connecting devices and generate design insights to reduce user difficulties. It also presents design implications and a solution that informs interaction

designers. Through problem-framing and design suggestions, this thesis ultimately aims to formulate knowledge to which designers can refer for user interaction design. Therefore, such information can serve for the improvement of user interaction in connecting wireless devices.

1.2.1 Research through Design

This dissertation explicitly does not follow the traditional psychology-based procedure for discovering and validating design problems and proposed solutions. Instead, it follows a research technique unique to the design field (but well-established within it): Research through Design. Zimmerman, Forlizzi, and Evenson (2007;1) described the process this way:

> *"Following a research through design approach, designers produce novel integrations of HCI research in an attempt to make the right thing: a product that transforms the world from its current state to a preferred state. This model allows interaction designers to make research contributions based on their strength in addressing under-constrained problems."*

By applying iterative design processes that interpret the interaction problem and generate solutions to overcome it, this study gradually frames an understanding of a user-system interaction and user interaction difficulties, design implications, and a solution.

In constructing design knowledge for improving the user interaction of connecting wireless devices, the specific research objectives of the overall dissertation are:

1) To be aware of accumulated knowledge in the related field and clarify the contribution of this thesis.

2) To reflect an appropriate approach for the research purpose by formulating knowledge for design.

3) To frame user interaction problems and generate design implications those are deliberately reflected through the iterative design research process.

4) To formulate research findings in the form of applicable knowledge by examining the stated problem and understanding and assessing the design insights through several interaction cases.

1.3 Targeted interaction and terminologies

This study determines the research target, not with specific technology or hardware requirements, but with the relation among a user and devices. The user interaction that this study targets must be more clearly clarified. This section also defines how this study uses a few frequently used terms, such as “design,” “design situation,” and “problem and solution.”

Targeted user-devices interaction

This dissertation investigates user interaction problems that arise when a user handles two or more devices to wirelessly connect two targeted devices. The interaction involves the change in the states of the devices, along with the user’s interaction. As is shown in Figure 1, the user interaction begins with two separate devices (a) and, at the end of the interaction, the two devices establish a virtual connection and work together (b). The process between the two states requires the establishment of a virtual connection among devices to exchange data before they can function as a system. The process has been termed “device association,” “pairing,” “binding,” and “coupling of devices,” as well as “device connection,” in related fields (Chong & Gellersen, 2012). In this study, the terms “device connection” and “device association” are used interchangeably.

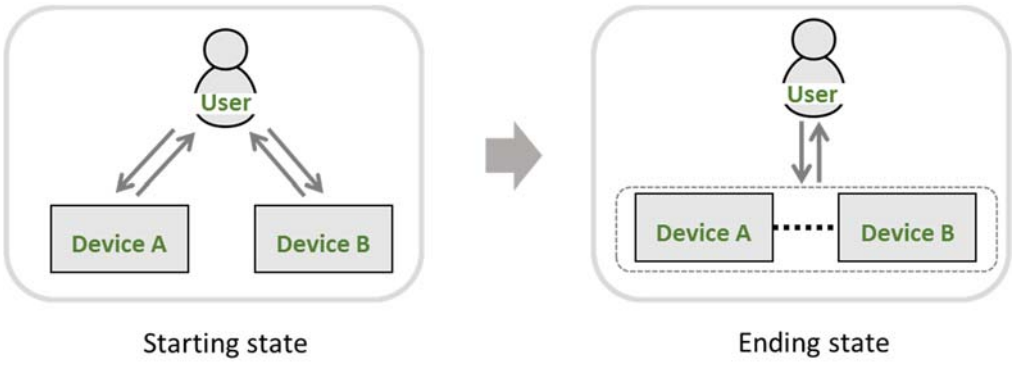


Figure 1. The user-device interaction that this thesis targets

Among a wide range of the interaction situations that arise when connecting two targeted devices, this research is focused on interactions that a user watches and acts on for both of the targeted devices. However, it excludes situations when a user cannot interact with one of the two targeted devices. For example, the targeted research boundary includes a user interaction with an RFID card and a reader in which

a user watches and interacts with both of the devices (holds and taps the card against the machine). A mobile phone connection to a telecommunication service is not considered a target of this study because it is not usually handled by a non-expert user and a user cannot directly interact with the device within a telecommunication company.

Design

Because this dissertation investigates a problem with applying a design process, it is required to clarify the term "design"—a generic, broadly used term. Design is frequently used as a term that describes a kind of human activity which everybody performs during daily life, such as manipulating the environment to adhere to a person's needs (Norman, 2004). The term can also be used to refer to a trained designer's approach to creative problem solving in the design community and related disciplines, such as architecture, product design, graphic design, or interaction design (Zimmerman et al., 2007, Buxton, 2007). This thesis uses the term "design" to state an activity, process, and ways of thinking that trained designers use in the design community.

Design situations

"Design situation" or "situation" is also frequently used in this thesis because it continuously reflects the understanding of current and future situations that a designer handles for a design. In their book, Löwgren and Stolterman (2004) clarified the terminology "design situation" as the starting point for the design, as well as the target of design. They mentioned that a designer should determine the situation at hand and decide what should be considered and what can be left out. In this thesis, "situation" is used to describe the complex aggregate of technological and social elements of user interaction as the target a designer should understand and improve. Only some elements of the situation are deeply investigated within the designer's (the researcher's) decision, while other elements are left out.

Problem and solution

In approaching the user interaction difficulties of connecting devices, this dissertation uses the word "problem" and "solution" as core terminologies. The word "problem," in regard to design research, refers to a designer's current understanding of a design

situation, and the word “solution” means the designer’s vision of how to shape the desirable future. It would be important to notice that the perspective and way of treating a problem and a solution in the approach is not the same as scientific, experimental, or engineering studies in which a researcher tries to give an answer on a specified and reduced question and the answer can be either right or wrong (Löwgren & Stolterman, 2004).

1.4 Contribution to the field

This dissertation contributes to the field of device association by suggesting a new perspective to approach the user interaction problem and solution.

First, not many research efforts help designers to deal with the complex interaction problem of device connection. This study would help designers by providing information about how to understand the interaction between a user and multiple devices, how to interpret user interaction difficulties, and how to overcome user difficulties within the design situation; none of these topics have been sufficiently addressed by previous research.

Second, this study provides a reasoned vision for desirable user interaction on the basis of thoughtful reflection on user system interaction situations and user difficulties. Previous research has proposed advanced technological solutions, but targeted only specific interaction scenarios. Studies have provided classified and specified knowledge on the complex user interaction situation, but they have not informed others on how to handle conflicting issues. This study suggests design insights for user interaction through intensively investigating what the system expects of the interaction, what information the system reveals to users during interaction, and how users understand and respond to technologies.

Third, with deep reflection on the research purpose, this study approached the user interaction problem with a design research way in which integrated knowledge and theories from disciplines and iteratively reflected upon the problem understanding and desired solution. The study, which is approached from a new perspective, would inspire researchers in the field by not only providing newly framed interaction understanding, problem statements, and a different solution, but also through widening ways to approach research.

1.5 Overview of the dissertation

The dissertation consists of eight chapters as follows:

Chapter 1 provides an introduction to the dissertation by presenting the research motivation and background. It defines the research aims and purposes and states detailed objectives to construct knowledge for improving user difficulties regarding wireless device connection. It also suggests a consensus of the research target and terminologies and addresses how this dissertation contributes to the field. It also defines the primary research method – Research through Design – and contrasts it with other approaches that are probably more familiar to the research community.

Chapter 2 serves to examine previously accumulated knowledge in the academic field and to position my contribution within established academic discourses. In particular, I address the interaction design issues of device association, which is spread throughout studies of framing the complexity of device/user interaction and demonstrating alternative ways to establish wireless device connection. More importantly, on the basis of understanding the previous academic efforts of not only wireless device association but also difficulties in domestic network configuration, this chapter constructs a foundation in which the feature of problem, a desirable way of approaching the problem, and preferred outcomes of research are discussed.

Chapter 3 studies the Research-through-Design approach. The advantages of the approach to complex problems occur through framing the problems and envisioning a preferred future state. I describe what the approach can contribute to the improvement of wireless device connection. Through extensive reflection on iterative design processes by formulating a problem and a solution, I determine how this dissertation approaches the investigation.

Chapters 4 to 7 describe the gradual progress on understanding user difficulties and generating design suggestions through an iterative design thinking process. Chapter 4 describes the early stage to establish a preliminary problem statement. In order to obtain a brief understanding of various aspects of user interaction, three different user interaction cases with current devices, including an RFID card and a card reader connection in a subway payment system, Bluetooth connection among an MP3 player and audio devices, and a wireless printer and a computer connection mediated by a network device, were observed with different strategies. From the observations, an inquiry appears for the next phase. User difficulties and related issues of user

interaction are also determined.

While difficulties that non-expert users cannot easily handle have been continuously observed, Chapter 5 explores the user difficulties in performing the required interaction. It defines the user interaction required by the system based on a technician's interview and reference study. Through comparing the non-expert users' interactions that are observed in Chapter 4 with the required interactions, the differences are determined and design implications are suggested to reduce the difficulties that arise. This chapter also reports an important insight of a design situation that is gained from working on early stages of design solutions.

Chapter 6 reframes the user interaction problem with further investigation in order to overcome the constraint of the design situation found in Chapter 5. Through reflecting difficulties that occurred in different stages of user action, it presents a new insight to improve user interaction. The chapter searches for a new solution with which to overcome the design constraint and that can improve the user interaction by applying "innovation by boundary shifting" method.

Chapter 7 tries to gain extensibility and formulate the research findings as applicable knowledge for interaction design. The stated problem is examined on three additional cases with different devices and technologies. The chapter also demonstrates new interfaces that were revised by applying the suggested design implications and framework and evaluated with paper prototypes. The chapter shows how the research findings and design solutions are applicable knowledge for interaction design.

Chapter 8 summarizes the findings from the study and discusses the dissertation's contribution to the field. It exposes how the problem framing has evolved through an iterative design thinking process and discusses an evaluation of the thesis. The major contribution of this dissertation can be determined through the new insights from a designer's point of research in understanding user interaction problems and providing intellectual reasons for the future desirable state.

Chapter 2. Related Works on Device Connection

2.1 Objective

As wireless products become more frequently and widely used as parts of systems connected to one another, several studies have been conducted that seek to help users to successfully interact with these devices' connection. In this chapter, I research the history of related studies and discuss a desirable way of approaching the research. The sub-objectives are:

1) To review previous research and become familiar with the knowledge that exists in related fields.

2) To establish a preliminary understanding of the interaction problem according to the previous insights.

3) To discuss a direction of this study and clarify its contribution to the field.

2.2 Understanding previous research efforts

Many researchers have studied how users can associate with wireless devices in a direct, natural, and intuitive way. Various techniques have been proposed in the field and influential factors have been discussed. In spite of continuous exertion, the difficulties that arise when seeking to connect devices constitute an ongoing problem and information regarding user interactions that designers can reference are still lacking.

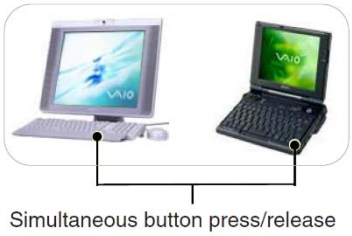
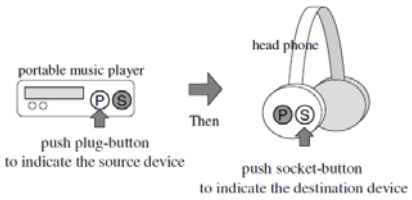
2.2.1 Efforts for natural and intuitive device association

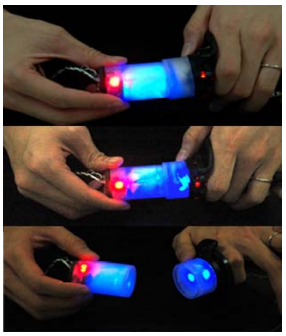
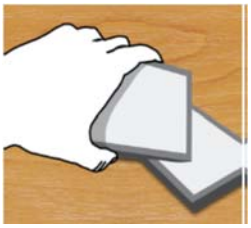
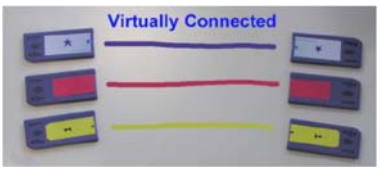
Proposed techniques for natural and intuitive device association

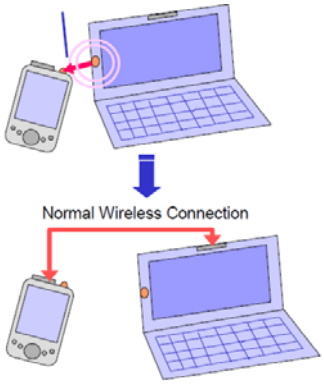
To address a question on how users can associate devices in a natural and intuitive manner, a variety of techniques have been proposed in the HCI arena. Many researchers focus on providing device connection by using collocated human movement or continuous action. These interfaces included: pressing buttons simultaneously on both devices (Rekimoto et al., 2003), pressing buttons sequentially

(Iwasaki et al., 2003), bumping the devices together (Hinckley, 2003; Lucero et al., 2012; Woo & Lim, 2009), shaking the devices together (Holmquist et al., 2001; Mayrhofer & Gellersen, 2007), and stroking the device (Hinckley et al., 2004). The spatial proximity of the two devices is sensed through infrared beaming or RFID technology (Rekimoto et al., 2003). Further, additional devices such as USB sticks may also be used to ensure connection authentication (Ayatsuka & Rekimoto, 2005). Previous research on wireless device associations is summarized in Table 1.

Table 1. Previously proposed techniques for wireless association

Technology (Developers)	**Methods for device selection and authentication**		**Required scenarios/ Implementation status**
	Image	**Description**	
SyncTap (Rekimoto et al., 2003)		Simultaneously press and release the "connection" buttons on both devices.	All devices already have IP (Internet protocol) packet access and can communicate with all other nodes.
Touch-and-Connect (Iwasaki et al., 2003)		Press the plug-button on the music player; then, press the socket-button on the headphones.	This requires a closed network in which each node can communicate with all other nodes.
Clipoid (Woo & Lim, 2012)		Move the slide switch on the Clipoid pairing mediator and transfer it to the other device.	Experience prototype (not a real wireless connection)

Technology (Developers)	Methods for device selection and authentication		Required scenarios/ Implementation status
	Image	Description	
Contact-and-Connect (Woo & Lim, 2009)		Put the devices together (the “spread” or “transmit” lights provide visual feedback on the connection status).	Experience prototype (not a real wireless connection)
Using synchronous gestures (Hinckley, 2003)		Touch the devices together.	The two devices should be able to exchange signals. Sensing hardware is required.
EasyGroups (Lucero et al., 2012)		Touch the left device to the device on the right to bind them.	Sensing hardware and visual feedback on a screen provide user instructions. Radio-based proximity detection technology is required.
Shake Well Before Use (Mayrhofer & Gellersen, 2007)		Hold and shake the devices together.	The pair of devices should be able to exchange signals. Sensing hardware is required.
tranSticks (Ayatsuka & Rekimoto, 2005)		Place a pair of tranSticks—physical memory sticks that contain device identification keys—into two devices.	Physical USB sticks are required.

Technology (Developers)	Methods for device selection and authentication		Required scenarios/ Implementation status
	Image	Description	
Proximal Interactions (Rekimoto et al., 2003)		Put two devices within proximity of each other or point one device at the other.	A near-field channel (infrared beaming or radio-frequency identification [RFID] technologies) is required, in conjunction with a normal wireless network.

Although these techniques were proposed to reduce the human burden of identifying the target device and authenticating the connection, a natural and intuitive manner of device connection seems to require long and agonizing effort for it to be adopted into real devices' interface and improve ordinary users' interaction. First, much of the research assumed that associated devices have primitive connections to other devices or services (Rekimoto et al., 2003; Iwasaki et al., 2003; Hinckley, 2003; Mayrhofer & Gellersen, 2007). These means cannot help when a user has a problem dealing with the primitive connections. Additional sensors or out-of-band channels that have been employed in addition to the original network connection may produce more complex problems when something goes wrong with the connection. Second, the advanced techniques have some barrier to be widely adopted in user interaction with different hardware, requirements, and limitations because most of these proposals target specific interaction scenarios (Chong & Gellersen, 2012).

More importantly, it is not yet clear what constitutes users' natural actions. Research has reported no single approach is preferred for representing natural connection. In a study in which users produced natural actions for device association by using low-fidelity plastic prototypes as thinking aids, Chong and Gellersen's study (2011) found that no single action is dominant for spontaneous association among five prominent categories of actions (e.g., search and select, proximity, button event, device touch, and gesture). Ion et al. (2010) reported a similar result in which preferred actions for device connection are changed depending on users and situations. They asserted that a technically secure and highly usable method is not always befitting of the users' needs.

Efforts for understanding design situation

Some research sought to help interaction designers choose association techniques and design preferred interaction by informing others of influential factors within user interaction. Ion et al. (2010) argued that designers need to be aware users' mental model, needs, and social situations for designing user interactions. They found that user interaction is influenced by the sensitivity of data involved, users' time constraints, and social conventions that are appropriate for a certain environment. Through surveying proposed models in the field, Chong and Gellersen (2012) discussed various components of device association in technology, user interaction, and application context categories. They suggested a framework (Figure 2) in order to help designers and researchers understand the complexity of influential factors.

However, this classified and specified knowledge on complex situations does not guarantee the resolution of user interaction difficulties. Although it helps designers to understand the complex design situation, designing interaction requires a challenging movement in which a designer makes connections and sees relations within the complexity (Nelson & Stolterman, 2003). While these research efforts classified tangled components, none of them informed designers of how to interpret user difficulties and how to approach the problem within the complex design situation.

2.2.2 Related works on connecting network devices

Accumulated knowledge from not only wireless device association but also academic research on network device connection would provide important insight for this research. This section reviewed previous studies for arriving at an understanding of user difficulties and developed examples in the field of network connection in a domestic environment.

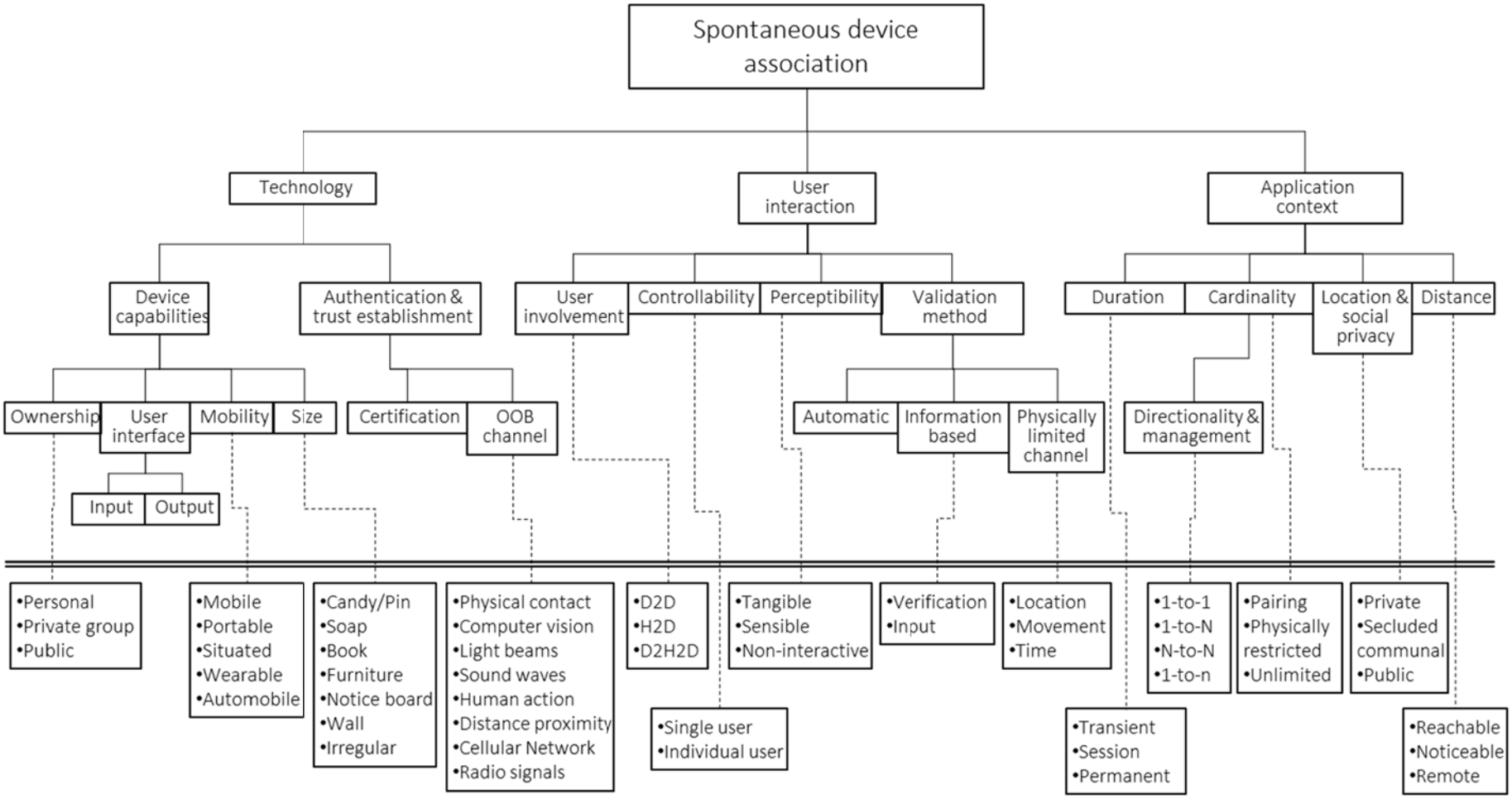


Figure 2. Complex components of device association in technology, user interaction, and application context: Classified by Chong and Gellersen (2012;79)

Efforts for self-configuring network connection

There have been improvements in providing automatic configurations for network connection. Technological efforts are demonstrated in research on self-configuring network connections, including Jini (Gupta et al., 2002), UPnP (Miller et al., 2001), and OSGi (Dobrev et al., 2002). When a new product is added to or removed from a network, solutions are aimed at removing the need for reconfiguration by providing negotiation protocols that provide the devices with greater plug-and-play capability (Burgess, 2007). For example, service discovery protocols (such as Jini and UPnP) address the process of finding and making use of services that are available in a network to provide mechanisms for dynamically discovering available services, as well as providing the information necessary to search and browse for services (e.g., the IP address) and choose and utilize the right service.

These technological solutions in automatic connection attempt to help users get the benefits of connected products with minimum configuration efforts. However, many researchers do not believe that self-configuring technologies can provide complete automated system solutions. Auto-configuration protocols do not really remove the user burden, but require a certain level of control (Burgess, 2007; Edwards et al., 2011). Utton & Scharf (2004) pointed out that the management of faults would be critically important for users because the complexity with different devices in various situations may possibly produce frequent errors. It seems that a certain amount of user interaction is necessary to interact with connecting devices, in spite of automatically configuring technologies, and is still important in order to develop an appropriate user interaction design, even for advanced device connection technologies.

Understanding complexities of network

The technological and social complexities surrounding user interaction of network connections have been studied, especially in domestic environment. Ethnographic studies (Grinter et al., 2005; Tolmie et al., 2007) have explored the complexity of managing home networks, including the demands for administration and troubleshooting in the domestic environment from a social machinery perspective. With careful observations, interviews, and experiments, researchers have discussed various network technologies and networking problems in a domestic environment (Teger & Waks, 2002), such as the mismatch that exists between how a person expects

to interact with a product and the product's capabilities (Bly et al., 2006), how users understand the network of devices in their home (Poole et al., 2008), and a rearrangement in the role of professionals and ordinary users (Brush, 2006). These researchers have identified many of the problems found in home networks and discussed the necessary requirements that would help households to more easily set up, manage, maintain, fix, and even understand their networks.

Researchers who highlighted the difficulties faced by home network users asserted that the sources of this trouble included the invisibility of settings and configuration information required to properly set up the network, as well as poor strategies for diagnosis and troubleshooting (Poole et al., 2008). Improving the visibility of the network (Grinter et al., 2005) and providing transparency within the home network (Tolmie et al., 2007) would help users to set up and manage the network by making it capable of inspection and accountable to practical reasoning.

However, they have illuminated relatively few solutions as to how designers can create a desired state of user interaction for device connections. A few conceptual, technical suggestions to reduce user difficulties have been given, including an increased visualization of the home network (Shehan & Edwards, 2006), a centralized network appliance (Yang & Edwards, 2007), direct manipulation tools (Humble et al., 2003; Yang et al., 2010; Newman et al., 2008), and a browser-style application for configuring and managing domestic devices (Newman et al, 2002). These researchers tried to develop dedicated management interfaces that represented the network.

Despite discussions of problems and suggested applications, questions still remain that interaction designers need to resolve. For example, what information must the interface provide to improve the usability of network configuration and how and when should the information be given to users to properly assist them? Providing overall visibility of a network was crucial, but special attention had to be paid to the way that visibility was achieved (including filtering information, providing feedback, and supporting user actions) (Newman et al., 2002). Design improvements have been encouraged for applications and interfaces for network connections (Edward et al., 2011), but there is still no sufficient reference for interface design, in terms of what the interface should look like and how it should be provided to users.

2.3 Understanding of a complex problem situation

Previous studies have discussed the complex and conflicting issues when designing multiple device systems for their connections. Understanding the related issues would provide a preliminary image of a user interaction problem and a design situation. Chong and Gellerson (2012) categorized the factors that influence the usability of wireless device associations, while Edwards and colleagues (2011) presented problems surrounding home network configuration. Figure 3 summarizes the issues mentioned by previous researchers that cause non-expert users to have difficulties with device connection and management.

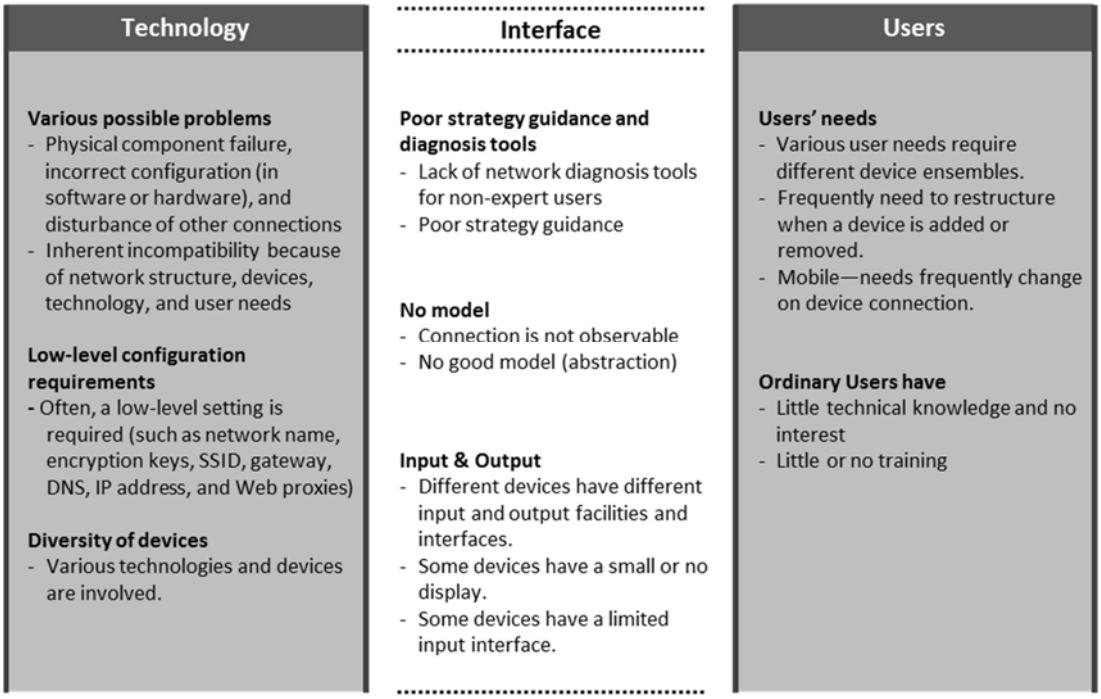


Figure 3. Influential issues on usability of device connection

The products and technologies users want to use often include a mix of wireless and wired connections, along with a range of devices, including PCs, printers, smartphones, tablets, cameras, audio devices, and gaming consoles that use LAN (local area network), Wi-Fi, Bluetooth, Zigbee, USB, or near field communication (NFC) radio frequencies to connect with one another (Schilit & Sengupta, 2004; Teger & Waks, 2002). Compounds of devices produce tremendous variations that are based on which devices are involved, how they are networked, what features the devices have, and what software and settings are provided; some function properly, but many

do not (Bly et al., 2006; Edward et al., 2011; Teger & Waks, 2002). For example, wireless networks often suffer from dead spots and interference from other devices. Failure of any of the involved devices, problems with the physical connection or signal exchanges, and incorrect configurations of an application can cause these issues. Although connections can fail for many different reasons, users do not get enough guidance or tools to solve any of the resulting problems (Yang & Edwards, 2010).

Moreover, users are frequently required to restructure the connections between devices when they add or remove a product. In a mobile technology environment, products are frequently connected, removed, and reconnected. For example, a user may create a connection for printing a hard copy of a document contained on a tablet PC with an available printer nearby. When moving someplace for another meeting, he or she may disconnect the device's connection and create a new connection between the tablet PC and different devices.

A designer needs to handle not only the diversity and complexity of the device connection, but also conflicting issues for designing user interaction. While users have little technical knowledge and are unwilling to get training, technology often requires difficult settings, such as network name, type of encryption keys, service set identifier (SSID), or an IP address in order to handle various possible problems. Sufficient guidance, diagnostic tools, and visible information are required to support users in dealing with complicated interaction (Yang & Edwards, 2010), but designers should often consider the limited input and output facility of small-sized mobile devices. A reliable and conceptual model is required to help users understand how device connection works (Edward et al., 2011), but we do not have enough insight into appropriate models for device connections. Designing user interactions with device connections requires a much greater challenge than simply dealing with a difficult issue to solve.

2.4 Contribution of this thesis in the field

In this chapter, I explored accumulated knowledge and proposed technologies in the field of wireless device association and network device connection. In spite of various techniques for wireless device association and self-configuring network technologies, user interaction design still remains important in order to manage the connection and deal with possible problems. Suggestions of network applications and device

connection methods have not demonstrated sufficiently regarding when or what information should be given to users in order to properly assist them. Research on careful user studies in laboratories and in real situations have helped designers to understand the intricate design situation by providing insights on the problems of user-networking device interactions and various components of interaction design. However, the knowledge is not linked into user interaction improvements without an interpretation of a user interaction problem in which these understandings are bridged and integrated. Figure 4 summarizes prior approaches in related fields and indicates the challenges that these approaches have for improving user interaction.

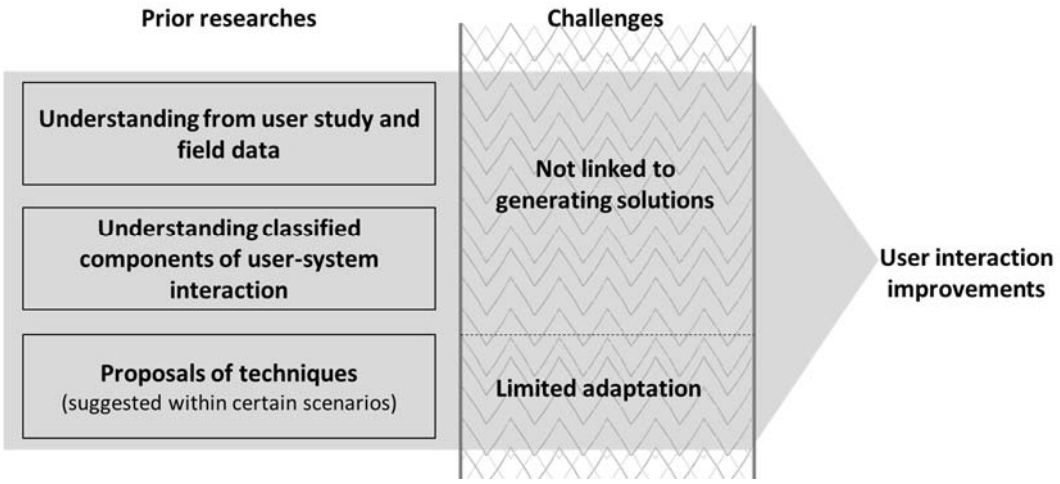


Figure 4. Prior researches in the fields and their challenges

While we continue to make an effort to propose advanced techniques and deepen our understanding of complex user system interaction situations, it is also important to broaden our research approach with different perspectives in framing the user interaction problem of device connection. Working with various visions and approaches of the problem may broaden solution choices (Löwgren & Stolterman, 2004).

While we are waiting for advanced device connection techniques that can enable non-expert user interaction with truly natural interaction, difficulties of handling device connections seem to make users hesitant to adopt new technologies (Edward et al., 2011; Newman et al., 2008). We need user interaction improvements that current technology can make possible and provide the same, or a similar, secure level without requiring advanced expensive hardware or software. Knowledge of current technology improvements would provide important insights for future technology.

We are required to integrate prior knowledge for certain direction and construct new insights that designers can reference in their designs. For design improvement of user interaction, not only approaches that specify the components of the design situations but also approaches to integrate knowledge and see relation among the situation are required. Such knowledge should help designers to construct meaning out of the complexity and conflicts: how to see the interaction, how to state the user difficulties and how to solve the problem, and what constitutes a better state for the future.

Chapter 3. Research through Design

3.1 Objective

In order to get new insights and broaden solution choices for user interaction with connecting devices, this dissertation addresses the user interaction difficulties of connecting devices with a Research-through-Design approach. Research through Design is a research approach employing processes and ways of design thinking. It addresses complex problems through an iterative approach to reframing the problem and generating solutions in which a researcher integrates different knowledge and theories (Zimmerman et al., 2010). Research through Design is actively discussed as one of the beneficial approaches in interaction design and the HCI research area. This chapter attempts to reflect why Research through Design is an appropriate research methodology for the purpose of this study, pursuing user interaction improvements to connecting devices.

Through reviewing references from the interaction design and design research domain, this chapter's objectives, in detail, are as follows:

1) To identify why a Research-through-Design approach is an appropriate methodology for the research of this dissertation.

2) To reflect how Research through Design formulates knowledge and what are the core features of a design approach that would apply to research.

3) To reflect how this study approaches the research problem through a design process.

3.2 Benefits of Research through Design

Zimmerman and colleges (2007, 2010) discussed how a Research-through-Design approach can benefit knowledge construction of interaction design and HCI, the purpose of which is to improve user interaction with technologies. On the basis of their insights, this section reflects why Research through Design is an appropriate methodology for improving user difficulties with connecting devices.

Firstly, Research through Design is an approach that could lead to actively formulating insights for preferable device interaction and that is based on understanding current user difficulties. Research through Design is one type of design research purposing knowledge construction for improving human-made things and systems. Zimmerman et al. (2007) state that it is different with other approaches in the HCI domain, such as behavior science approaches interested in what is true and anthropological studies focused on what is real. Research through Design focuses on envisioning what a desirable state is as well as understanding what the current state is. The unique design inquiry process, in which a researcher develops problem comprehension via working on an artifact, forces the researcher to actively construct possible futures (Forlizzi et al., 2009). Research through Design can help achieve the goal of this study: not only to deepen understanding of user-device interaction problems, but more importantly to gain insights for desirable states of devices, improving user interaction.

Secondly, Research through Design can approach the complex problem of user-multiple device interaction. As previously understood in Chapter 2, the problems of device connection are intricate, with various technological, interactional, and contextual issues. Many critical questions are not clearly understood or answered, such as what the problem situation consists of, what difficulties are currently happening, what the causes of the problems are, what a more desirable state is, and how to make it. Not only the diversity and complexity of the device connection, but also conflicting issues of user interaction, make the problem difficult. Previous researchers have approached the problem through classifying and specifying the constituent factors and worked on understanding some of them, but it is not clear how to improve user interaction difficulties. An effective research approach should be considered in order to explore the messy situation and find solutions. Research through Design is an approach suitable for resolving a complex problem. Zimmerman et al. (2010;310 & 312) state that Research through Design helps “where the important relationships between phenomena are unknown and therefore difficult to focus on” and to approach “messy situations with unclear or even conflicting agendas; situations that are not well suited to other methods of inquiry.” This approach can provide a different perspective in understanding the messy problem of user interaction difficulty of device association and finding alternative solutions.

Thirdly, Research through Design is a way to produce knowledge and theory which can provide insights for design improvements. Zimmerman et al. (2007) argued that the theory formulated by Research through Design is more designerly than the theory

produced by qualitative fieldwork because the process of composition and integration brings many ideas together and because it focuses on uncovering relationships between phenomena for the speculative future state. The purpose of this study is to formulate knowledge to help designers so that it serves to improve user interaction in connecting wireless devices. A research methodology constructing knowledge through ways of design will benefits appropriate design insights to which designers can refer for their design process, to inspire more design ideas, and to provide integrated and holistic framing for user interaction problem.

3.3 Knowledge construction of Research through Design

Research through Design applies design reflection to the intellectual inquiry process. It would be important to understand how Research through Design formulates and verifies knowledge and how the knowledge is different from that constructed by other research approaches.

“Problem” and “solution” in Research through Design

Research through Design pursues solving a problem, but the terms “problem” and “solution” in the design domain are differently used and treated than in other research domains. Löwgren and Stolterman (2004) define that “problem” in this design research means a designer’s current understanding of a design situation, and “solution” refers to the designer’s vision of how to shape the desirable future. The perspective and way of treating a problem and a solution are distinguished from those of scientific, experimental, or engineering studies which try to give an answer to a specified and reduced question, and the answer can be either right or wrong. Löwgren and Stolterman (2004;31) insist constructing “an image of reality that makes a good foundation for design” is more meaningful in design rather than verifying the truth of the answer. In accordance with the different precondition, the perspective on selecting methods, dealing with data, and finding solutions in design research is not the same as perspectives scientific researchers have used, although both try to understand reality. Nelson and Stolterman (2003;121-3) described the different perspectives of the scientific approach and the design approach as a “difference between how facts serve truth and how interpretation serves meaning.”

Knowledge construction through integration and iteration

Design researchers explained that knowledge from the design process is generated when designers work on an artifact (Fallman, 2007; Stappers, 2007; Löwgren & Stolterman, 2004). During the process of interpreting phenomena that occur on an artifact, a designer absorbs, integrates, and contextualizes different knowledge in various disciplines. Research through Design makes connections between them and creates new meaning (Fallman, 2007).

Not only by bridging different theories but also by testing hypotheses and theories on the artifacts does the design process return new insights (Stappers, 2007). When a designer tries to solve a problem, he creates a situation based on his current understanding of the problem. Then, through tests on the proposed situation, he examines his understanding, hypothesis, and knowledge. He learns something he has not recognized through reflecting on what happened and what caused the unexpected results. This learning creates a new basis for advanced questioning and generating solutions (Löwgren & Stolterman, 2004). A better understanding of the situation is evolved and refined by repeating spiral in which a designer continuously criticizes the current state, examines solutions, and reflects his interpretations. Figure 5 drawn illustrates the iterative cycles of investigation and ideation of design research. The vertical arrow presents a product of the design process, a prototype or a piece of theory.

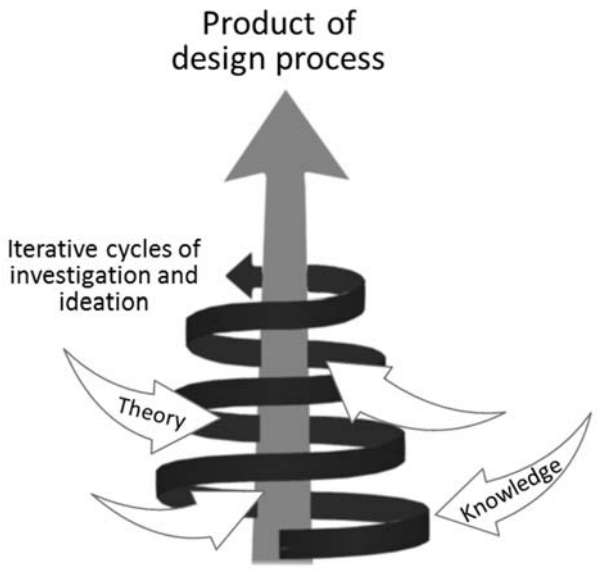


Figure 5. The iterative spiral of design research (redrawn from the Illustration by Stappers (2007;84))

Thoughtful design is considered as a unique reflective and intellectual inquiry process to look at the human condition (Nelson & Stolterman, 2003; Zimmerman et al., 2007; Löwgren & Stolterman, 2004). Research through Design employs the thoughtful reflection of design activity as a systematic inquiry method to generate knowledge. It produces a reflected problem framing an articulated desirable state and a series of artifacts, models, prototypes, and products, as well as documentation of the design process as the final output of research (Zimmerman et al., 2007). It can provide holistic understanding of integrated knowledge from various disciplines and unfold new insights through testing understanding.

Assuring research understanding

Löwgren and Stolterman (2004) argued that the acceptance of produced knowledge from design research should be judged with different criteria from the validation process of other approaches. Generally, research trying to verify truth is evaluated based on the way each study has been carried out. If research is accurately done, the research result is considered correct. However, Research through Design deals with not only what exists but also what could exist, and the understanding cannot be evaluated simply by judging whether the research properly analyzes the current situation or not (Löwgren & Stolterman, 2004). Therefore, design research is not assured by research methods and techniques. The gained information from design research should be assured by repeated interpretation of the current state and experimentation with a possible future within the iterative spiral of the design process. The quality of design research is shown in the systematic nature and the clarity and transparency with which a design researcher develops his understanding and supports his claims (Fallman & Stolterman, 2010).

3.4 Core features of design

Zimmerman et al. (2010;310) defined Research through Design as a research approach that “employs methods and processes from design practice,” but they did not clearly define what it means to applying this design method to research. The design process is too diverse in various situations, problems, and environments to be defined in the form of a method, techniques, or distinct phases (Löwgren & Stolterman, 2004). Nonetheless, it has been agreed among different designers and researchers that there is a generic feature of the design process in spite of different

goals, media, and discipline knowledge for different design areas (Schön, 1983; Löwgren & Stolterman, 2004). This section reflects the core features of design processes in order to bring awareness to how they should be applied to research.

Dynamic reflective iteration: Design thinkers agreed that a core feature of the design process is iteration of "grounding" and "ideation" states. A designer gains multiple perspectives on a problem in the "grounding" stage, and he or she generates many possible alternative solutions in the "ideation" stage. However, it is important to understand that iteration is not simply repeated combinations of the two stages but a dynamic process in which a designer makes new moves in accordance with the changed state of understanding (Schön, 1983; Löwgren & Stolterman, 2004). The dynamic process provides a foundation in which a designer continuously reflects different aspects of the situation, integrates additional theories and knowledge, reframes the design problem with various perspectives, and tests different possible solutions.

Chaos of initial phase and gradual interpretation: The beginning task of the design process is to learn about the design situation as much as possible. The early struggles of design inquiry are extremely difficult because a designer does not know where to focus and the designer's principle to organize the situation is vague. During the design inquiry, the situation is understood not through gathering enough facts to be rationally analyzed, but through formulating an interpretation out of the conflicting perspectives. The search space is gradually narrowed, in accordance with the constructed interpretation, and the core characteristic of the design is unpacked as the designer continuously reframes his interpretation (Löwgren & Stolterman, 2004).

Simultaneous problem-solution generation: Approaches in IT (Information Technology) fields, such as information systems, software engineering, or human-computer interaction, assumes that a solution is generated after a problem is clearly defined. The design approach formulates a problem and solution simultaneously (Löwgren & Stolterman, 2004). A designer develops solutions following the early unsettled interpretation, and the proposal works as a conceptual tool that helps the designer work with a complex situation during the design process. As a designer's current understanding of a situation grows, the formulated solution also grows in a close relationship (Löwgren & Stolterman, 2004).

Perspective on methods and techniques: Stolterman (2008) argued that the way of

handling the complexity of reality in design research is very different from the way of handling complexity in the scientific approach. He stated that the reality is understood in science “by deliberate and careful separation of aspects (Stolterman, 2008;58).” Careful experiments are devised to demonstrate the statistical validity of the results, often in an explicit hypothesis and test paradigm or in the careful comparison of alternative conditions. The controlled experimental methods help a researcher focus on one relevant aspect or variable so that he verifies a rational analysis. Research on this approach is evaluated based on the way the study has been carried out. If research is accurately conducted with proper methods and techniques, the research result is considered correct (Löwgren & Stolterman, 2004).

Compared to a scientific approach purposing verified truth, design inquiry purposes to understand the complex reality for meaningful design. The design research is aimed at solving an undesirable state in the complex, ill-controlled environment of actual usage. Therefore, Stolterman (2008;59) stated that design inquiry methods and approaches “have to take the whole composition,” while a designer makes decisions about how to approach the reality, such as how to frame the situation, who to listen to, what to pay attention to, and how to explore. Design research is not assured with research methods and techniques, but should be assured by repeated reflection and examination within the iterative design process.

3.5 Evaluation of Research through Design

Research through Design is an emerging research approach whose evaluation criteria are not fully developed, but Zimmerman et al. (2007) suggested four criteria for evaluating an interaction design research: process, invention, relevance, and extensibility.

Process: Researchers must provide enough detail about their research, covering the whole process, including problem framing, the articulation of the preferred state, and the evolution of research. It is also important to document the rationale for why researchers selected the specific methods in their research.

Invention: Interaction design research should demonstrate its contribution to how the study advances the current state of knowledge and artifact. The invention from the research can be demonstrated through detailing how theories from disciplines

were integrated into the process and how the research reflection contributes to the disciplines (Zimmerman et al., 2010).

Relevance: Interaction design research should demonstrate relevance. The methods by which scientific research demonstrates its contribution are not an appropriate criterion for evaluating design studies. Different design studies of the same problem cannot expect the same problem framing and solution from different designers (Zimmerman et al., 2007; Fallman & Stolterman, 2010). It is not appropriate, either, to evaluate by judging whether the methods and techniques are accurately selected and conducted for rigorousness (Fallman & Stolterman, 2010). Zimmerman et al. (2007) argued that instead of validity, design research should be evaluated with relevance, demonstrating what is real, what the preferred state is, and why we should consider the state as desirable.

Extensibility: The design research must be described and documented sufficiently so that the research community can build upon and extend the knowledge derived from the work. Forlizzi et al. (2009) pointed out that reflection on a single example may be difficult to recognize as research because of limited extensibility. Design research should have extensibility so that findings contribute as knowledge that can be used for understanding common problems.

3.6 Research through Design approach to wireless device connection problems

Based on the reviewed benefits and characteristics of the design inquiry process, this section reflects on how and why this dissertation employs the Research through Design approach for investigating user interaction problems in wireless device connection.

3.6.1 Research approach decision

The ultimate goal of this study is to generate a possible design solution that would provide desirable user interactions. The goal of finding a design solution is quite different from the traditional research problem of determining the correct theoretical understanding of the underlying issues. The design solution must have practical impact, but it does not need to be the optimal solution. In practice, adequate

approximate answers are sufficient (Löwgren & Stolterman, 2004; Gaver, 2012; Norman, 2014). Therefore, a design solution might not be concerned with the details that are important for distinguishing theories competing for an optimal solution.

This issue means that for designers, practical value takes precedence over other intellectual problems, such as determining key factors in user interaction difficulties, or developing an in-depth description of user problems in a given situation. Research through Design, which focuses on generating a desirable future (Zimmerman et al., 2010), is considered the most beneficial research method for accomplishing the primary goal of this research.

This thesis applies the Research through Design approach. In user interaction design for wireless device connection, many factors are involved and their effects are highly inter-connected (Chong and Gellersen, 2012). Because of the complexity, it is difficult to get a clear view of what the key factors are and how to control them for a proper experimental study. A large number of factorial experiments and analyses are required before design insights emerge with regard to how to handle the many complex factors. Research through Design is an effective research method that approaches a complex problem through an iterative process of problem framing and solution generation without requiring massive experiments.

Through the application of the Research through Design method, this dissertation contributes to the exploratory study of device association. Existing theories in related fields are not yet mature enough to provide a clear understanding of user interaction difficulties. Some significant factors are possibly yet to be revealed. Zimmerman et al. (2010) and Gaver (2012) advise that Research through Design could contribute to nascent and propositional theory. The problem framing and corresponding solutions of Research through Design may provide new insights for understanding user interaction problems and discovering key influencing factors.

As the field of design matures and the kinds of problems investigated in this dissertation become better understood, a different approach will be needed. This dissertation's major focus is upon determining the major design parameters that will help people cope with the complexities of interacting with connected devices. As these issues become better understood, when the initial explorations such as performed in this dissertation and the works that will follow have been developed into a mature theory, then the traditional experimental research approaches will be

required. At that point, the traditional experimental design concerns will be of importance, coupled, of course, with the appropriate statistical analyses, in order to verify, refine, and optimize the insights of this thesis through robust evidence.

3.6.2 Applying Research through Design

Iterative design process

Within the next four chapters, this dissertation examines user difficulties with gradual comprehension and generates solutions via an iterative inquiry process using a Research through Design approach, as in Figure 6.

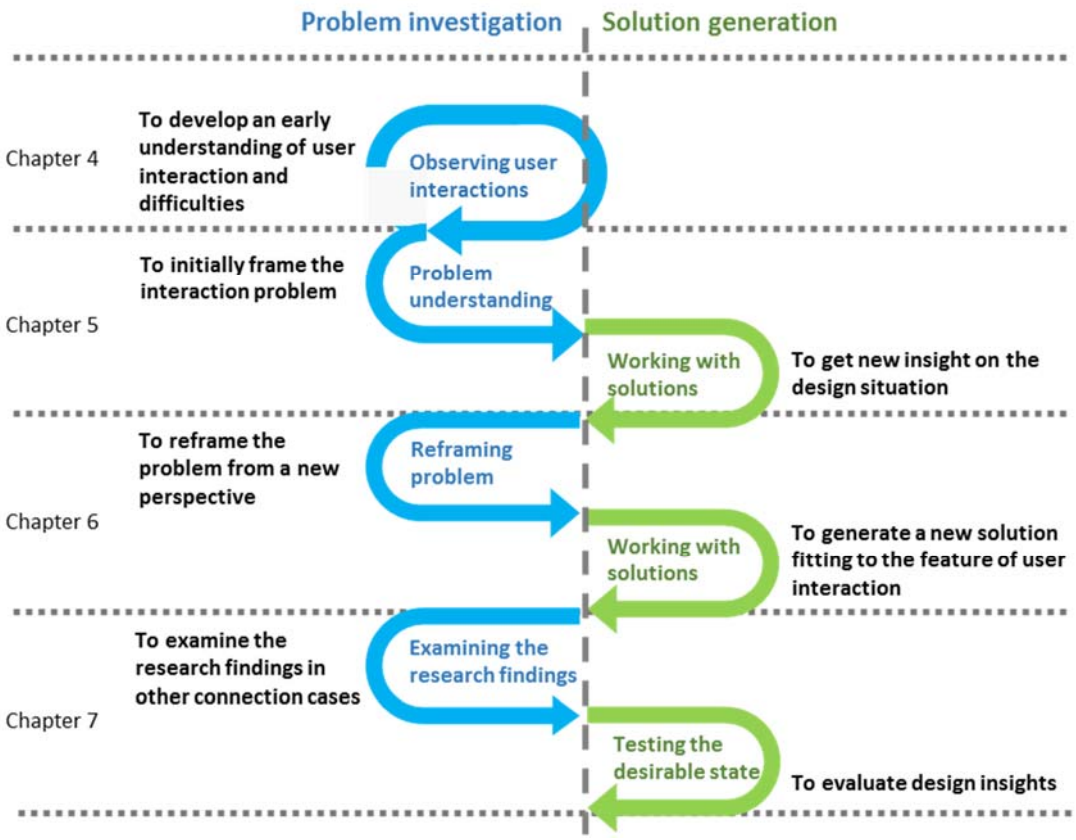


Figure 6. Iterative design process of the study

Chapter 4 struggles to understand the chaotic user interaction situation, observing cases with different technology, interface, and context. The initial struggle is not approached with specification of factors or a reduced point of view to analyze a specific phenomenon, but observes the overall composition of complex interaction situation.

Chapter 5 formulates an initial interpretation and generates an initial state of solution idea simultaneously. The solution is generated not because the problem is clearly defined, but because the proposal works as a conceptual tool in order to construct deeper understanding of the design situation in the design process.

Chapter 6 reframes the user interaction problem with a different perspective and generates an alternative solution with a new angle. When a designer faces a situation such that his solution cannot effectively deal with the design problem, a new frame of the problem can bring other solutions (Schön, 1983, quoted from Zimring & Graig, 2001; Löwgren & Stolterman, 2004). A new solution is pursued through analysis of user difficulties with a new framework.

Chapter 7 shows how the research findings are applicable knowledge for interaction design. In this chapter the problem framing and design insights are evaluated through expanded studies.

Chapters 4 through 7 follow the Research through Design paradigm of iterated phases in which I gain comprehension of the design problem, and generate possible solutions. Each phase of the iteration is moved forward based on continuous reflection on the problem interpretation and design suggestions.

Gradually reframing the problem

Research through Design which aims to improve the current state of artifacts is naturally interested in designable and changeable aspects of human-artifact interaction (Schneider, 2007). In interpreting the current state and envisioning the future state of user interaction, this study spontaneously focuses on designable and changeable aspects of devices' interface.

In the beginning phase (Chapter 4) of this study, it is not clear what problems there are, what to pay attention to, how the connection state changes, or what the influence of many related issues may be. Although the initial phase is approached with loosely managed inquiry methods and vague analytic principles, during the following phases of the design process, research focus on the complex user interaction is gradually narrowed, user interaction difficulty is continuously reframed, and a vision of the desirable state of user interaction is successively evolved.

Decision of inquiry methods

Each of the phases is approached with different analytic foci and methods, as in Table 2. Although the approaches and methods in the research are thoughtfully chosen, they cannot be argued as a scientific logic of research. Rather, the methods are decided based upon reflection on what information would reveal an image of the current situation and a possible future.

Table 2. Approaches for objective of design research phase

Chapter	Objective	Approaches
Chapter 4	To gain a brief understanding of the user interactions and user difficulties	Three different user interaction cases with current devices are observed.
Chapter 5	To initially frame the interaction problem	The originally required user interactions on two connection cases are understood through technician interviews and a reference study; User difficulties are explored through a comparison study with non-expert users' interactions with the required interaction.
	To get new insights into the design situation	The design situation is reflected upon by generating and evaluating design alternatives.
Chapter 6	To reframe the problem with a new perspective	User difficulties in handling the sequence of interactions are investigated, specifically regarding the execution and evaluation stages of performing the actions.
	To generate a solution that overcomes the design constraint	An innovative design solution is generated using the boundary shifting method.
Chapter 7	To examine the research findings in other connection cases	Three additional cases are observed to confirm the problem understanding.
	To evaluate the generated design implications and a solution	The generated design implications and the framework are applied to improving user interactions in three cases and are tested by non-expert users with paper prototypes.

Rigor of research

Unlike traditional HCI approaches with careful experiments, this study does not aim to analyze or verify one relevant phenomenon. Because this study aimed at providing a design framework for interpreting and approaching the complex and ill-controlled user interaction problems, this study cannot be evaluated with traditional research criteria. The rigor of this design research should not be assured by the methods this study has been carried out but by the repeated reflection and examination within the iterative design process.

Chapter 4. Early Statement of Problem Understanding

4.1 Objective

The early stage of the design process is to establish a preliminary understanding of the issues to be addressed. I follow Krippendorff's advice (2007) of starting with observations of how the current versions of artifacts are used in different situations. I do this by watching some user interaction cases of a few different current connecting devices and inquiring about the problems I observe. The objective of this chapter is to use this understanding to establish a preliminary problem statement. The sub-objectives are:

1) To establish an early image of the user interaction situation that provides the foundation of design.

2) To state a preliminary problem understanding that directs further research.

4.2 Study method

Three cases with different technologies and complexity were observed. All three cases use two separate devices that need to be connected. The three observed cases have different complexities of interaction, from (a) very simple user interaction with a subway payment card and card reader connection, (b) simple connection of two audio devices among multiple devices, and (c) the complex connection of a printer and a notebook computer which requires mediation of other devices (Figure 7).

The three cases of user interaction were observed in different situations with different strategies in order to reveal broad aspects of the user-devices interaction situation. While the study of the subway payment system is intended to observe user interactions in-situation (at the subway station in real usage), the other two cases (the Bluetooth connection of audio devices and a printer and a computer connection) were observed in laboratory environments.

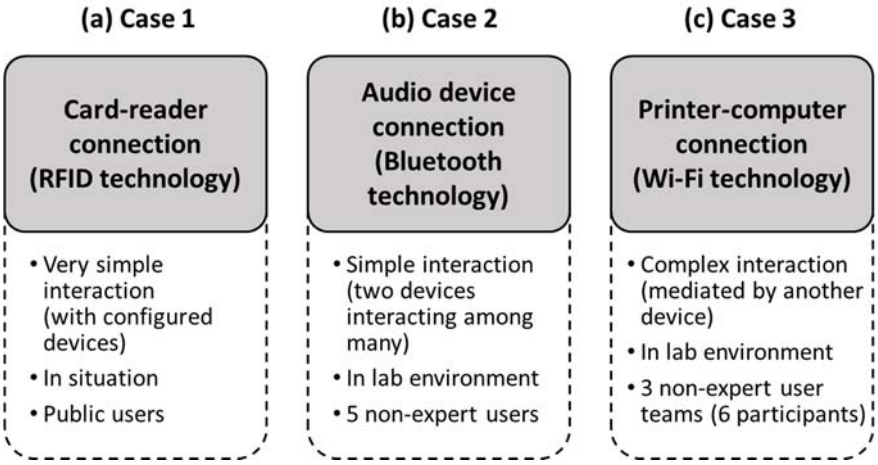


Figure 7. Three observations of different cases

In the Bluetooth connection study, I observed user interaction handling of the two devices' connections among multiple devices. In the study connecting a printer and a computer, I wanted to understand what users perceived from the device's interface and what influenced their understanding and decision-making during the interaction. I asked teams of two people to do the tasks collaboratively: their conversation reveals their perception in a more natural way. Observations in this research were intended to look at non-expert users' interactions, which can effectively reveal problems associated with information and interfaces of the devices with limited influences from previous knowledge and experiences.

In this chapter, none of the three observations were controlled experimental studies. This is because the goal is to understand the potential for improved design: these are not traditional experimental tests. These observations deliberately reveal different user interactions to provide for a broad overview of the complex problem situation. When a study purposes to reflect user interaction problems and get design insights, observing three to five users reveals the majority of important design problems (Barnum et al., 2003). The three observations were terminated when the observations provided sufficient information for the design researcher, over the minimum of three interaction cases.

All the think-aloud protocols and interviews of all three studies were carried out in the native language of the participants: Korean. The main language of the devices' interface was also set to Korean.

4.3 Observation 1: Simple interaction using an RFID card and a reader system

4.3.1 Observation method

The first observation was conducted with a two-device connection consisting of an RFID card and a card reader in a subway payment system (as seen in Figure 8). The devices require a very simple user interaction: the two separated devices come to work together when a user touches the card to the panel of the reader so that the reader reads stored data off of the card. The observation was conducted at three different subway stations in Daejeon City, Korea. The card readers at the stations can be operated with tokens, prepaid cards, and some Korean credit cards that have RFID chips embedded in them. Operating the card and reader should be a very easy task for all users.

Figure 8. RFID card and reader of Daejeon subway paying system

Because this study was observed in public spaces, it was not video recorded but was observed from a near distance and noted in the field. In addition to the observation of anonymous passengers, a station employee was interviewed in order to understand what causes interaction problems. The employee was in charge of helping people pass through the card payment system.

4.3.2 Understandings from the observations

Surprisingly, frequent users had trouble ensuring the very simple connection of a RFID card and a reader working together (Table 3). Frequently, it was not easy to diagnose the problem when something went wrong with the system's operation. When a passenger's card has not properly read, often the subway RFID card system only beeps and flashes a red light without any further guidance. Passengers tended to deal with this by repeating their actions, without knowing the cause of the failure. Some passengers gave up after several trials and decided to ride illegally.

Table 3. Observed problems from Subway paying system

Station	Observation time	Number of observed troubles (crowdedness)	Note
Station 1 (Daejeon station)	30 minutes (from 11:30 am to 12:00 pm on Thursday)	32(600)	A station employee helped passengers.
Station 2 (Jungangno)	30 minutes (from 12:30 pm to 13:00 pm on Thursday)	16(240)	
Station 3 (Jung-gu office)	30 minutes (from 13:20 pm to 13:50 pm on Thursday)	10 (120)	

*Crowdedness represents the number of passengers having passed through the gate during observation time. The number was calculated approximately based on the number of passengers counted during five minutes.

Because of frequent problems, a station employee stood near the system to help passengers. One of the most frequent problems occurred when a technological connection between the devices was not properly established. One common cause of the difficulty was the passenger's rush to get through the system: it takes two seconds, for the reader needs to establish a connection with the card and read its data. Another frequent problem occurred when the reader would try to read several cards in a wallet simultaneously. Another source of difficulty was the use of the wrong card: users confused the payment card with other general credit cards that are not visually different.

In addition, passengers were not able to pass through the gate when a card was out of order or when a card did not have sufficient funds (so that it would need to be recharged). Problems also happened when a user was confused about which reader to use (to their right or left), or when a user was confused about where to touch the card to the reader.

Although a card and a card reader connect with a very simple user interaction, the user interaction situation is not simple, as shown in Figure 9. It includes problems of identifying one device among many, disturbance from other devices, and problems with the device itself such as a card needing to be recharged, as well as connection problems between the two devices. The complexity of the user interaction situation make this apparently simple task difficult to diagnose when there are problems.

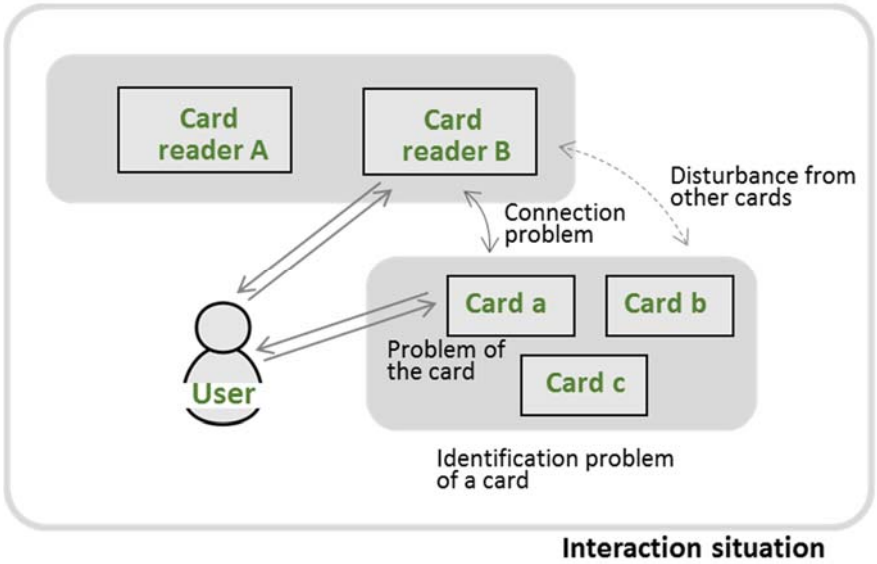


Figure 9. Complex user interaction situation of a card and a card reader connection

4.4 Observation 2: User interaction on Bluetooth audio devices connection

4.4.1 Observation method

The second study was intended to closely investigate what problems users faced when they established connections between wireless products. Non-expert users' were observed as they tried to establish Bluetooth connections between two devices.

Participants were given three Bluetooth products as Figure 10: an MP3 player (Samsung Yepp R1), a set of earphones (TSW-MH-806), and a speaker (Motorola EQ5). Participants were asked to connect either a speaker or an earphone to the MP3 player. Then, after the successful completion of the first task, the participant was asked to connect the second device to the MP3 player.

All connections from the MP3 player were removed, and the power was turned off for all three devices before the devices were provided to another participant. Participants were provided a very short introduction to the devices and were instructed how to turn them on before they started the tasks. However, because this study focuses on interpreting user interaction problems occurring from the current device interface, the study was intended to eliminate other influential information regarding user interpretation of the device interface. Instructions on the graphical and physical interfaces of the products and product manuals were not provided. Instead, the moderator answered questions if a participant had repeated troubles with a task.

Figure 10. Devices used in Observation 2
(Left: Samsung Yepp R1 MP3 player and graphical interface of Bluetooth connection screen; Center: Motorola EQ5 Bluetooth speaker; Right: TSW-MH-806 Bluetooth earphones)

All observations were conducted individually in the same room. Participants were asked to think aloud to expose their interpretation of and confusion about the devices' interaction. All user activities were video recorded and transcribed. Figure 11 shows examples of the recorded user activities. An example of transcribed user protocols (translated into English) can be found in the Appendix A.

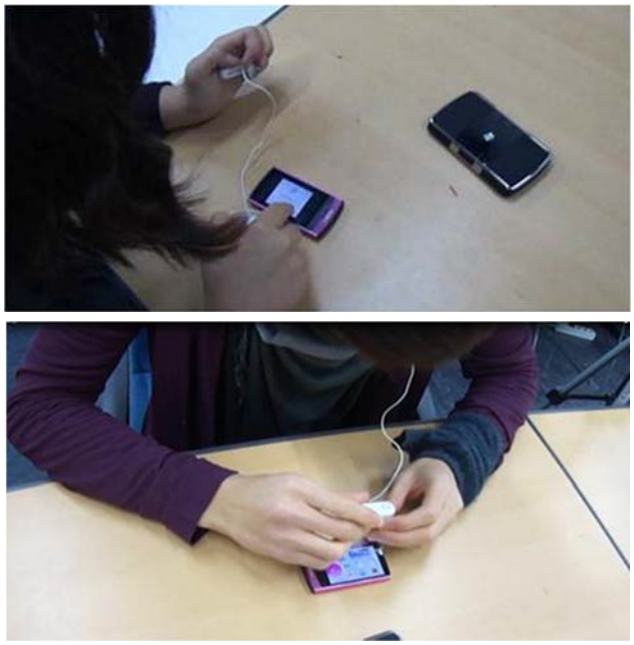


Figure 11. Video recorded user activities during Observation 2

Five non-expert users participated who had not experienced connecting similar device pairs. For instance, users who had experienced pairing any type of MP3 player and a Bluetooth speaker or earphones were excluded because their interpretation of device interaction would be formed not only by their perceptions and understanding of the devices' images but also from training and instructions in previous experiences. Non-expert user participants were recruited from among university undergraduate and graduate students in their 20s, who feel relatively comfortable handling new technologies. The interactions of the five participants' interactions are referred to as P1 to P5.

4.4.2 Understandings from the observations

Among five participants, three participants (P1, P3, P5) connected the earphones first and connected the speaker in their second task. The other two (P2, P4) connected in the opposite order. Although all participants succeeded, they struggled while connecting the products.

Some usability problems caused difficulties in user interaction. Firstly, technological words, like "pairing" and "PIN code" were not understood. Unfriendly device codes, like 0018E4227C5D, or model numbers, such as TSW-MH-806, were shown on interfaces. Participants (P2, P3, P4, P5) had trouble figuring out what those words or

codes meant and what to select.

Secondly, unrecognizable product interfaces caused user confusion. The TSW earphones needed to be set up to a certain status with blinking red and blue lights in order to establish a new connection; this was done by pushing a physical button for a long period of time. All five participants had difficulties setting up the status with the earphone's unclear button interface. Another difficulty arose from the MP3 player's interface, which requires dragging a device icon onto the central icon to establish a connection (as Figure 12a). Three (P1, P3, P5) out of five participants had difficulty figuring out this action.

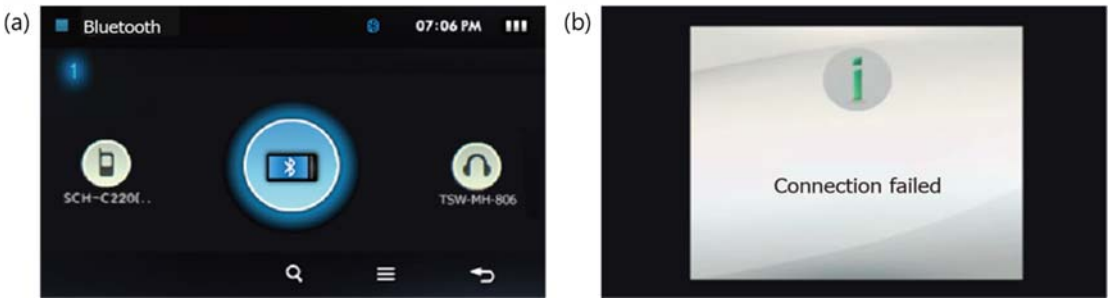


Figure 12. Graphic interface of Samsung Yepp R1 MP3 player when (a) R1 searched other Bluetooth devices and (b) the connection failed

Thirdly, another user difficulty was device identification. While the interface showed the devices with codes (such as 0018E4227C5D) or model numbers (such as TSW-MH-806), two participants (P3, P5) were confused with the matching of codes to the model numbers or by the matching of model numbers to the real devices. Identification problems also occurred with interface feedback messages in two participants' interactions (P2, P4). Users were confused about which device was being referred to because the interface did not provide any device information.

When the Bluetooth connection failed, the MP3 player only showed a short message (Figure 12b): "Connection Failed." The feedback messages did not provide useful information regarding what had caused the problem or what the user could do to fix the connection. When something went wrong with a connection, the most frequent participant strategy was to try to change the status of the involved devices and test to see if the change worked for the system (P1, P3, P4, P5). Another frequent approach was to repeat the trial without knowing the cause of the failure (in P2 and P3's cases). Four participants (P1, P3, P4, P5) verbally expressed annoyance or sighed when they did not understand what the problem was or what they should have done

for the configuration. Table 4 summarizes findings from the initial analysis.

Table 4. Initial findings from user interaction of Bluetooth connection

	Observed user interaction problems
Difficult technical terms	Difficult technical terms, such as “pairing,” “PIN code,” and “0018E4227C5D” (the device code) were used.
Unrecognizable interface	It was difficult to determine how to make earphones connectable. It was difficult to know to drag a detected device to the central icon.
Device identification	The participants were confused about matching a product to its representative icon. The participants were confused about matching a message to the corresponding product.
Inappropriate diagnostic support	The participants did not know why their connections failed. The participants were given no specific guidance on what to do when a connection had failed.

The observations of the Bluetooth audio devices showed that devices involved in a previous connection can confuse users in a new connection. When some participants (P2, P3) turned off the device but did not remove it from the MP3 player interface; the icon remained on the screen, which led to confusion regarding device identification.

Some connections were influenced by previous tests also. Reconnection procedures were observed (in P2, P3, P4 cases) despite the fact that all connections and device information were removed from the MP3 player. Although the reconnection procedure provided a simple pairing method, two (P2, P3) of three participants ignored the reconnection procedure and acted as if this was an initial connection.

4.5 Observation 3: User interaction on a printer and a computer connection via wireless network

4.5.1 Observation method

The third study observed when non-expert users established a wireless connection of a printer and a notebook computer through a network. It was intended to look at a complex connection mediated by additional devices.

Participants were given a Samsung CLX-3185WK Wi-Fi color laser-jet printer and a notebook computer with Windows XP for a connection. Also available to participants were an ipTIME N604S Wi-Fi router, an extra LAN cable, an extra LAN port for the university network, a USB cable, a desktop computer with Windows 7 which was connected to the university network, and an extra set of network addresses, including IP, DNS (Domain Name System), and subnet mask. For this complex user interaction, additional information such as manuals for the printer and router could not be completely eliminated. Instead, manuals were provided after five minutes, so the researcher observed primitive user understanding before additional information influences user interpretation of device interface.

Figure 13. Samsung CLX-3185WK, Wi-Fi color laser printer and product interface

Technologically, the Samsung CLX-3185WK printer can connect with a notebook computer through a router or through the university ipv4 Wi-Fi network. If the printer is connected to a network and has its own IP address, a computer can be connected on the printer's own ad-hoc network as well. The Samsung printer has a small display panel and buttons to configure the network functions. A written guide for "one-touch networking" was placed near the interface panel, as shown in Figure 13. It says to "push a WPS button for two seconds on the printer (in step 1), to push a WPS button

on the router for two seconds (in step 2), and then the connection is established (in step 3).”

The tasks were performed by three teams of two participants (T1, T2, and T3) so that their natural conversation would reveal their understanding of the interaction. In order to maintain the targeted user interaction form of this study, only one participant was asked to physically control the devices, and the other to assist the first through verbal communication. Six participants were recruited from among people who had not had training in networking, but participants’ expertise in computers or printers was not controlled. An example of a transcribed conversations was attached in the Appendix A.

4.5.2 Understandings from the observations

Each of three teams spent more than one hours on the task, but only one team (T1) succeeded in connecting the printer. Participants in all three teams verbally expressed annoyance several times. Two teams (T2, T3) could not complete the task even after they carefully read the product manual. They stated that they would give up attempting the configuration in a real-life situation. It is important to note that the only successful team (T1) had a member with software development experience, but configuration of the devices was not an easy task for them, either.

Difficult technological terms used in the network interface and manuals, such as “ad-hoc,” “IP,” “DNS,” and “WPS (Wi-Fi Positioning System),” made participants feel uncomfortable. Most abbreviations in the manual and interface were used without description. Participants demonstrated difficulty understanding what those words meant and what to do with them. Simple but serious usability problems of the printer increased user confusion; for example, network configuration menus were located under an unexpected category, “copy configuration.” The printer manual was not organized and was difficult to understand. Two participant teams tried the many different connection methods suggested in the manual, but none of them were successful. Participants repeated their trials according to the manual, but they could not figure out how to solve the problems.

Conversations between team members showed how the feedback from the printer, manual, and text information on the printer influenced user interaction. For instance, the following dialogue is from a participant team (T3) as they found the written guide

to “one-touch networking” and showed how they reacted to the written guidance that was placed near the control panel of the printer.

> *P1: “Tara, Tara; Oh, it is turned on.”*
> *P2: “Is it turned on?”*
> *P1: (He reads the display panel of the printer.) “Preparing. Please wait, it says. ‘One touch networking’!” (He reads the text on the printer.) “Push WPS button for two seconds, and push WPS button on the router for two seconds.”*
> *P2: “Push this for two seconds.” (He pushes the WPS button on the printer.) “One, two.”*
> *P1: “Where is the router?”*
> *P2: “Uh, we don’t have one.” (He moves to get a router and turns it on.)*

The non-expert user participants of two groups, including the group quoted above, who did not have technological training, followed the manual or guidance without thinking of any other conditions. All three teams tried this WPS connection, but all of them failed. Users expected that the connection would be made after they tried what the guide recommended, the connection between the printer and the computer was not made with this method. When the participants used a physical USB cable to configure the printer and the computer, they tended to perform similarly.

Table 5. Initial findings from user interaction of Wi-Fi printer connection

	Observed user interaction problems
Difficult technical terms	Technological terms such as “IP,” “DNS,” “Ad-hoc,” “access point,” and “WPS” were not understandable. The users were confused by vague words in the manual and interface: “configuration,” “network,” “product,” and so on.
Confusion about the products’ interface	The printer network menu was difficult to find.
Inappropriate diagnostic support	The users did not know why connections failed. The manual was difficult to understand. Connections often failed, even when the user followed the manual. The printer did not work after a “connection success” message

> *"The biggest problem (of the interaction) is that I cannot infer what the problem is. I cannot find any clues."*

Above quoted sentence is what one participant (of T3) explicitly pointed out after the team failed to configure the connection. The two teams that did not succeed had difficulties dealing with the problems of devices' connection. Participants continuously tried to infer how the devices should be connected and what they should do, but all of their efforts (including careful reading of the manual and continuous observation and reflection) did not work. Table 5 summarizes the interaction difficulties observed during the user study.

4.6 Findings

4.6.1 Understanding the interaction situation and related issues

The three observations of this chapter provided preliminary understanding of the complex user interaction situation of wireless device connections. The situation is intricate regarding several issues.

Firstly, not only are various technologies, devices, interfaces related to the wireless device connection problems, but their connections have different complexities. For instance, a preconfigured card can work together with a reader at a subway payment system with a simple touch, but some device connections require more complex user interaction, like configuring a wireless network printer that can be connected to a computer via a mediating network. Also, the connection between two devices can be established via an initial association procedure or through a reconnection procedure. The differences between these two procedures are not clearly understood in non-expert interaction.

Secondly, a connection between two devices can be influenced by other devices in the area. Multiple devices can influence each other when they try to connect to the same device simultaneously, or a connection can be influenced by previously configured connections. The problem of identifying the correct device among multiple devices adds more difficulties and confusions to the interactions.

Thirdly, non-expert interactions are influenced by many factors: how they interpret

the device interface, actions, and feedback, manuals or other guidance, by their previous knowledge, and by the well-intended but often confusing (or even contradictory) assistance from others. These issues provide numerous challenges and opportunities for design.

4.6.2 Problem statement and further reflection

The observations show that it is not just the complex connections that cause problems: even the simple touching interaction of an RFID card and reader can be problematical. While different usability problems were found in the three cases, non-expert users have difficulties with connected devices. In all three cases, users had difficulties in recognizing what the problem was and how to handle. The first problem is simple: (Figure 14)

Problem statement:
Non-expert users have difficulties handling interaction problems in connecting two devices.

Figure 14. Problem statement from the initial phase

In order to get further understanding of the interaction problem and generate design solutions for the stated problem, it is necessary to explore what interaction is required and where and why users have difficulties. These questions are addressed in Chapter 5.

4.6.3 Summary of the chapter

This chapter describes the initial phase of design research. I observed three device connection cases to gain broad understanding of user interaction. The studies in this chapter are intended to provide a broad but abbreviated image of the design situation. From the repeated problems observed from the three cases, several issues related to user interaction situation were also determined. Figure 15 presents the progress of research from this chapter.

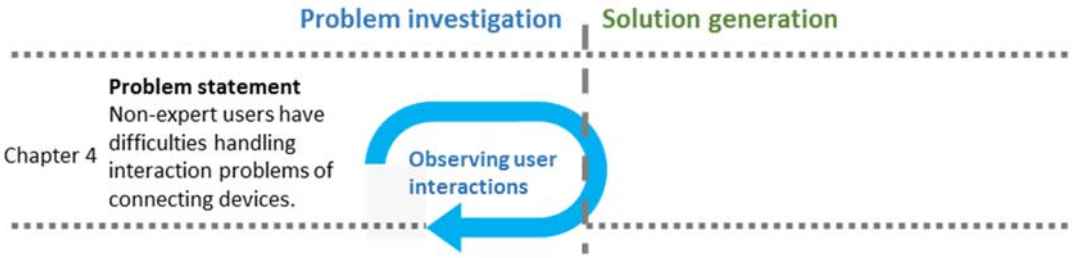


Figure 15. Design research progress in Chapter 4

Chapter 5. Exploration of User Interaction Problems in a Sequential Connection Procedure

5.1 Objective

This chapter explores difficulties users encounter when performing the required interaction to connect devices and begins the process of providing solutions to the problems. The sub-objectives are:

1) To understand what interaction is required in Bluetooth and wireless network device connections through reference study and interviews with technicians.
2) To explore where and why user interaction problems occur by comparing interaction of the non-expert users with the required interactions.
3) To get design insights by working with early stages of design solutions.

The RFID card and reader interaction study is excluded in this chapter because those observations were performed in public spaces, and therefore were not video recorded to protect privacy.

5.2 Exploration of required interaction

5.2.1 Required user interaction for Bluetooth connection

Two interviews were conducted with an expert Bluetooth engineer, a PhD student at an engineering school and expert in short-range wireless connections, including Bluetooth. Understanding from the interviews was enhanced with additional references (Ciarletta & Dima, 2000; Day & Zimmermann, 1983; Liu, n.d.; Nokia, 2003; Palm, 2005; Rathi, 2000).

Figure 16 illustrates the common connection procedure of Bluetooth devices. Time flows from left to right along the x-axis and the devices are shown along the y-axis. The connection requirements are given as text along the y-axis between the devices, and the stages of interaction are shown as text along the x-axis. The figure summarizes user-related requirements and interconnection procedures, rather than

Bluetooth hardware specifications or signal transmission packets.

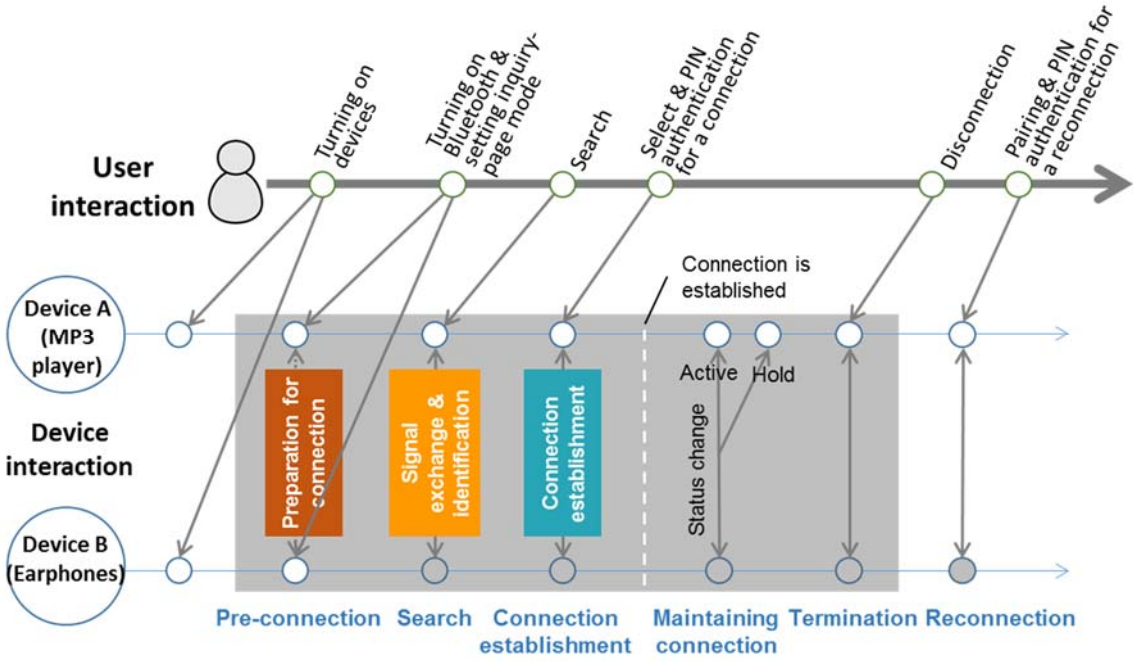


Figure 16. Common user-devices interaction for Bluetooth connection

Devices connection includes several stages for the users: pre-connection, search, connection establishment, maintaining the connection, and disconnection. In the pre-connection stage, the user needs to ensure that each device allows exchange of communication signals. The connection between devices is initiated when the user targets one device from another after the devices recognize one another. The complete connection is established when the devices are paired, often requiring the users to select which device is intended or to enter an authentication code (often called a Personal Identification Number or PIN). Profiles specify the Bluetooth services, such as hands-free, stereo headset, file transfer, and so on.

During the interaction after their connection is set up, the connection status of the two devices fluctuates through a variety of states—hold, park, and sniff—and returns to an active state depending on the frequency of functional activities. Finally, the connection ends either by automatic completion of the desired functions, deliberate action by the user, or an error at any time during the interaction.

Many factors affect the connection of the devices at different levels, such as the physical distance between the devices, device compatibility, profile compatibility, and even such seemingly straightforward issues as whether the devices are turned on and

working normally. In addition, some of the devices may already be involved in a network connection that prohibits additional interconnections due to its structure of Bluetooth technology or functional usage such as in audio device connections.

5.2.2 Wireless network printer and computer connection

Three technicians who are relatively skilled at network configuration were interviewed to determine how the current wireless network technology expects users to interact. Two technicians came from a university's network-management team and a third from a computer agency that sets up devices for customers and provides after-sale technical support.

In-depth interviews were conducted in order to learn as much as possible about the technicians' interaction strategies with device connections and to allow them to explicitly describe the network-connection procedure, possible problems, and problem-solving strategies. The major interview questions concentrated upon key knowledge or know-how needed to configure network connections, the common problems participants encountered when asked to connect products, how they would approach the problems. The interviews were conducted individually and were unstructured.

When a user wants to connect a printer and a notebook computer wirelessly, an easy and popular way to do so is to use a router and establish a small network of devices. A technician described the connection procedure as follows:

> *"If we connect a printer with a notebook computer wirelessly, we need a wireless router or AP (Access Point). Also we need a notebook computer and a printer providing wireless technology. If they want to communicate, they need IPs. If a router provides IP for the computer and the printer, we can set up printer application after checking if the two devices can communicate…Devices need to be connected with wire or wirelessly. A router is a device making the connection."*

The wireless connection of two devices, a notebook computer and a printer, has much in common with Bluetooth connections in that it requires communication between and mutual approval from two appropriately prepared devices. However, Wi-Fi networks have the additional requirement that the two devices connect via the third device, in the cases examined here, a common router. There are two sets of connections: one between a router and the computer and the other between the

router and a printer. Figure 17 shows general user-related requirements and interconnection procedures based on the interviews.

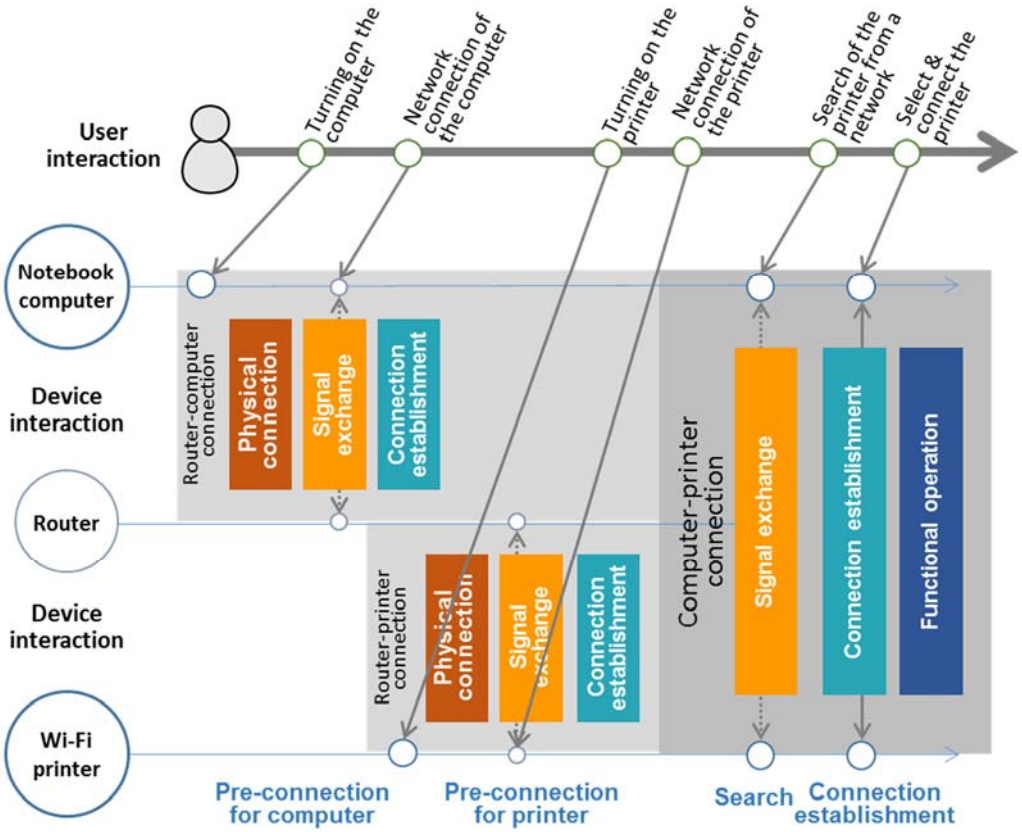


Figure 17. User-devices interaction for wireless printer connection mediated by a router

5.2.3 User interaction on connecting devices

The user interaction procedures from Bluetooth connection (Figure 16) and Wi-Fi wireless network connection (Figure 17) have different requirements but can be explained with a similar sequential procedure as in Figure 18. Connecting two devices requires 1) preparing each device for a new connection in the pre-connection stage, 2) exchanging signals and identities between the two devices in the search stage, and 3) selecting and establishing a connection in the connection stage.

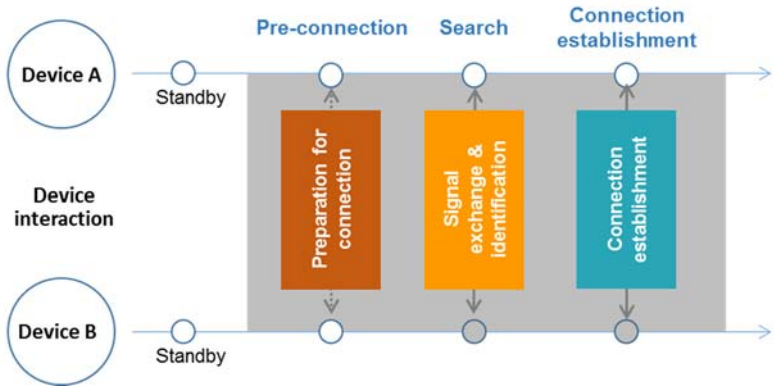


Figure 18. Devices connection procedure in their initial connection

The user interaction required to handle a two-device connection is not same as user-system interaction with a single device. Norman's explanation about the interaction between a person and a single device has been most common in HCI research (Figure 19a). A user controls the function by interacting with a system with a single device (Norman 1988, 2013). A key difference of the two-device interaction (Figure 19b) is that a user manages not only the devices' functions, but also the interaction between the two devices (Song et al., 2011).

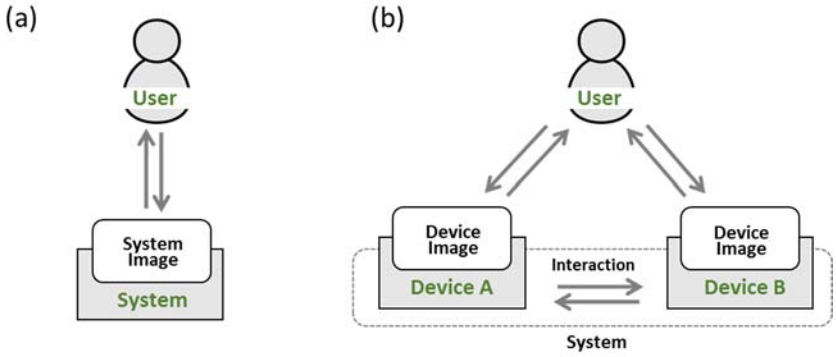


Figure 19. User interaction in (a) single-device system and (b) multiple-device system

When a user interacts with a system in which two devices are connecting with one another, the user controls the interaction by controlling Devices A and B on the basis of his or her interpretation of the images of Devices A and B. During the interaction, a user needs to handle a complex procedure, including preparing connection, search, select and connection, and usage. As the interaction becomes more complex, such as a wireless printer connection mediated by another network device, the users' models and interpretations become much more complicated. The result is that their models are often incomplete or erroneous.

5.3 User difficulties in sequences of connection

I compared the non-expert users' interactions with the interaction that the experts said were required. This comparison is shown in Figure 20. The comparison diagrams have been drawn using the internationally accepted symbols of the Unified Modeling Language (UML) sequence diagram (Bell, 2004) because these drawing conventions were designed with these complex interactions in mind.

5.3.1 Comparison study of Bluetooth devices connection

Pre-connection and search stage

In the process of connecting MP3 player with Bluetooth earphones, three participants (P1, P2, P3) had difficulty finding the earphone connection on the MP3 player because, unknown to them, they had not made the earphones ready for the connection. One participant (P5) had difficulties executing the search step itself because he did not realize that the MP3 player requires user involvement in order to search for devices.

Even when participants recognized they needed to control the earphones, it was not easy for them to make the earphones ready for the connection. The TSW-MH-806 earphones needed to be set up to "inquire-page" mode in order to establish a new connection by pushing a physical button until the red and blue lights blinked. All participants had difficulties performing the step, and three (P1, P2, P3) of the participants had to ask the moderator for assistance. One participant (P5) learned it by himself through several trials. The inquiry-page is not a naturally inferred step for non-expert users; the problem of the preparation step made it difficult for participants to be succeeded in the search step. They wondered what to do but could not properly perform the search step several times.

Compared to connecting the earphones, performing the device search of the speaker and MP3 player connection was not very difficult. The speaker could be found on the MP3 player without setting up inquire-page mode as long as the speaker was turned on. The simplified connection procedure helped non-expert users to perform the connection.

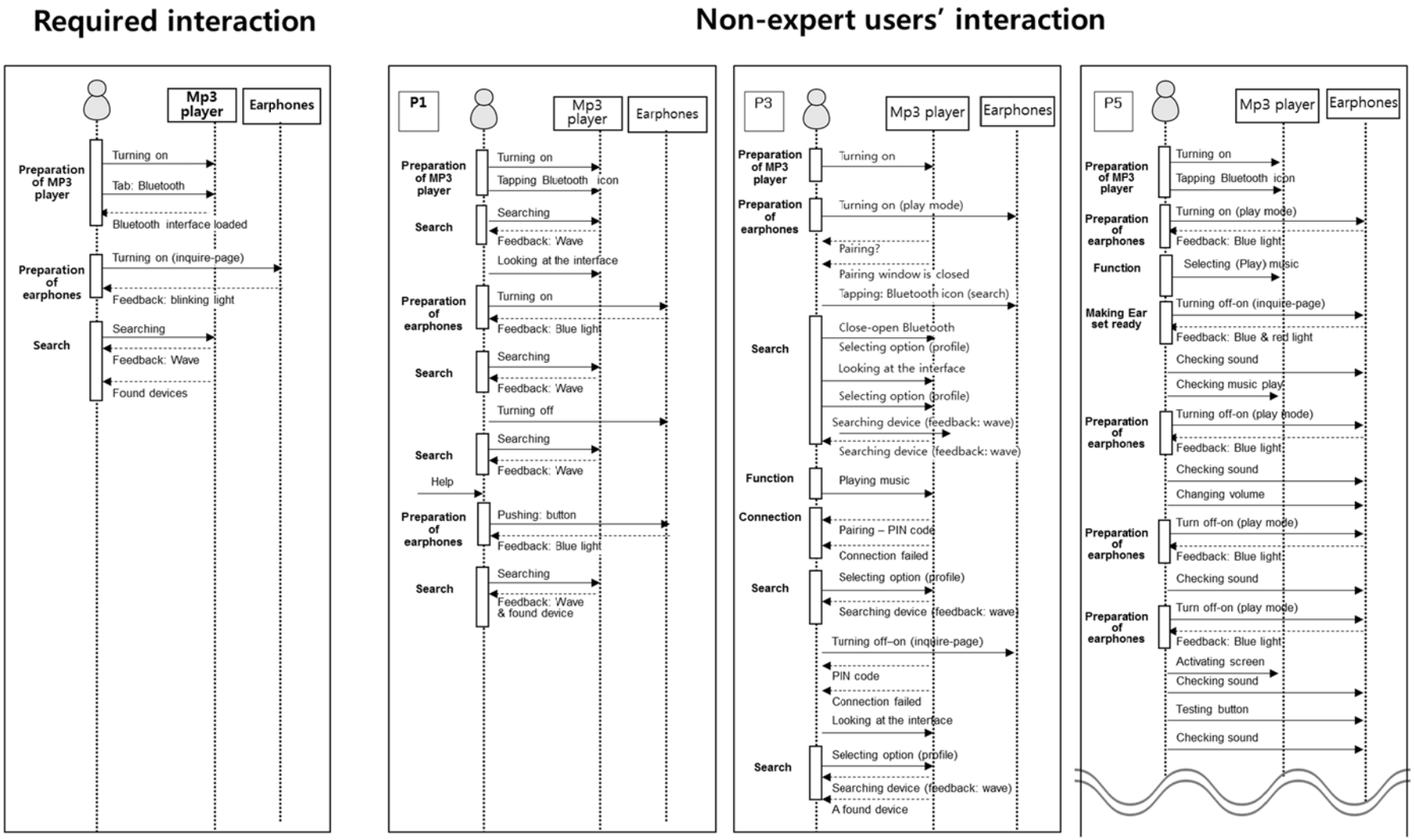


Figure 20. Comparison of required user interaction (a) and non-expert users' interaction (b) (Device preparation and search steps of the MP3 player and the earphones connection)

Connection establishment stage

All five participants had trouble with connection establishment on the MP3 player when connecting the earphones or the speaker. Four of them (P1, P3, P4, P5) expected to see a completed connection when a device was identified on the MP3 player. Participants could not recognize that pairing was required and had problems figuring out how to trigger the connection stage. They tried several things to find the reason the connection was not functioning, such as turning a device on and off (P1, P3, P5), changing the volume (P1, P5), changing the profile of the connection (P3, P5), and so on. Connection problems were also observed when a participant tried to connect the wrong device (P3; speaker) or when a connection failed for an uncertain reason (P3; earphones). The interface of the MP3 player did not guide users to recognize an appropriate connection sequence.

Reconnection stage

Often, the reconnection stage occurred during the observations, but the participants could not recognize if the devices interaction was in the reconnection procedure or if the operation was related to the devices association. Although the reconnection stage occurred with three of the earphones and MP3 players' connections (P2, P3, P4), two participants (P2, P3) ignored the reconnection stage and performed the whole procedure as if conducting an initial connection. The reconnection stage provided a simple sequence for connection, but participants could not associate the reconnection stage with the intended connection procedure. Only one participant (P4) performed the connection in the reconnection stage.

Overall

From the analysis, it was found that user interaction mainly occurred on the MP3 player, which had a touchscreen display on which most connection interaction happened. Non-expert user participants focused their interactions on the MP3 player. While Bluetooth devices require certain sequences in the connection procedure, the inquire-page and connection establishment steps were not naturally recognizable to non-expert users. It seemed that the interface of the MP3 player did not indicate properly what steps in the connection procedure needed to be taken. A device requiring a simplified sequence of user action (the speaker) reduces users' difficulties compared to a device requiring a complicated sequence (the earphones).

5.3.2 Comparison study of a printer and a computer connection via wireless network

The wireless network printer and computer connection requires a complex relation of the devices and a complicated connection procedure. As a result, two of three teams (T2, T3) could not complete the tasks in the pre-connection stage even after more than one hours trying. Therefore, I was only able to analyze these users at the pre-connection stage. Only one teams' (T1) interaction was analyzed in the search and connection stage.

Pre-connection and search stage

In order to be connected, the two devices had to have the proper wireless technology as well as to be properly prepared, which required connections of each device to the same mediating network device such as a router. Two teams of non-expert user participants did not understand this requirement, which made it very difficult for them to perform the pre-connection stage.

All three teams tried to follow a printed guide for "one-touch networking" located near the control panel of the printer, but the graphic guidance did not help non-expert users. Figure 21 shows the participant's interactions (T2, T3) after they had found the written guide on the printer; it said to push the WPS button on the router for two seconds after pushing the WPS button on the printer for two seconds to set up the connection. It only guided the search and connection stage and did not include pre-connection steps. As a result, the non-expert users of a team (T3) expected that the connection between the printer and the computer was established by pushing the WPS buttons and tried to print although the computer was not connected to either the router or the printer. All three teams tried the WPS connection, but two of them (T2, T3) failed because they did not know that the "one-touch networking" could only be established with proper pre-connection. One of the teams (T3) suspected some information was missing from the guidance but they could not infer what it was. Only one team (T1) inferred that connection requires proper preparation before pushing WPS buttons on, but even they failed.

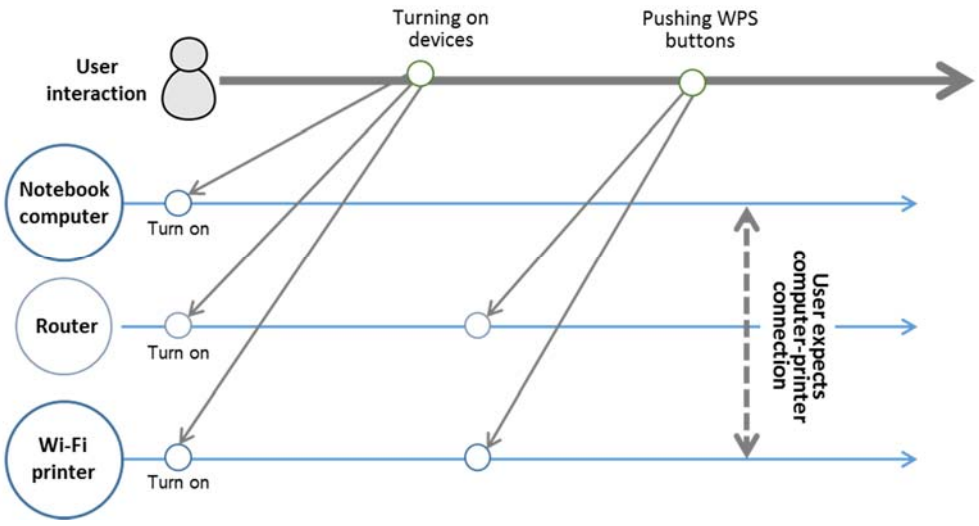


Figure 21. User trial connecting a Wi-Fi printer to a notebook computer

Neither the software program nor the printed manual provided by the manufacturer helped users perform the pre-connection stage properly. Non-expert participants did not understand what tasks they were performing nor why the tasks were not performed properly. Participants felt they were following a mysterious procedure.

Overall

The wireless connection of the printer and the notebook computer requires a complex procedure because preparation of the two devices requires sub-connecting each device to a mediating network device. It was difficult for non-expert user participants to understand the connection sequence. Participants could not infer how the two devices connect through another device's mediation and could not successfully complete the connection. While the devices interaction requires the complex procedure of making and checking sub-connections, non-expert users could not think of how the devices should be related in the network. The incomplete guidance of "one-touch networking" confused users in understanding the connection procedure. One team (T1) accomplished the task through connecting devices physically with a USB cable, but they understood sub-connection requirements among the devices.

5.3.3 Problem statement and design implications

For the connection of two devices, a user needs to handle the procedure of preparing the connection (device standby and connection preparation with a specific mode or sub-connections with mediating devices), search (discovering a device through signal exchange), select and connection (selecting a targeted device from the other device and establishing connection), and functional usage.

Bluetooth connection requires a certain procedure, but the inquire-page steps in the pre-connection stage and the pairing of the connection stages were not naturally recognizable to non-expert users. In the network-mediated connection of the printer and computer case, which requires a complex procedure among the targeting devices and mediating network device, participants had difficulties in understanding the connection requirements and procedure. Non-expert users had difficulty in performing the connection procedure.

The images of current devices do not act as a proper guide for the connection procedure. The involved devices did not provide enough recognizable visual clues that an action needed to be taken. Incomplete guidance on the connection procedure such as for the “one-touch networking (of the printer)” confused users more. Therefore, this study reframes the problem statement as follows in Figure 22.

Problem statement
Non-expert users cannot properly recognize some required sequences of the connection procedure. Current devices do not properly help users handle the connection procedure, including the preparation of the involved devices, discovery of a device from the other device, selection of a targeted device from the other, and connection establishment.

Figure 22. Problem statement of sequential interaction procedure

These observations allow me to proceed to the next stage of Research through Design: proposing a design solution. I suggest two ways to help users perform the required sequence (Figure 23). One way guides the complete sequence. The other designs a careful user interaction sequence.

Design implications

A device's interface should help users handle the sequence of connection interaction.

A. A device's interface should provide information to help users perform a sequence for connection, including preparation of the involved devices, discovery of a device from the other device, selection of a targeted device from the other, and connection establishment.
B. A device's interface should be designed to reduce unnecessary user action.

Figure 23. Design implications from the understanding of sequential interaction

5.4 Working with solutions

Research through Design requires the examination of potential solutions in the early stages of the investigation. New insights on the design situation can be gained through the analyses and examination of the strengths and weaknesses of these early proposals. Löwgren and Stolterman (2004; 22) stated that "the search for design solution is also a way of revealing the design situation." It is the designer's way of deepening learning and testing his or her understanding about the design problem that cannot be achieved without struggling with solutions (Schön, 1983; Löwgren & Stolterman, 2004). The early phase solution in this section is generated not because the problem is clearly defined, but because the proposal works as a conceptual tool to construct deeper understanding. The aim of this section is to get further insight on the interaction problem and design situation through working on solutions.

The ideas and assessments were reflected by a way of design rationale and the QOC (Questions, Options, and Criteria) method suggested by MacLean et al. (1991) to aid understanding the possible space of a design. Through identifying key design issues (questions), one can assess possible design solutions for the questions (options) while reflecting on whether the options satisfy required desirable properties of the artifact (criteria).

5.4.1 A question and options

The early solutions of this section focused on the first implication of the two elicited

design guidelines, which are for providing information on the connection sequence (design implication A). The solution idea can be searched for on a more abstract level and can have wider applications compared to the second implication (design implication B: careful design of required sequence), which should be developed only for a specific interaction sequence. Therefore, a solution should answer the question "how do we provide information to help users perform a connection sequence?"

Although this study seeks a conceptual design solution, the design should be generated with more specific images within a specific case to be externalized and evaluate how the solution would work in the world. Design is for creating something specific and particular (Stolterman, 2008) and that cannot be shaped without some specification. Also the complexity and dilemmas of a specific situation force a designer to be creative (Löwgren & Stolterman, 2004). Solutions were generated and specified for a specific case: improving the connection between the MP3 player and earphones. However, conceptual options were considered to satisfy the design implications in wide cases and were not focused on developing detailed interfaces. Two options were generated on different strategic foundations to find solutions to the question of how to provide procedural information.

Option1: Graphically guiding a connection procedure

The first option provides a graphical model guiding the required interaction. Current MP3 player R1 provides graphical interface, but users could not recognize the required sequence. Compared to the graphic interface of the current R1 MP3 player, which uses a symbol of the R1 device as the central figure (Figure 24a), the modified interface intends to act as an image of devices interaction to help users have a model of the overall system interaction of the two devices and guide required action (Figure 24b). The icons representing the two devices and a dimmed or flashed dotted line provide clues for the required user action in the search and connection establishment stages.

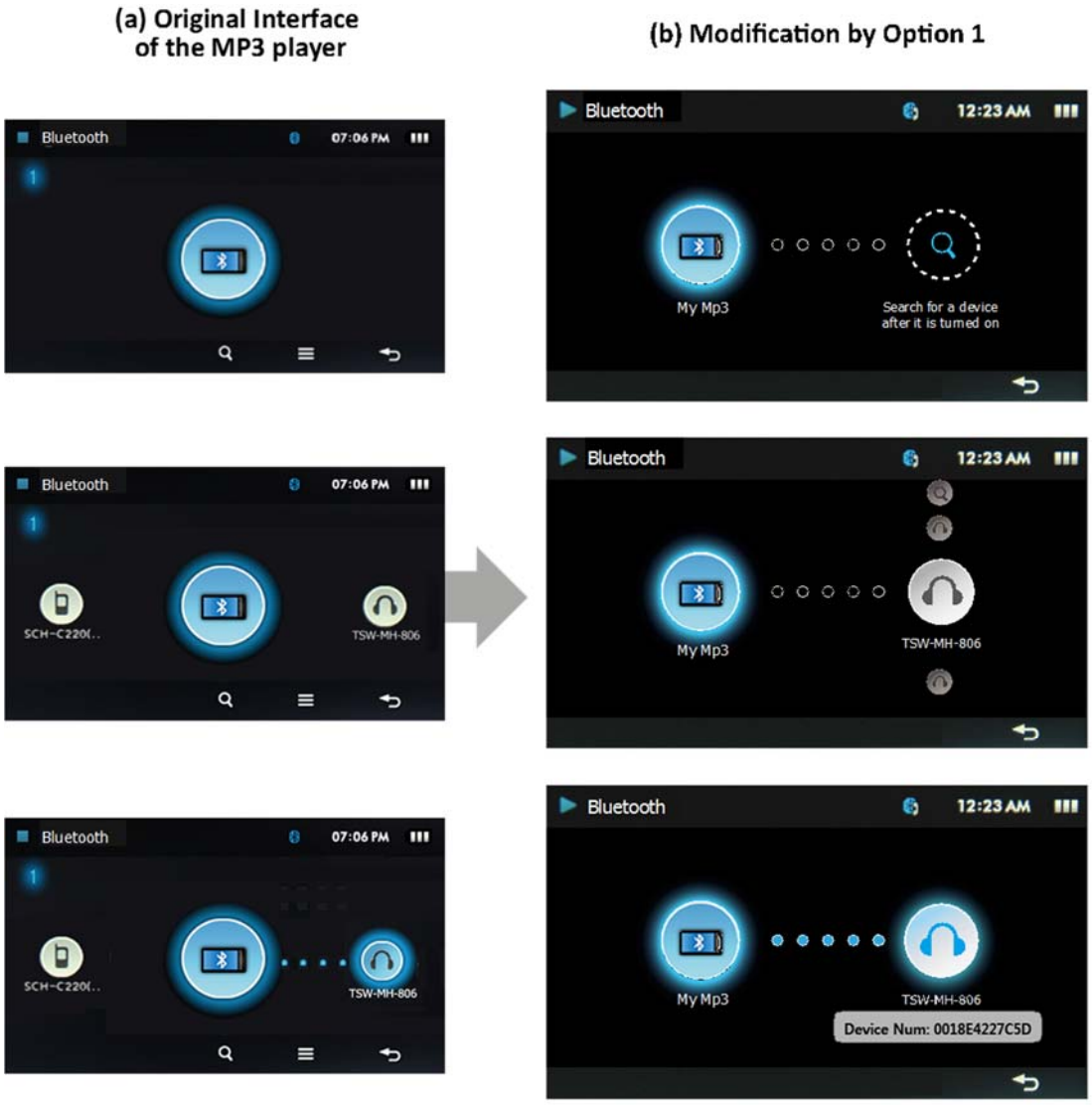


Figure 24. Option 1: Graphically guiding interface for connection procedure (compared to original interface: User interaction sequence of each interfaces flow from top to bottom.)

Option 2: Providing step-by-step guidance

The second option (Figure 25) is suggested to more specifically guide a connection procedure. A carefully designed step-by-step guidance provides helpful information for particular problems while connecting devices. The dotted line connecting the symbols of the two devices shows the required four steps of connection sequence. In each step, the interface guides non-expert users on what to do and what to check if they have problem. Through following the sequence, users may accomplish the requirement and establish a connection.

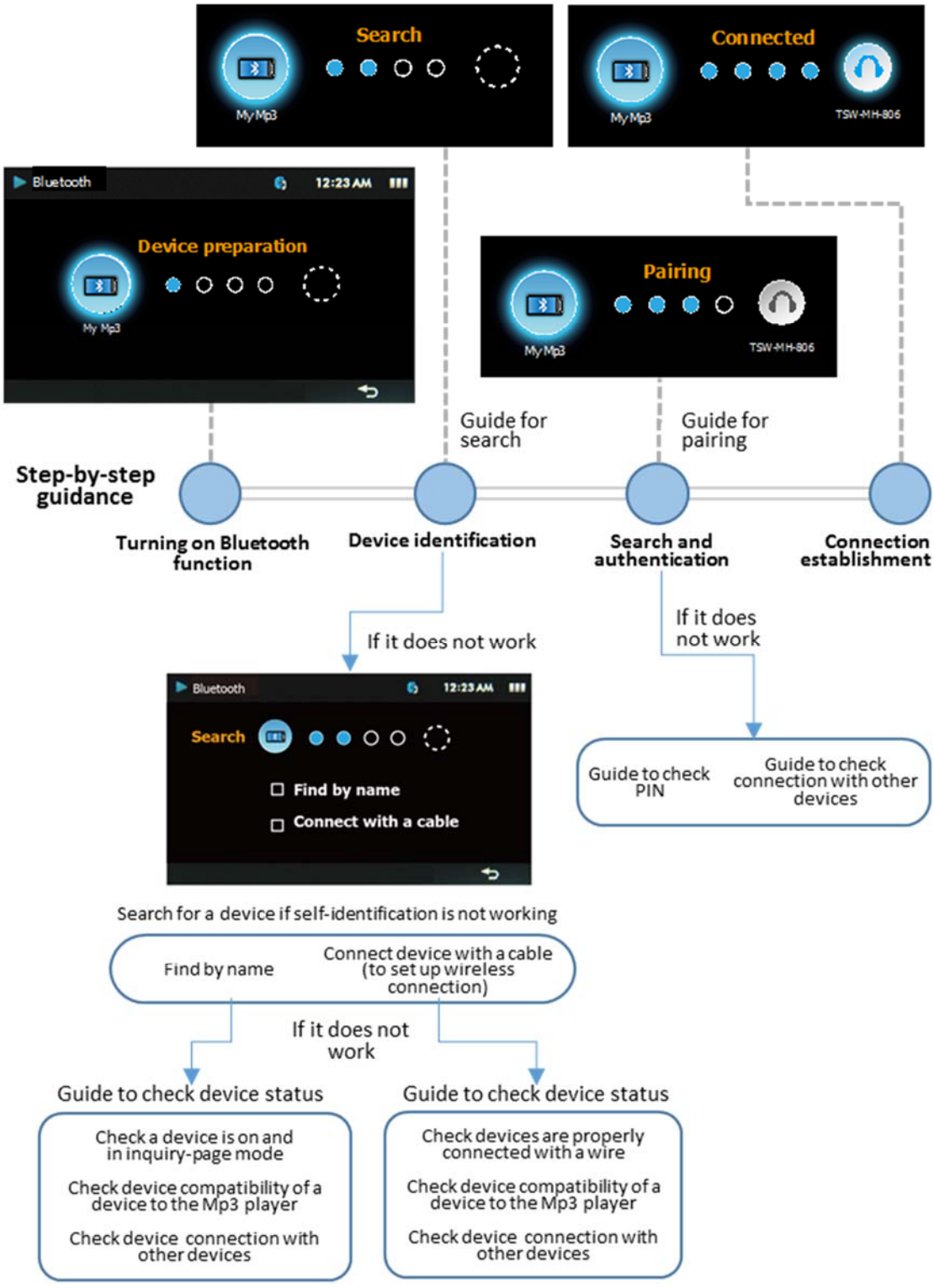


Figure 25. Option 2: Interface option for step-by-step guidance: User interaction sequence flows from left to right

5.4.2 Evaluation of alternatives

The generated options were assessed as to whether the option satisfied the purpose of the design implication and whether it improved observed user difficulties from user studies in the QOC method (Figure 26). Firstly, evaluation criteria were decided on per whether an idea can guide each of the required steps of the connection procedure—preparing an MP3 player for connection (turning on the device and turning on the Bluetooth function), preparing the earphones (turning on the device and setting it up for inquire-page mode), searching for the earphones from the MP3 player, selecting the earphones, and establishing connection between the two devices. Secondly, the criteria were added to evaluate whether an option improves user performance, such as reducing or eliminating the difficulties of setting up the inquire-page mode of earphones and triggering the connection on the MP3 player. They were also added to check if the ideas can help when a device is not searched for on the MP3 player and when a connection is not accomplished.

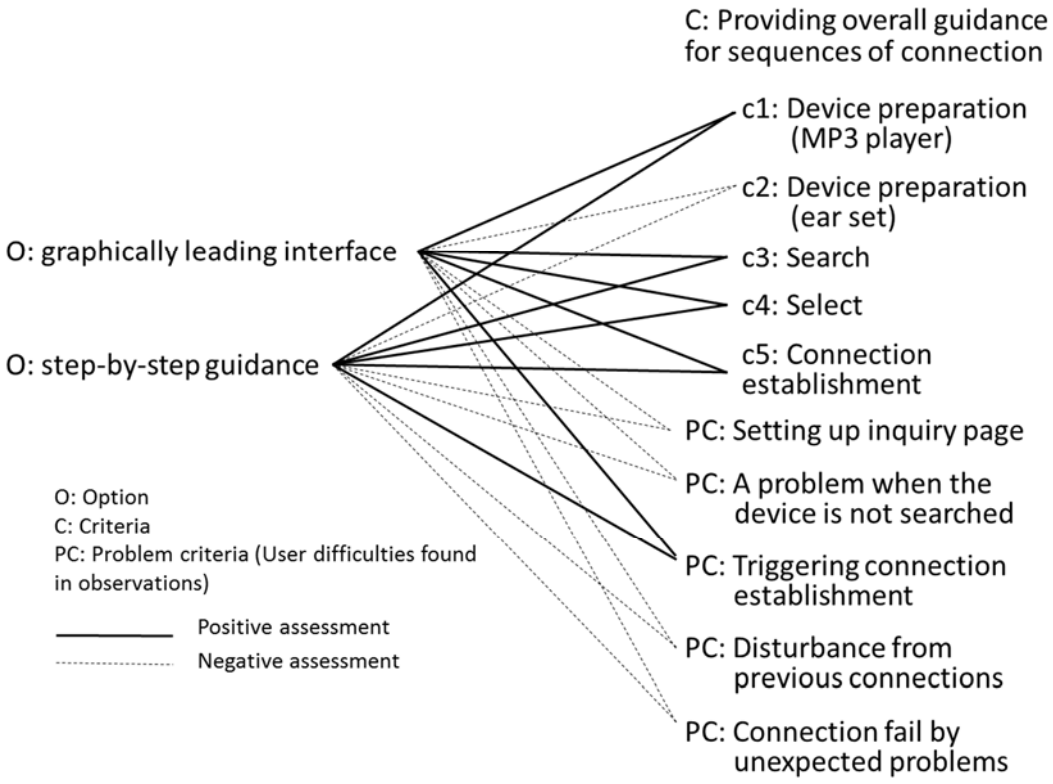


Figure 26. Assessment of options with criteria

These first iterations of suggested solutions reveal further deficiencies. None of the ideas sufficiently guide user interaction. For example, the options cannot help users when setting up earphones for a connection if the user fails to search for the device, or if the device fails to connect for an unknown reason, or if there is a connection, but to the wrong device. Careful analysis shows the two options insufficient. The study is required to begin the iteration phase of Research through Design.

5.4.3 Understanding of the design situation

Reflecting why the suggested solutions fail would provide further insights on design situation. For both options, the MP3 player cannot provide sufficient guidance for how a user should interact with the other device, for example the earphones. This is because the MP3 player cannot obtain information about the other device: what it might be or what its status is. After all, the MP3 player might be asked to connect to a computer, earphones, loudspeakers, smartphones, or some new device that was not known about when the MP3 device was designed. If the device to which connection is required is not turned on, then it is impossible to gather information about it, not even enough to know that it exists. How can the MP3 recommend to the user that the device needs to be pushed long when it cannot even tell if the device exists?

The MP3 player cannot monitor information of what tasks the earphones require or control the function of the device (Figure 27) until a connection is established between the two. In other words, when a user needs information about the devices interaction and required tasks during the connection procedure, the MP3 player cannot provide appropriate help.

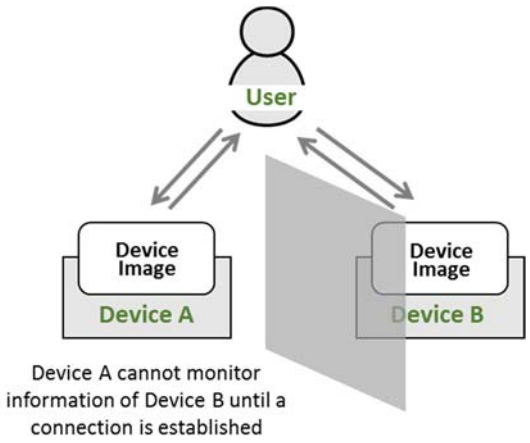


Figure 27. Interaction before accomplishing connection

This presents us with a significant design constraint: before there is a connection, other devices simply cannot acquire the information necessary to aid the user, neither through a well-prepared interface that has enough necessary information regarding the user guidance nor through automatic operations.

Therefore, the interaction problem of connecting multiple devices cannot be solved with the approaches used in designing a single-device interaction, such as computer guidance, automatic configuration, or improvements on the graphical user interface of a single device. An approach for single-device interface can neither improve overall visibility of the devices' connections nor provide enough information for user-devices interaction. The interface for connecting multiple devices is challenging design problem, very different from those involved in user-system interactions around a single device.

5.5 Summary and further reflection

Chapter 5 studied the user-interaction problems with performing the required interaction. Firstly, user interactions for connecting devices were defined through technicians' interviews and reference studies. The consideration of users, devices, and required interactions revealed the differences of user interactions with multiple devices compared to interactions with a single device.

Secondly, the preliminary problem understanding of Chapter 4 was reframed, and initial design implications were suggested. The non-expert users' interactions in two observed studies on Bluetooth audio devices connection and a printer and computer connection were compared to the expected user interaction of the two technologies. These comparisons provided the understanding that current devices do not properly help users handle the connection procedure. Through exploring where and why user interaction problems occurred, the user interaction problem is restated and design implications were suggested to improve the problem.

Thirdly, further insight on the design situation was gained while working on the early stage of design solutions. Two alternative solutions were generated to answer the question of how to provide procedural information on devices connection, but none of the suggestions could satisfy the desired improvements of user interaction. Through reflecting on the assessment, I realized that a single device's improvement

cannot solve the challenging problem of device connection. In order to improve user interaction to overcome the design constraint, it is necessary to reflect on the user difficulties with new perspective. Figure 28 shows where Chapter 5 is in the state of the Research through Design understanding.

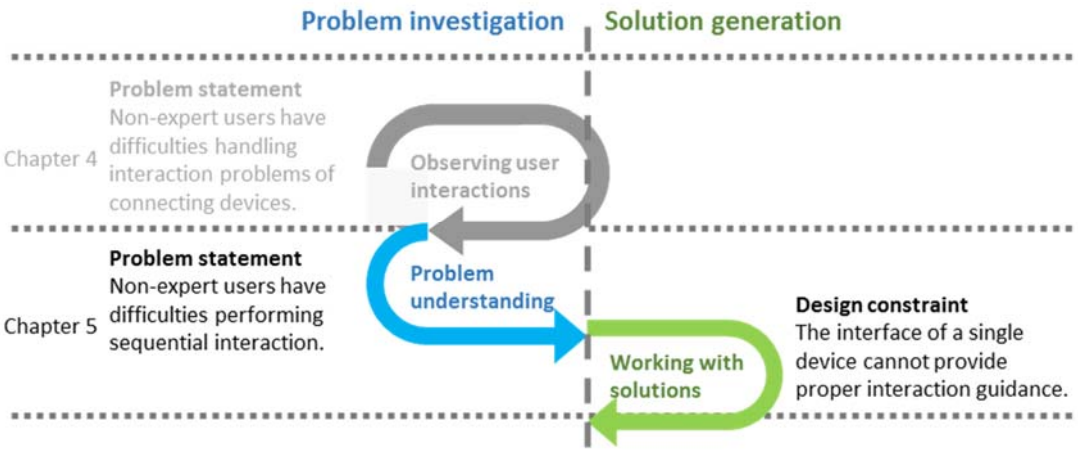


Figure 28. Design research progress in Chapter 5

Chapter 6. Investigating User Difficulties in Performing Action

6.1 Objective

When designers face problematic situations that cannot be managed under their current understanding, they need to construct a new perspective to interpret the problem's situation (Zimring & Graig, 2001). Because the understanding from Chapter 5 did not bring about desirable solutions that resolved the interaction difficulties, Chapter 6 reflects upon the user interaction problem further in order to reframe the problem. The user difficulties of the two studies—involving a Bluetooth connection between audio devices and a wireless connection between a computer and a printer—were then analyzed with new framework.

The chapter's objective is to frame the user interaction problem in a new way in order to find design implications and solutions that overcome the encountered design constraint. The sub-objectives of the chapter are:

1) To reframe the user interaction problem through further investigation. User difficulties in performing the interaction are reflected using different stages of action for execution and evaluation.

2) To find a new solution that overcomes the design constraint, so that it can improve the user interaction. Innovation-by-the-boundary shifting method was applied to the design ideation.

6.2 Investigation of user difficulties in action stages

6.2.1 Advanced analytical point of view

Through closely investigating what occurred when a user has done something, we can better understand what makes something difficult to do (Norman, 1988, 2013). The observed participants' interactions and protocols were re-analyzed to understand why users had difficulties in performing each step of the connection procedure.

According to Norman, a person's actions to meet a goal involve two aspects: execution and evaluation. Execution involves doing something to the world including 3 detailed stages, as shown in Figure 29: a goal is translated into an intention to do some action, the intention is then translated into a sequence of actions, and finally the actions are executed upon the world. A human evaluates what happened in the world due to his or her action using three stages: perceiving the change, interpreting the state of the world, and finally comparing what happened with what was desired. Reflecting the amount of effort that a user expected in order to execute an action and evaluating the results of an action can help a designer to understand how a system successfully supports user interaction.

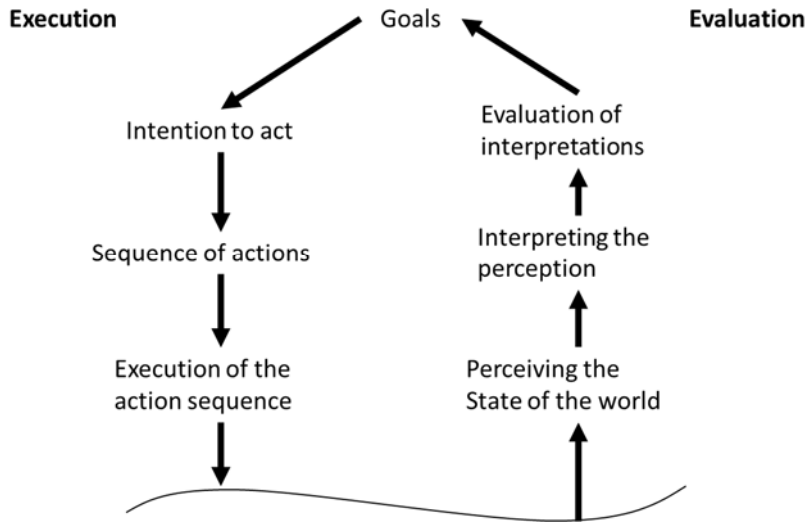


Figure 29. Stages of execution and evaluation for performing an action (Norman, 1988;47)

In order to look into where non-expert users have difficulties in performing actions for the connection procedure, the participants' protocols in each connection step have been coded and reflected in the 3 stages of execution and 3 stages of evaluation, as shown in Table 6. Analysis codes of each participant's interaction are attached in the Appendix B. Norman stated that the seven stages are suggested as an approximate model and that the stages are not discrete entities; likewise, the coding of the 6 stages was not clearly determined in some parts. Because the purpose of the analysis was not to clearly measure each of the 6 stages but to understand the user difficulties in performing sequences of action, the protocols were coded as general execution or evaluation difficulties, if specific stages could not be determined. Next two sections describe findings from the protocol analysis in each stage of the two observations.

	P1		P3		P5	
Step of connection	Quote	Problem with performing action	Quote	Problem with performing action	Quote	Problem with performing action
Connection establishment step	Is it finished (connected) after finding?	Evaluation (interpretation): The connection was not established yet, but according to the graphical interface she confused the devices' interaction status.	"What is pairing?"	Evaluation (interpretation): She could not interpret a sudden message, so she didn't know the message was associated the intended connection.	Well, it was found, but why is it not functioning?	Evaluation: He could not evaluate why the connection was not made.
	(She moves to the screen for music play and plays a song.) Uh? Sound is not coming out. What is this? Is the volume too low? (She increases the volume but no sound is heard.) Isn't this? It's stifled.	Evaluation: The connection was not established yet, but she evaluated that a connection was established and searched for the cause from other problems.	(An icon is loaded on the MP3 player.) Uh? Is it done? (She moves to play a song.) I don't know what (state) it is. It seems they (devices) are connected, but (they do) not function. (Moderator informs her the connection is not established.) Was not accomplished?	Evaluation: She evaluated the devices were connected from the graphic feedback.	Bluetooth is functioning. It had been done. If I go back, will the Bluetooth work?	Evaluation: He could not be sure of the device's status.
	Was this disconnected when I got out of the Bluetooth screen? Or, was this not connected originally? Ah, so complicated.	Evaluation: She could not evaluate the devices' status and was confused about the interaction.	"Isn't it done? Then, why isn't it working again?	Evaluation: She could not evaluate the connection status and the cause of the problem.	It says there is a Bluetooth (device), but (it is) not connected. A song is still playing, but (I cannot hear it).	Evaluation: He could not evaluate why the connection was not made.
	Is there a separate thing to do for a connection?	Execution (sequence): She suspected the interaction sequence and searched the exact execution method after she spent much time to recognize he needs to perform an action for making devices to connect.	(She drags the icon, but connection is failed.) Uh? What is the problem?	Evaluation: She could not evaluate the cause of the problem.	Now that it is detected, it seems that there is a way to connect them, but I don't know how to do it.	Execution: He searched for a correct execution method.
			"Why is it (light on the earphones) changed?"	Difficulties in evaluation: she couldn't know what the lights means and why it is changed.	I will try everything (every action).	Execution: He tested each menu to know a correct execution method.

6.2.2 User difficulties in performing actions for connecting Bluetooth devices

Pre-connection and search stage

The most notable finding during the pre-connection stage for the MP3 player and earphone connection is that non-expert users had difficulties with interpreting the status of the earphones from the earphones' interface. At the beginning of the task, while briefly explaining the involved devices, the moderator noticed that the earphones had two different modes that a user could set by pushing the central button for a short or long period. Although a simple task (pushing the button long) was required to make the earphones ready for a new connection, the participants felt that it was difficult because the status of the earphones (specifically, what blue or blinking lights mean) was not properly interpreted and the participants could not evaluate whether the earphones were ready for the connection. Four of the participants (P1, P2, P3, P4) learned the meaning of the feedback from the moderator' information, while one participant (P5) learned this by himself after testing how the devices work several times.

The difficulty of the interpretation and evaluation made the overall connection process confusing to the non-expert users because they could not evaluate why a device was not searched for or where the problem occurred. In several attempts to make the MP3 player search for the ear set, the participants suspected several causes to the problem, such as that the devices needed their positions moved (P2), that there was another way to configure them (P5), or that the devices needed to be touched (P5). Some participants asked questions about how to make the MP3 player search for the earphones, but the participants' difficulties with making the devices search seem to have been caused by problems with evaluating the earphone status. Although the evaluation problem did not create problems with user interaction, several participants (P1, P4) also had difficulties with evaluating the speaker's status. The speaker does not require the inquire-page mode; however, whether the device was prepared and connectable without further configuration was not clearly interpreted or evaluated.

Selection and connection establishment stage

Another important evaluation problem occurred when participants misinterpreted the device's graphics. A majority of the participants (four of the five: P1, P3, P4, P5)

expected a completed connection when the MP3 player indicated that it had identified the desired device. But this was wrong, because the indication only signified that the MP3 player was aware of the device's existence: a further step had to be taken to cause the connection (in this case, by dragging the device's icon onto the central icon). The confusion is illustrated by this quotation from P1:

> *"Uh, sound is not coming out. What is this? Is the volume too low? (She increases the volume but no sound is heard.) Isn't it this? It's stifled. What is this? What is this? Was this disconnected when I went out of the Bluetooth screen? Or, was this not connected originally? Ah, so complicated!"*

Because of this evaluation problem, the participants had difficulties with diagnosing and inferring further execution. Eventually they realized that the connection required a specific action.

The evaluation problem also occurred when the participants tried to identify an associated device. A participant tried to connect the wrong device (P3), but she could not know what was happening. Another participant (P4) showed an evaluation difficulty for a connection involving which device had failed between two neighboring devices: "(I don't know) if 'Connection failed' means failed with this (the earphones) or failed with this (the speaker)."

When a connection failed, the only feedback was a message saying that the connection had failed. The participants did not get sufficient information about the device status to evaluate and diagnose the interaction problem.

Reconnection stage

The participants were observed ignoring the message asking to pair in the reconnection procedure. The analysis found that many of the participants (P2, P3, P4) ignored the reconnection stage because they could not interpret or evaluate the sudden pop-up messages. They could not interpret what the messages meant for the connection procedure they were proceeding with and could not approve the pairing.

Overall

In the protocol analysis on the user difficulties, the participants could not properly interpret or evaluate the Bluetooth device's interaction status. One particularly interesting behavior exhibited by the non-expert users (P1, P3, P4, P5) was that they

frequently evaluated the connection through testing the system function, rather than by interpreting specific feedback from the interface. The information provided by the interface is clearly deficient.

Because it was difficult to evaluate the interaction status, some of the participants (P1, P5) tested the devices to get information on how to interpret the status. The following quotation is an example of an interaction in which the participant (P5) was trying to evaluate the status.

> *"Well, it seems the device has searched for 001b42… But still, sound is not coming out. Then, let me check whether it (an icon on the MP3 player's screen) disappears if I turn these (earphones) off. Search again! Ah. (The icon is not shown.) I found it is a status: (The earphone is) turned on. Then, I will check what happens if I push (the button on the earphones) once. Now, only the blue light is on. (The icon is not shown on the MP3 player.) Now, the blue light status is not for Bluetooth. The blinking status is for Bluetooth."*

In particular, the participants expressed that they could not evaluate what the problem was in the sequence. They frequently mumbled "Why isn't it working?" (P1, P4, P5) or "What is the problem?" (P3).

6.2.3 User difficulties in performing actions to connect a computer and a printer

Pre-connection stage

While the participants were required to handle complex interactions, including sub-connections to a mediating network device, simple feedback like a blinking LED or sound did not provide enough necessary information to help users interpret the printer's interaction status. The participants had difficulties in evaluating whether it was connected to a mediating network, or whether it was ready for use. While the printer presented operational feedback when searching for a Wi-Fi signal and connecting to an AP, one team (T3) decided that the devices were ready to use and tried to print something. In the following team conversation, the two participants expected that the connection between the printer and the notebook computer would be ready to use when the lights on the printer blinked, after they had pushed the WPS buttons on the printer and the router (which had not yet been connected to the computer):

> *P1: "Push this (the printer's WPS button) for two seconds: one, two. Push here (the router's WPS button): one, two. Is it done?"*

P2: "Ah, a connection. It (the printer LED) is blinking. Good!"
P1: "I am smart!"
P2: "Let's find the file to print from the notebook."
P1: "Should we print the file to finish the task?"
P2: "Uh. It is still connecting."

Another team (T1) was not sure whether the blinking signal had any meaning. Because the team had engineering experience, they actively looked for and interpreted the system feedback. However, the interface with a blinking LED did not give meaningful information, as indicated in the following conversation:

P2: "Push two seconds on the router!"
P1: "Is there any change on the printer? Do I release (my hand from the router)?"
(They look at the printer together.)
P1: "I don't understand what it means. The wireless connection (light) is blinking. Did you check this (how it appeared) before?"
P2: "No, I didn't."
(P1 turns off the printer and turns it back on to check the original LED status.)

It was difficult for the participants to determine whether the light was a meaningful signal. The team continuously checked to see what the original LED status had been and compared it with how the LED light had changed, in order to determine whether the blinking signal was meaningful. When they could not evaluate the status—because they did not check the original status—they restarted the printer to check it.

Connection establishment stage

All three teams used the manufacturer-provided installation software for the connection, but only one of the teams succeeded in establishing a connection by using the software and a physical USB cable. The participants from the successful team (T1) tried to actively check, interpret, and guess the devices' interaction status, which was not easy. The following conversation occurred when they used the USB cable to configure the connection between the computer and the printer through the router:

P2: "We do not need to do this (access a network), do we? It is already connected. Isn't it?"
P1: "It seems to be connected, (and) these (the computer and the printer) are connected through the USB."
P2: "It is asking to connect through a (wireless) network. Is this (the printer) sending a signal?"
P1: "Maybe it is, but what is (the name of the signal)? Terrible…"

The participants tried to check the device's status in order to infer what they should do, but the devices' status and the interaction among the devices were not clearly provided to the users, other than that the printer and the computer were connected by a USB cable. During the connection stage, they had to depend on their guesses when inferring the system status because the team had difficulty getting the necessary information from the devices.

Overall

While the interaction became more complex when mediated by another network device, the participants were dependent on guidance from the manual or the installation software. However, the participants frequently could not evaluate whether their interactions had been properly performed for a status from the manual or the software guide. This evaluation problem made user interaction very difficult because they could not be sure about whether the devices' status were the same as in the manual or software program said, so they did not know what they were missing or what else was required. The following quotation shows the participants' difficulties in checking the devices' status. It was recorded from the participants' dialogue within a team (T2) while trying to follow the manual's guidance.

> *P1: (From the printer installation program running on the notebook computer) "Can I select 'next'? Did I do something wrong?"*
> *P1: "It says 'unidentified network.'"*
> *P2: "Not connectable…."*
> *P1: "We followed the manual exactly, didn't we? I think there are no problems"*
> ….
> *P2: "Why don't we go back to the original status and try again?"*
> *P1: "How do we go back?"*

The evaluation difficulties are important causes for why the users could not perform the connection with guidance from the installation program and the written manual. When something went wrong while the users followed the guidance, they were only informed that the connection had failed, and the participants could not get enough information to evaluate the devices' status, what stage was proceeding, what was different from the guidance, or how to remedy the situation. The evaluation problems aggravated the user difficulties with handling the complex connection of matching the two devices through a mediating device.

6.2.4 Reframed problem statement and design implications

The participants in the two studies tried to explore and learn about both device interfaces at the beginning of the task, but they could not deal with the interaction after they had explored the devices for a while. This seems to have been caused by the evaluation difficulties, in that the users did not receive meaningful or understandable information and feedback from the connecting devices; thus, they could not interpret or evaluate the devices' interaction status regarding the sequence of connection. The non-expert users could not determine through the current images whether the devices were in a proper status for a certain stage of an intended procedure or whether the devices' status had changed as expected after executing an action for the connection procedure.

With the current interface, the participants had difficulties with interpreting what the blinking signals or sound meant, or even whether the blinking signals even had meaning. The feedback and messages—which only delivered the results of an operation—did not help the users evaluate what steps had been accomplished or what steps remained for the connection procedure. When the users actively tried to determine the interaction status, they did not receive enough information and depended on guesses. For the non-expert users, the devices' interaction status should be provided in a way that can be interpreted and evaluated in relation to the sequence of the connection procedure. Therefore, the problem statement has been reframed as follows, in Figure 30.

Problem statement

Non-expert users have difficulties with interpreting and evaluating the devices' interaction status regarding the sequence of the connection procedure. When an evaluation problem occurs, they have problems dealing with the required sequence or diagnosing the error in their interactions.

Figure 30. Reframed problem statement from the understanding of user difficulties with performing actions

Based on the new problem framing, the design implications have been altered from direct guidance for user execution to helping the user evaluate the devices' interaction status (Figure 31). The suggested implications are presented into three categories in order to deliver more detailed insights, as understood from the analysis.

The device interface should be clearly interpretable, not only for the device's operation but also for the interactions between two devices, and evaluable in relation to the sequential connection procedure. A clear image when the device is not ready can reduce user confusion and help them to understand the system's status, without checking the system's function or testing the system status. The design implication suggested in Chapter 5 for designing the user interaction sequence thoughtfully has been kept because reducing unnecessary user action reduces probable errors, such as when connecting the speaker and MP3 player.

Design implications

A. The device interface should provide proper information and feedback, so that users can interpret and evaluate the devices' interaction status regarding the connection sequence.

1) The information and feedback from the devices should not only be clear when operating the devices in user–single device interactions, but should also help the user to evaluate the interactions between two connecting devices.

2) When a user interacts with a connection between two devices, he or she performs a connection sequence that includes device preparation, identification, and selecting and establishing a connection. The devices should provide information and feedback, so that users can interpret the devices' status and evaluate the status regarding the required stages of the connection procedure.

3) The information and feedback should help users evaluate whether the overall procedure has been accomplished and whether the devices are ready to be used, or if the devices require further configuration.

B. The devices interface should be carefully designed to require user interaction and reduce unnecessary user action.

Figure 31. Modified design implications based on the reframed problem statement

6.3 Generating a solution to overcome the design conflicts

In Chapter 5, I identified the design constraint that the interface of a single device

could not provide proper information for user interactions with two devices. The innovation-by-boundary-shifting method proposed by Jones (1992) was used to overcome the design conflict between what is desired and what is available.

6.3.1 Innovation by boundary shifting

Innovation by boundary shifting involves resolving a design problem by shifting the design problem's boundaries and using outside resources to solve it. It has four steps: identifying the essential functions, identifying conflicts, searching for possible resources outside the problem's boundaries, and finding compatible solutions.

Step 1: Identify the essential functions of any design that would achieve the desired objective

The essential design requirements were identified from the design implications. The device interface should provide proper information and feedback so that users can evaluate the interactions between two connecting devices.

Step 2: Identify conflicts between the existing means of achieving these functions within the assumed problem boundaries

A design conflict exists between the interface that is provided and what is desired. While user interaction mainly occurs on one of the two connecting devices, a single device's interface cannot appropriately support user interaction while connecting two devices, but users need information and feedback to help them evaluate the interactions between two devices. New boundaries must be found for the interface design.

Step 3: Identify resources outside the assumed problem boundaries that might be made available by transforming the problem

When a person is trying to connect two devices, both are available but the interaction mainly takes place on one of the devices. The problem boundaries become the interaction between the user and the main device (device A) of an interaction (Figure 32). What is outside the problem boundaries? : Device B, the manual or information from the Internet, and outsourced help from technicians or expert users. These need to be considered as new resources.

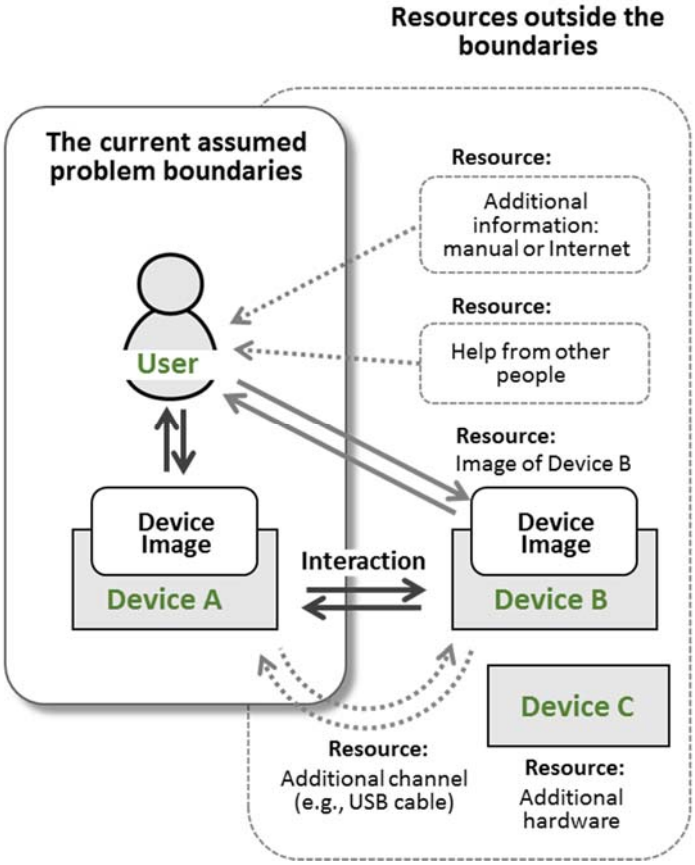


Figure 32. Assumed problem boundaries and determined resources outside the boundaries

Step 4: Seek compatible sub-solutions to the problem that would provide channels for the use of some or all of the newly identified resources

In order to find compatible sub-solutions to help the user discover the interaction status of both devices, two alternative have been ideated with different interface resources: getting assistance from outsourced hardware; considering the system image as composed of two devices, not just one.

Sub-solution 1: Using outsourced hardware

The first option considers using a separate piece of hardware as an additional resource. Earphones provide limited feedback because of their beeping sounds and blinking lights cannot provide information that is easy to interpret. Therefore, I propose adding a new piece of hardware, a display, as shown in Figure 33, to provide intelligible, easily understood information. This new hardware could simply be the person's smartphone.

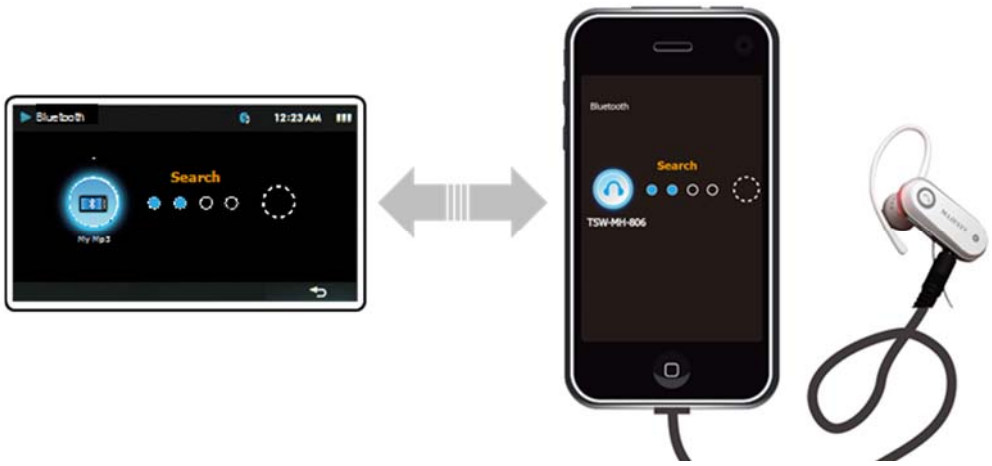


Figure 33. Sub-solution 1 using new hardware

The problem is that adding an additional device could make the interaction even more complex. Now, instead of two devices, there are three. Although the third device can simplify part of the task through its large display, it adds extra complications due to the need to connect yet another device. So this is not a satisfactory solution.

Sub-solution 2: Using both devices' images for user evaluation

The second option considers what happens when we physically connect two devices together. We can see the readiness of both devices from their physical appearance. For example, when a user connects a USB drive to a USB port, the physical shape of the devices aids the connection task. We can see whether the USB port is available (Figure 34a) or whether USB driver is ready to connect (Figure 34b).

a) USB port b) USB drive

Figure 34. Devices for physical connection: The physical forms of a USB drive and a port visually reveal the status between them.

Not only can images from each device (part) reveal two devices' interaction status, but so can the relations between components. The connection can be determined through the shape and tactile feeling, as well as the sound and digital feedback from the computer. The interconnection of physical components provides visibility of the connection status: providing the same thing for wireless connection may help users. Figure 35 suggests a framework of a solution using both devices' images to reveal the devices' interaction status through a graphical assembly model.

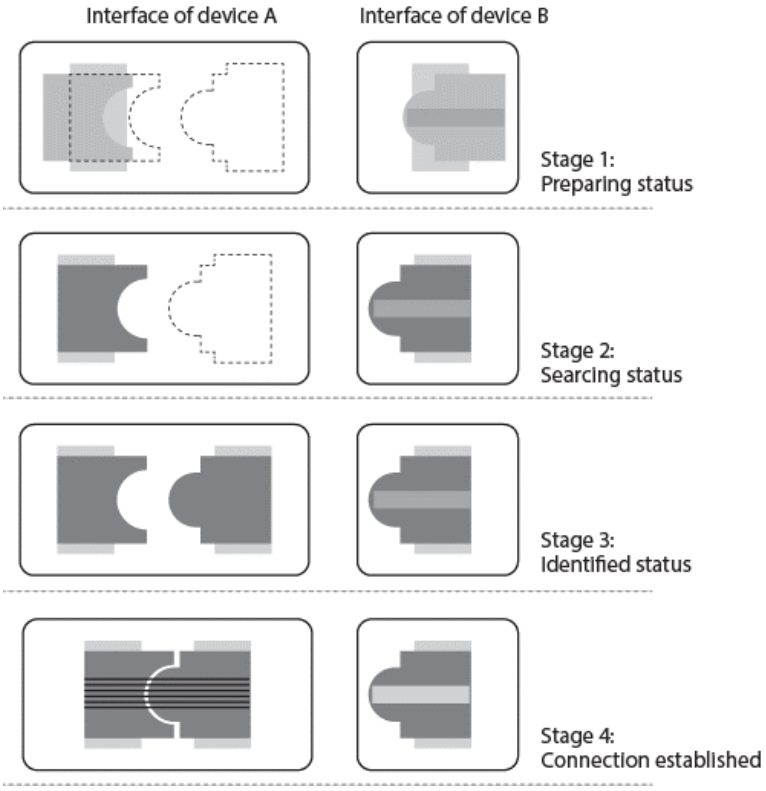


Figure 35. A framework with graphical assembly model for using both devices' images to reveal their interaction status

The solution has to improve users' evaluation of the devices' interaction status (Design implication A-2) and help users to evaluate whether the overall procedure has been accomplished (Design implication A-3). The next paragraphs assess whether Figure 35 can do this.

The system shown in Figure 35 aims to solve the difficulties through two properties: Firstly, the framework provides visible information about the devices' interaction status during the connection procedure. In Figure 35, several discrete steps of the assembly procedure are mapped onto a device-connection procedure, thus helping

users understand the interaction status. In Stage 1 of the model, the pieces cannot be connected without being prepared. Through the statuses of unready tabs, devices can reveal their status as requiring preparation for connection, including whether they are turned on, ready to exchange signals, or technologically identified. If both devices are properly prepared to connect, the two devices will have pieces that are ready to be put together, as seen in Stage 2. In the searching step, a shadowed piece will appear if a device has been properly searched for and identified by another device in Stage 3. However, the stage may show unassembled pieces, meaning that the connection has not yet been established. Finally, Stage 4 shows the assembled model and provides information indicating that the two devices have been properly connected and are ready to function as a system.

Secondly, the framework shows a clear image of the system's status, by easily displaying whether the system is connected and ready to use. The dissembled pieces can provide clear clues as to whether the devices require some configuration tasks. A clear image of being unready can reduce user confusion and provide proper information, so that users can understand the system's status without checking the system's function or testing the system's status.

The model of the two devices seems capable of providing a solution. The suggested option can reveal each device's status regarding whether a device is ready for a connection or if the device is in a connection. The assembling framework also provides information so that users can evaluate whether a connection has been accomplished or further action is required. But these assumptions need to be tested. This is discussed in the next chapter.

6.4 Summary and further reflection

6.4.1 Summary of the chapter

Chapter 6 reframes the user interaction problems with a new perspective in order to gain design insights to overcome the design constraint. Firstly, the user interaction problems are further investigated based on understanding the stages of user action, as defined by Norman (1988, 2013). Non-expert users had difficulties interpreting and evaluating the devices' interaction status based on the insufficient information and feedback from the current devices. When an evaluation problem occurred, the users

had difficulties dealing with the required sequence of the connection procedure. Through reflecting upon the user difficulties with evaluating the devices' interaction status, the problem statement and design implications were reframed.

Secondly, this chapter generated insights into desirable images for connecting devices using the innovation-by-boundary-shifting method. Through revealing the connection status from both devices, the images of the involved devices work together to provide users with useful information for evaluating the system's status. Figure 36 presents the research progress from this chapter.

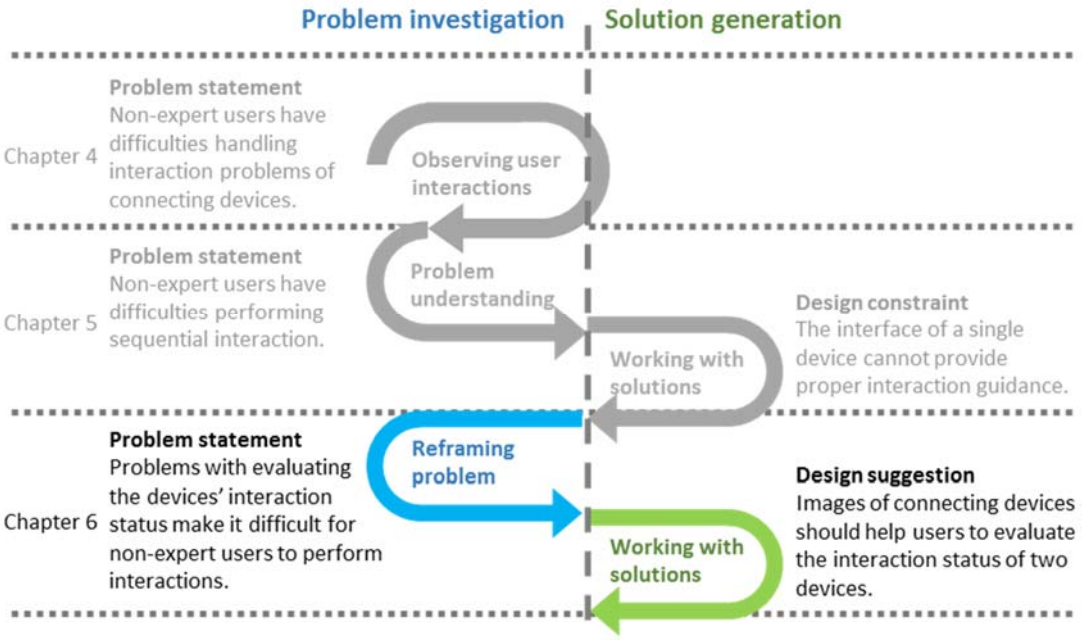


Figure 36. Design research progress in Chapter 6

6.4.2 Further reflection

The problem framing and design implications were elicited based on the two observations of non-expert users interacting with connecting devices. In order to turn the research findings into useful knowledge, this study should have extensibility.

Firstly, the findings of the thesis must be observed as common problems in other interaction cases. While wireless connection technology and devices continue to develop and transform, it is important to confirm that the problem framing and design implications are not only confined to the particular device cases but are applicable to understanding and designing common user interactions with wireless

device associations.

Secondly, the suggested design framework needs to be assessed with a user test. The suggested framework has been examined in 6.3.1 with design implication criteria, but it cannot replace a study with actual user interaction. Moreover, a study with a design suggestion can provide further insights into the interaction problem and design situation. Therefore, the next chapter will refine the research boundaries and assess the problem understanding and the suggested solution to formulate this dissertation's findings as applicable knowledge.

Chapter 7. Examining the Research Findings

7.1 Objective

Research through Design should have extensibility, “focusing on inquiry across several cases” (Zimmerman et al., 2010; 311), so that its findings are distinguished from insights of a single design case and can be used for understanding common design problems. In this chapter, I gain extensibility by examining the problem understanding through expanded cases and evaluating design insights applied to improve user interaction. Here, I aim to formulate research findings as applicable knowledge for interaction design. The sub-objectives are:

1) To examine whether the stated problems are observed in common interaction cases with different devices and technologies.

2) To evaluate the generated design implications and framework by applying them to interaction cases.

7.2 Studies of the chapter

In order to examine the stated problem understanding and assess the generated design insights, I did several additional studies. Additional cases were determined from situations, where non-expert users would be involved in device association in their home, office, or mobile situations were selected. I examined the connection of an ear set to a smartphone via Bluetooth technology, association of a pocket printer to a smartphone, and wireless connection between a printer and an iPad. Two of which examined the previously observed technologies of Bluetooth and Wi-Fi. Third case examined the use of Near Field Communication (NFC) to determine if the problem with understanding was also applicable to the connection with a different technology. NFC refers to a collection of very short-range (within 4cm) wireless technologies that represent one type of RFID technology (White and Roland, http://www.nfcworld.com). In this additional case, the technology is used to assist user interaction for connecting devices via Bluetooth and installing an application. The three interactions are summarized in the Figure 37 below.

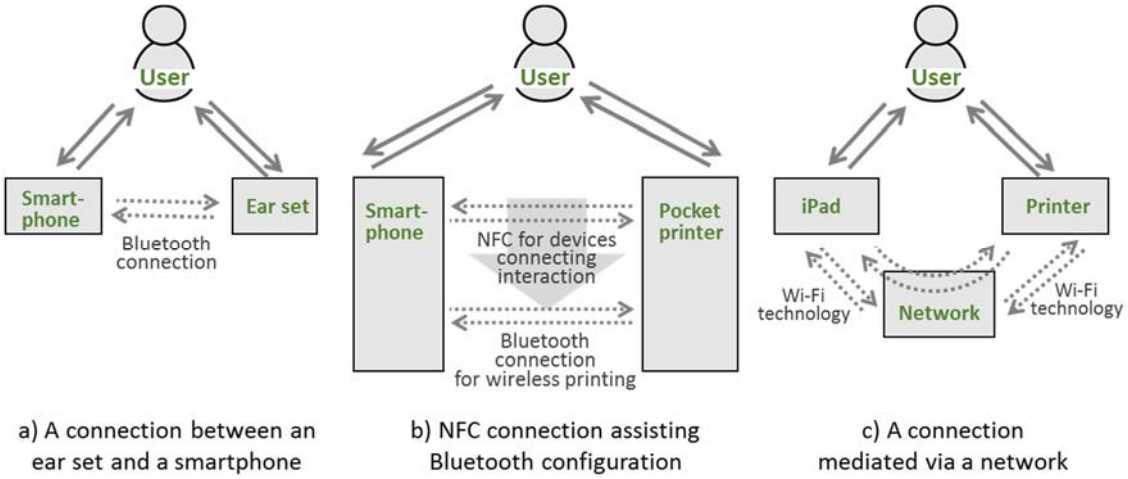


Figure 37. Interaction of additional cases

Each case was tested with both the original device interfaces and the suggested device images (paper prototyped interfaces). Testing of the original device interfaces aims to examine the problem understandings while the latter aims to evaluate the proposed solutions. The background information for each case test is listed in Table 7.

Table 7. Added user interaction cases

	Connection task	**Technology**	**Number of participants (Referred code of individuals)**	
			Original device	**Revised interface**
Case 1	Smartphone and ear set (BT S-10)	Bluetooth	4 Android users (BO1-BO4) and 3 iPhone users (BO5-BO7)	5 (BR1-BR5)
Case 2	LG Pocket Photo printer (PD233) and Android smartphone	Bluetooth connection assisted by NFC channel	5 (NO1-NO5)	5 (NR1-NR5)
Case 3	IPad (iOS 7.0) and Samsung multi-function printer (SL-C462FW)	Wi-Fi connection	5 (WO1-WO5)	5 (WR1-WR5)

7.2.1 Study method

Due to the design research feature whereby a researcher does not limit the focus of research to a single specific phenomenon, the previous observations were conducted having unclarified issues. Observation methods of the additional cases were carefully determined based on advanced awareness of the interaction problems that comprise the focus of this design research.

Targeted interaction: This thesis investigates user interaction problems when a non-expert user configures two wireless devices. Although this study observed user interaction with verbal assistance from a second person, the observations do not cover the issues that arise from multiple users. In the additional cases, all observations were conducted individually.

In order to focus on the narrowed research problem of devices' initial connection, the additional studies were designed to observe the first connection between two devices. If both devices had been used in a previous test (in Case 3) and the two devices were expected to connect via a reconnection procedure, the devices' configurations were reset before subsequent testing commenced. If a device had no prior association with the particular device of the study, the device was used without manipulation.

Additional information: Because this study focuses on problems relating to device image interpretation and response, previous observations (in Chapter 4) attempted to reduce influential information from manual and additional resources regarding user interpretation of the device image. In the additional cases, participants were provided with product manuals in case they lacked basic knowledge of the devices. Participants started their tasks without a manual, but they were allowed to read a manual, to ask the moderator for advice, or to search information from the Internet depending on their needs and available resources. When participants sought additional information, they were asked to verbalize the nature of the information they were looking for. This enabled participants to access information necessary to the completion of their task, and the researcher to learn what information was missing from the current interfaces. However, the studies did not investigate how the additional information assisted user interaction.

For both studies, with the original devices and the paper prototypes of the revised interfaces, participants recruited were university students in their 20s who had no experience connecting similar device pairs. All participants carried out the tasks in

their native language, Korean. The main language of the device interface and paper prototypes was also set to Korean.

7.3 Examining problem understanding through additional user interaction cases

7.3.1 Case 1: Bluetooth connection between smartphone and ear set

The first study observed participants performing the task of connecting the provided ear set (iriver BT S-10) to a smartphone with Android OS or iOS. The devices used can be seen in Figure 38. Participants who tested Android phones used their own smartphones, but participants who tested iPhone connection used a device provided by the moderator if their personal phone used Android OS.

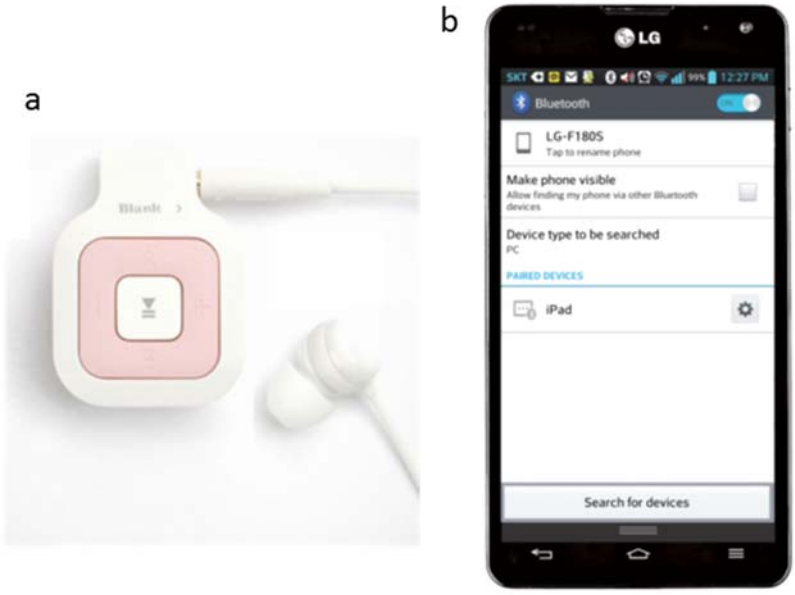


Figure 38. Devices used in Case 1: a) iriver BT S-10 ear set; b) Bluetooth interface of a smartphone (LG model is an example)

Test results

Although all participants completed the task successfully, six participants (BO1, BO2, BO3, BO4, BO5, BO7) of the seven had problems engaging the devices' Bluetooth connection. User difficulties were observed during connections with both iPhone and

Android phones. Three participants (BO1, BO3, BO5) reported not having been able to complete the task without a manual or help from others.

Whether or not the ear set had been prepared for a connection was not specified. Participants (BO1, BO3) believed that the ear set was ready to connect, when the device was not configured properly; Two participants (BO2, BO4) comprehended the state of their given ear set by observing the smart phone's response to their actions. One participant (BO2) recognized the ear set was not ready when he observed that the device was not detected on his smartphone but another device was detected. Two participants (BO5, BO7) did not recognize that the ear set was not turned on until the moderator informed them.

With the provided device images of smartphone and ear set, participants could not determine why the search had not concluded properly or how to proceed therefrom. They sighed: "Uh? It (my action) seems right, but (why is it not working)…" (BO3) or "what is the problem?" (BO7). Some participants referred to the manual (BO1, BO3, BO4) and others asked the moderator for help (BO1, BO2, BO3, BO4, BO5, BO7) or attempted several methods to achieve the desired result (BO7), such as waiting longer for the search to be completed, trying several buttons on the phone, and changing the distance between devices. The evaluation difficulty bothered two participants (BO1, BO3) after they learned from the manual how to set up the ear set for connection. The above results show that difficulty in understanding device status made user interaction problematic.

7.3.2 Case 2: NFC connection of a pocket printer and smartphone

The second study observed user interaction when connecting a Pocket Photo Printer PD233 (Figure 39), produced by LG, with smartphones. The devices can be connected by configuring the Bluetooth connection or by physically tapping an Android smartphone on the printer, which activates the NFC channel and enables Bluetooth and application (LGPocketPhoto, v2.3.4 for android) installation. During the test, participants were informed that the printer provides an NFC-assisted connection method, but participants decided on their own how to configure the connection.

Figure 39. Devices used in Case 2: a) NFC configuration interface of a smartphone (LG model is an example), and b) LG Pocket Printer

Test results

Even though an NFC channel was provided for connection, four out of five participants (NO2, NO3, NO4, NO5) tried the Bluetooth configuration first. It seems that participants preferred the familiar Bluetooth technology over the new NFC technology. However, only one participant (NO3) succeeded in the Bluetooth configuration. The other three participants (NO2, NO4, NO5) gave up configuring the Bluetooth connection and used the NFC channel instead. Participants had difficulty interpreting whether or not pairing was actually working (NO4) and why the function did not work properly (NO2, NO5).

When participants used the NFC technology, problems in the search stage were not observed because the tapping interaction of NFC technology substitutes for the device identification procedure. However, the tapping action itself did not proceed smoothly (in NO1, NO2, NO3, NO4's interaction). Even after participants (NO2, NO3, NO4) learned that two devices needed to be tapped together, they had trouble in recognizing how and where to tap the devices together properly.

When a smartphone was not prepared for NFC interaction (NO1) or when NFC connection was not properly established (NO2, NO3, NO4), participants could not get any information from either device. They also could not evaluate what problems had occurred. Participants' evaluation difficulties were expressed as follows: "Is it done (or not)?" (NO3) or "Why is it not working?" (NO2). One participant (NO4) expressed

his annoyance: “I didn’t know tapping works this way. It did not show my tapping had worked.” Another participant (NO2) had to manually search and install the application from a store because he could not diagnose the problem when his tapping action failed to work properly. Although NFC technology provides easy and simple connection, I found that users are frequently required to evaluate the state of device interaction. Participants experienced difficulties due to lack of information required to evaluate device interaction.

Another evaluation problem was observed when the printer was powered off during interaction and the participant (NO2) could not perceive the status change. The problem caused him annoyance because he believed that the devices were ready to function. The above results confirmed my problem statement that evaluation difficulties were an important cause of user troubles.

7.3.3 Case 3: Connection between iPad and printer (via wireless network)

Figure 40. Devices used in Case 3: a) Samsung SL-C462 printer, and b) Mobile Print application on iPad

The third study observed user interaction when connecting a printer and an iPad. Samsung multi-function printer SL-C462FW (Figure 40) and an iPad with iOS 7.0 were used in the study. The iPad and the printer can be connected via a wireless network, so both devices are required to connect to a same network during the preparation stage. The Samsung printer provides a software application (Samsung Mobile Print, v1.06.29) to help printing from the iPad, and all participants were informed that the

application can be used. Information of two available networks (router name and passcode) was provided.

Test results

Four participants tried the connection via a network from a router (WO1, WO2, WO3, WO4), and one participant used a mobile hotspot from his smartphone (WO5). In the preparation stage, four participants (WO1, WO2, WO3, WO4) had difficulty recognizing sub-connection requirements of the printer for connection to a network. More importantly, all five participants had difficulty in their interaction after they learned that the devices' connection is feasible through connecting to the same network; two participants (WO2, WO3) did not succeed in the interaction task.

One frequent user evaluation difficulty occurred when the printer failed to connect to a network because participants typed their passcode in all capital letters, when lower-case letters were required. All five participants believed that the printer was connected to a network and was ready to be searched by other devices on the network. Participants (WO1, WO2, WO4) mentioned that they assumed the printer was connected because the "Wireless connection" signal of the printer was on.

This evaluation problem made the overall interaction very complicated. Participants (WO2, WO3, WO4) expressed that they could not identify the cause of the problem. Participants suspected the error was due either to their conceptual understanding of the connection structure (WO2), overall sequence of their interaction (WO1, WO5), network problem (WO5) or other missed requirements (WO4). Two participants (WO2, WO5) evaluated the status through testing with an additional device; they checked if their own smartphone could search the printer in the same situation. One participant (WO3) expressed: "There is a problem… because I don't know (what) the problem (is), I can't solve it." She also mentioned: "Because I don't know why the connection hasn't worked, I don't know what (information) I should look for (from the manual)." The observation confirmed that evaluation problems cause difficulties in dealing with device interaction; participants could not determine how to proceed. The Mobile Print application of the iPad could not help participants evaluate the situation nor diagnose the problem.

7.3.4 Examination of problem statement

Non-expert users' difficulties were frequently observed during all three additional cases. Many problems occurred when participants were not provided proper information or feedback for evaluating device interaction status. User interaction problems occurred with various devices: not only a wireless printer requiring complex network connection, but also a simple ear set or pocket printer. The evaluation problems made it difficult for participants to determine why their interaction had not worked properly during the connection sequence. Smartphone or iPad with dedicated software for a certain device's configuration could not help users to complete the interaction. Participants suspected not only the overall sequence and execution they had performed, but also their mental model of the connection procedure and other requirements. The problem statement of Figure 41 was confirmed through the examination.

Problem statement
Non-expert users have difficulties with interpreting and evaluating the devices' interaction status regarding the sequence of the connection procedure. When an evaluation problem occurs, they have problems dealing with the required sequence or diagnosing the error in their interactions.

Figure 41. Confirmed problem statement from additional user studies

7.4 Assessment of design solution

7.4.1 Improvements to device interface and paper prototype test

Device interfaces were revised based on the design implications and the framework:

1. The design framework with graphical assembly model (suggested in Figure 35) was applied to the images of two devices in order to provide information about the device interaction status (see Design implication A in Figure 31). The assembly model was adjusted for the interaction requirements of the specific technologies.

2. The sequences of user interaction were redesigned to reduce unnecessary user

interaction (see Design implication B in Figure 31).

3. The images of each connection step were adjusted to be feasible within the input and output facilities of the device. For example, the framework was adjusted on an ear set to present the status with an illuminating button, which is the current output facility of the ear set. However, the signal was revised to present different states of the device in a connection sequence.

4. Text information was added to communicate device connection states more clearly.

The diagrams of the revised interaction sequence are attached in Appendix C. It should be noted that the modified interfaces in this study were not thoroughly considered for all technological specifications, customer needs, and usability requirements for which a designer should handle many design conflicts relating to device functions, manufacturing issues, or marketing perspectives in real design practice.

This study used paper prototypes for assessing how information and feedback from the revised interface are interpreted and evaluated by users and whether such information helps users deal with device interaction. The prototypes were prepared in black and white in order to reduce the influence of color on participants' perception, which was not under investigation in this research (Figure 42). Non-expert user participants were asked to configure a connection between devices with prototypes. Also, in a few circumstances (Table 8), paper prototypes were provided to the participants whom were then asked to explain how they would proceed and why.

Figure 42. Paper prototypes to assess revised interfaces

Table 8. Tested circumstances of three cases

	Connection task	**Circumstances for diagnosis**
Case 1	A smartphone and ear set	When the smartphone cannot identify the ear set (the ear set is not prepared) When connection failed (the ear set maintains a connection with a different device)
Case 2	Pocket printer and smartphone	When NFC does not properly act because the smartphone is not activated for NFC, and P2P communication When Bluetooth connection is broken because the printer is turned off during the interaction When NFC connection is not properly established (because tapping is incomplete and connection is not properly established.)
Case 3	IPad and printer	When printer fails to connect to a network When printer and iPad connect to different networks When iPad is not properly connected to a network

7.4.2 Case 1: Bluetooth connection of a smartphone and ear set

The smartphone interface for Bluetooth configuration and the ear set interface were revised as shown in Figure 43. The smartphone interface was designed to reveal connection states of two devices through the graphical assembly model. The model presented different connection states when the smartphone required user action for preparation, when the smartphone is ready for connection, when a device is selected for connection, and when a connection is established. A button on the ear set was revised to indicate Bluetooth status separately from the device's other functions and illuminated when the device was prepared for Bluetooth connection. A horizontal status light was to indicate when a device shares an active connection with another device.

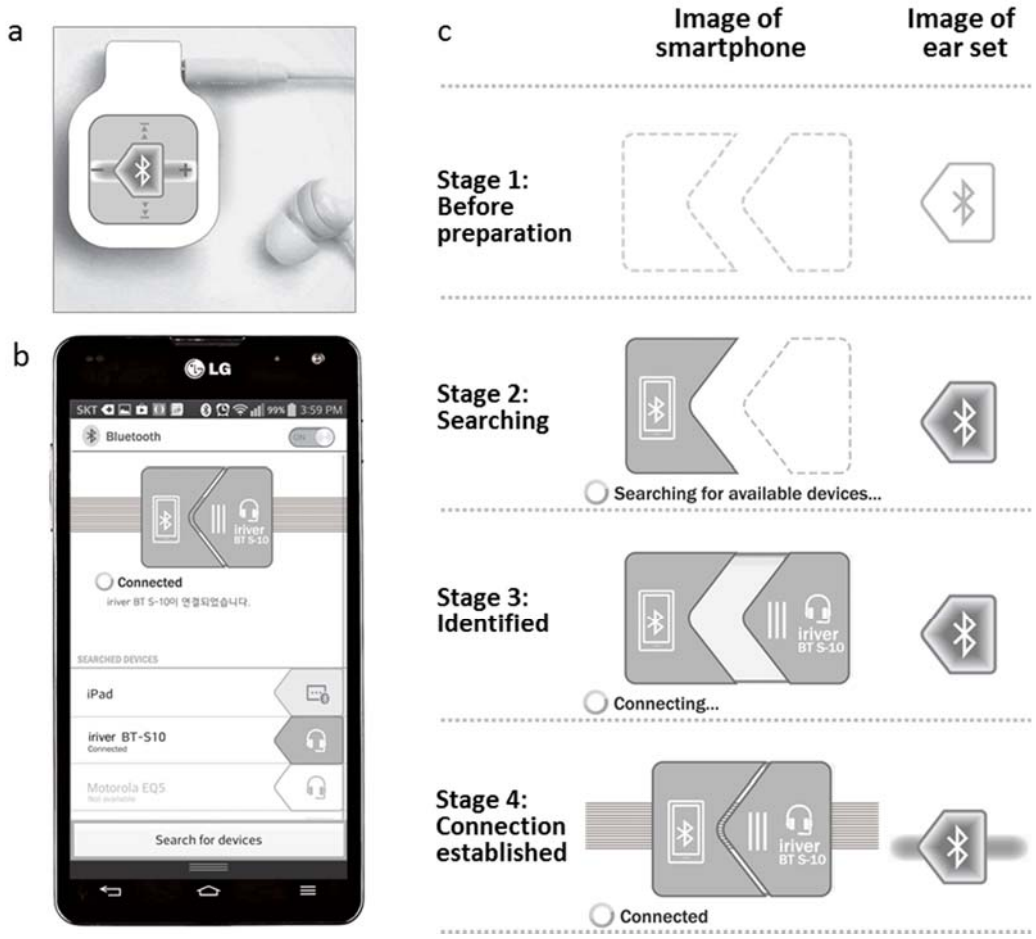


Figure 43. Revised images of a) ear set and b) smartphone, and c) images of the two devices in different connection stages

The user interaction sequence was revised to reduce unnecessary user action. When the ear set is turned on and does not have an active connection with another device, it proceeds to inquiry-page mode automatically and prepares for a new connection. Also, the smartphone does not require a separate action for initiating the connection establishment stage when a user selects a target device.

Test results

Participants (BR2, BR4, BR5) proceeded to the device preparation and search steps with few problems. All participants could determine the situation wherein the ear set was not prepared. It was observed that participants interpreted the graphical information, text messages, and signals on the ear set and the smartphone to interpret and evaluate device interaction status. The following sentences (quoted from BR3) show how a participant evaluated this situation:

> *"This (ear set) is off. (The Bluetooth of the) Smartphone is on, but the Bluetooth of this (the ear set) is off, so it (the smartphone) couldn't search and it was not in the list."*

Two participants (BR1, BR3) waited for the device to be found by search without checking the ear set and turning it on. However, when they checked the status of the ear set, they easily proceeded with the preparation stage; turning it on and checking the Bluetooth light.

Based on the evaluation, participants determined how they would proceed. When participants were asked to diagnose interaction errors, they decided to turn the ear set on (all five participants; when the ear set signal was off) or disconnect the existing connection of the ear set (BR1, BR2, BR5; when the ear set signal showed an active connection).

A participant (BR5) who had experience with Bluetooth connections between different devices mentioned the improvements of the revised interface in the following quotation:

> *"When I used Bluetooth (before), it was difficult. Sometimes the devices suddenly would not work perfectly although they had been working before. I think this (the revised interface) is easy because I can see if they are working or not. I think this is much better."*

Although some problems were observed, such as difficulties in interpreting text information (BR3) or in recognizing that the smartphone had not operated a search function (BR2), it is clear that the improved device interfaces reduced user evaluation difficulties.

7.4.3 Case 2: NFC connection of a pocket printer and smartphone

The interfaces of a pocket printer, its smartphone application, and smartphone's NFC interface were designed as per Figure 44. The graphical assembly model was used on a smartphone interface to help users evaluate device interaction status whether the smartphone is prepared for NFC operation or whether the smartphone has properly detected a device and a connection is therefore established. Because the devices require another interaction sequence for establishing Bluetooth connection via the application, the application is also revised for the Bluetooth connection steps. The NFC and Bluetooth connections were distinguished by assembly model having pieces

of different shapes. The interface of the pocket printer was revised to reveal the status of Bluetooth and NFC operation with two separate signals.

Figure 44. Revised interface of a) smartphone and b) pocket printer, and c) images of the two devices in different connection stages

Test results

All five participants interpreted information regarding whether the graphical model on the smartphone was on (illuminated status presented with solid lines) or off (shadowed status presented with dotted lines). Participants (NR2, NR3, NR4) examined if both devices were prepared by checking the illuminated signals of the printer and illuminated indicator on the smartphone before performing the tapping action. When asked to diagnose an interaction error whereby the smartphone was unprepared for NFC operation, one participant (NR4) explained: "Here, this is not lit (on the smartphone), something seems not activated here." Another participant (NR1) evaluated another circumstance wherein the NFC connection was not properly established after tapping:

> *"Because it seems shaken or detached when (they stacked) done like this, I will stack again after checking if they are turned on. (Moderator asked why she thought that.) Well… before responding this (graphic) showed a dotted line. The changed solid line looks like it was detected, but (not finished connecting)."*

The revised interfaces helped participants to evaluate device interaction and diagnose interaction errors. After her task was completed, one participant (NR4) mentioned the benefit of the graphic interface as follows:

> *"This (revised interface) shows clearly whether it is connected or not with text and color (illuminated state of a piece). If only check marks are shown (as per the original interface), it looks as if it's connected but it might not be properly connected. I like this (revised interface) because it shows (the status) visibly."*

Some remaining problems were observed from the test. Three participants (NR3, NR4, NR5) had difficulty recognizing how to tap the devices. Two participants (NR1, NR2) had difficulties when they attempted the interaction without checking whether the printer was turned on. Through interpreting different assembling models, one participant (NR4) recognized that the connection technology of the application (Bluetooth) was not the same as the technology with which she had interacted (NFC), resulting in confusion relating to status. These difficulties may need further investigation for improvement.

7.4.4 Case 3: Connection between iPad and printer (via wireless network)

The interfaces of the printer and iPad application were revised as per Figure 45. The user interaction sequence of the application was revised to automatically load a configuration menu presenting graphical assembly model when the application does not detect a properly connected printer. This can reduce unnecessary user burden in determining the configuration required and searching the exact menu. The graphical assembly model of the iPad application consists of three pieces to present two targeting devices and a mediating network. The central piece presents the name of the network to which the iPad is connected. A couple of buttons were added to the panel of the printer for controlling network function. The shape of the buttons was designed to mimic the two assembling pieces on the iPad application, and the buttons illuminate to signify operation of network function (one illuminated button) and network connection (two illuminated buttons).

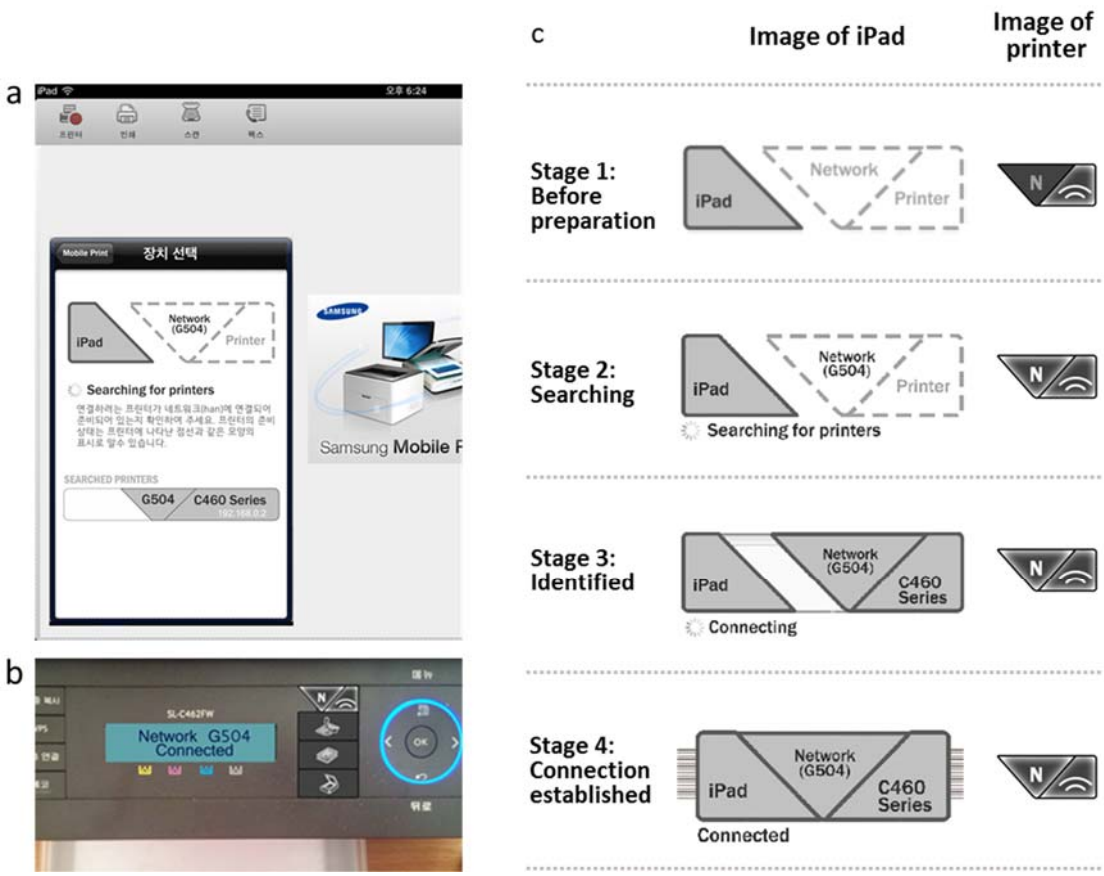


Figure 45. Revised interface of a) application and b) printer, and c) images of the two devices in different connection stages

Test results

The three assembling pieces of the application interface helped participants to easily evaluate which network is mediating (WR1, WR2, WR3, WR5). One participant (WR5) mentioned how the network information of the central piece helped her to determine the mediating network:

> *"It (iPad) shows (information of the network) here (the presentation of assembling pieces on the application). It (determining the network) was not difficult because they are presented. They show (network information) here (iPad) and there (printer). I knew because they were showed. I tried to match them."*

Another participant (WR3) learned that she was required to connect devices to the same network through testing the device search and evaluating the situation. She thought the iPad could search for devices from several nearby networks. When the iPad only searched for devices from the connected network, she recognized that the two devices should be connected to the same network.

When the moderator asked participants to diagnose a circumstance in which the iPad failed to search the printer on the network (when the printer failed to connect to the network because of wrong passcode), all participants narrowed their suspicions to problems of connection between the printer and router based on the connection fail message of the printer. Participants answered that they would retype the pass code (WR1, WR3, WR4), or suspect problems with the router (WR2, WR4, WR5). Providing clear information indicating the success or failure of a connection step helped participants to handle the overall interaction with greater ease.

Problems during the connection stage were rare, but one participant (WR4) became confused and thought a list of searched printers were connected to the iPad without performing the action of selecting and connecting a printer. However, when he found the iPad was not ready for printing, he quickly understood he needed to select one and establish a connection. The test showed that the suggested design solution helped participants evaluate the device interaction status allowing them easier determination if how to proceed.

Three participants (WR1, WR3, WR4) did not check the device interface at the very beginning of the task. Two participants (WR2, WR3) had difficulty searching the exact menus within the small display of the printer. Two participants (WR2, WR5) had difficulty recognizing the requirement for connection to be mediated by a network.

In spite of a few problems, overall interaction showed that the modified interface helped user evaluation and improved interaction.

7.4.5 Assessment of design implications and framework: Reflection from paper prototype test:

From the paper prototype test it was observed that participants interpreted the graphical assembling model, text information, and signals of devices for evaluating device interaction status; in doing so they could properly diagnosed the problems. Participants said that the interface clearly shows the current status of device interaction.

Participants understood whether a device was prepared for connection, identified a device, selected, and connected. They evaluated the circumstance of a device not having been prepared, a device not having been searched for by another device, and a connection not having been properly established. Participants suspected errors on a specific connection stage and did not doubt overall connection procedure or the ways devices connect. Participants used their evaluation of device interaction status to determine why a problem occurred and how they would proceed with the sequential interaction. Testing of the suggested interfaces and design framework with assembly model confirmed that the system image revealing the connection statuses of both devices provides desirable interaction between connecting devices, as per Figure 46. The carefully designed interaction sequences reduced unnecessary requirements and promoted easy interaction. Overall, the suggested interface improved user interaction.

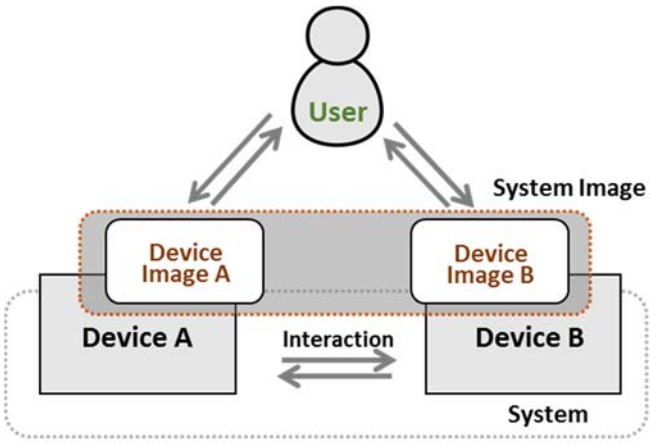


Figure 46. System image for desired user interaction

Reflection upon the remaining problems would provide important insights for further investigations. First, execution difficulties were observed in tapping two devices for NFC operation. The action seems difficult because a user is required to execute on two devices instead of acting on a single device. Methods by which to guide users to perform this new type of action (executing on multiple devices) would be an important future inquiry.

Second, some participants assumed the devices were prepared without checking the devices. Further investigation is required to ascertain how to help them quickly check the interface of both devices and reduce errors at the beginning of the interaction.

Third, the suggested interface solutions could not guide users to a complete mental model of connection sequence or interaction requirements. Instead, the suggested solutions with the assembly model helped users to explore the situation and evaluate the results of their actions, so that participants can infer the required sequence and determine the best means of execution. Continuous efforts toward providing users with a complete mental model can develop the interaction model further.

Limitation of the assessment

Paper prototype tests showed that suggested design solutions reduced participants' evaluation difficulties and changed their interaction. However, this study has not verified the improvements from increased success rate of user performance or reduced error rate.

First, this study has not approached the user interaction problem with a specified or reduced question. From a holistic view of design research, two major implications were suggested to help users evaluate device interaction status and reduce unnecessary requirements. The efficiency of each suggestion cannot be measured from user interactions in which two implications interplayed. In addition, the success rate of a separated connection stage cannot be measured in connection procedures for which user execution and evaluation are determined within the continuous interaction.

Second, two studies with original interface and suggested interface cannot be compared for success or error rate of user tasks. Unexpected operation errors or user interaction problems occurring in prompt perception or unconscious user behavior could not be tested with paper prototypes. Therefore, the two interactions of the

original devices and paper prototypes cannot be compared quantitatively.

Moreover, in this study, the perspectives from which to approach the problem, selecting methods, and data handling have been approached differently with previous HCI studies. The assessment of this study as design research is not the same as other research in which statistical comparisons were used for verifying arguments, but this study attempted to evaluate the improvements through assessment whether design suggestions brought meaningful changes to user interaction. The paper prototype test showed that the revised interfaces helped users evaluate device connection status and non-expert users used their evaluation in dealing with the sequence of interaction and diagnosing problems.

7.5 Summary

In this chapter, I examined problem understanding and evaluated the suggested design insights. The problem statement of the thesis was examined with three additional device connection cases involving different wireless technologies – Bluetooth, Wi-Fi, and NFC – and various devices, including ear set, pocket printer, and office printer working with an iPad and smartphones with iOS or Android OS. The additional studies confirmed that user interaction difficulties are commonly observed with different technologies and devices. Many problems occurred when the user was not provided proper information about device interaction status or when the user had difficulties interpreting the information, which caused difficulties in evaluating interaction status. Evaluation difficulties are important causes of user interaction problems.

This chapter assessed the design solutions suggested in Chapter 6 using paper prototype tests. These designs improved performance. Using the graphical model presented on the prototype interfaces, participants could evaluate device interaction status. As a result, non-expert users were able to determine what they should do in the sequence of interaction or diagnosed problems they faced. The assessment confirmed that system images revealed from both devices can improve user interaction to a more desirable level. Figure 47 shows the research progress from this chapter.

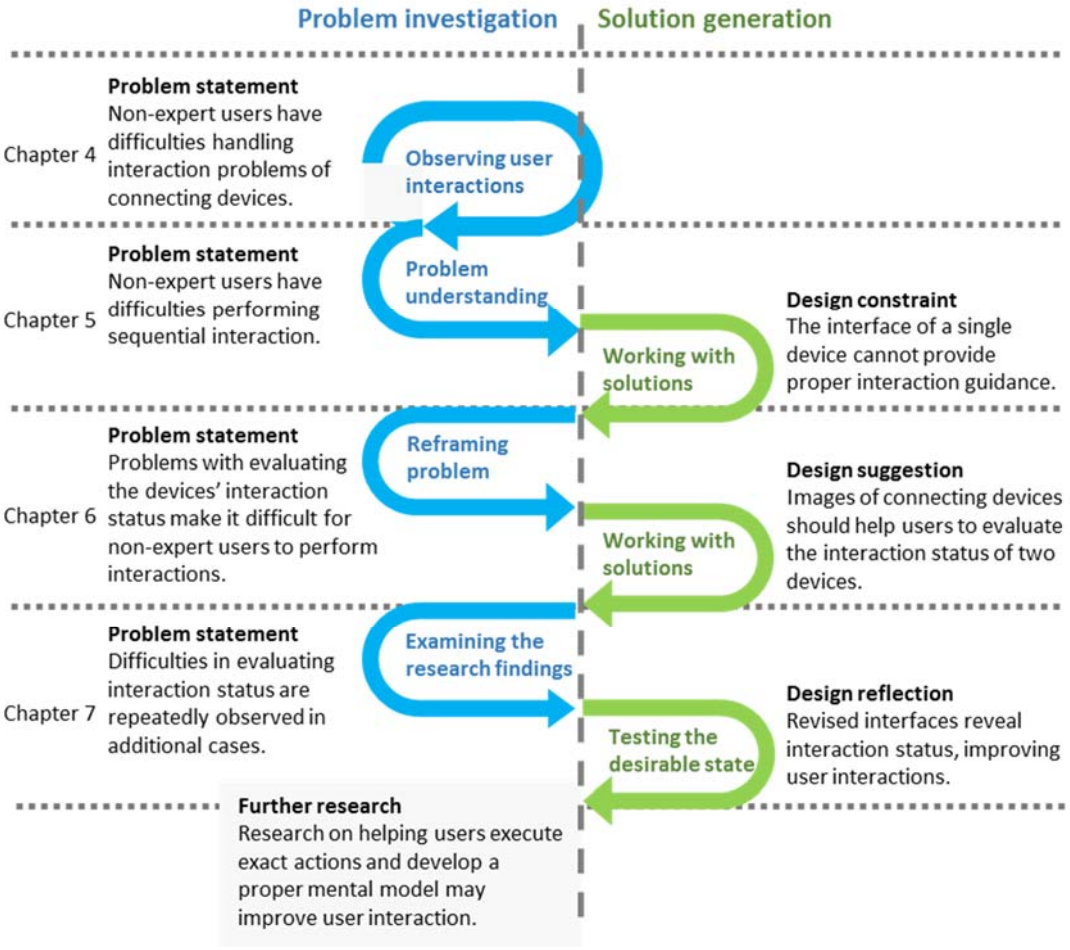


Figure 47. Design research progress from Chapter 7

Chapter 8. Conclusion

The complex problems of wirelessly connecting devices have been studied with a Research-through-Design approach through the iterative process of design research. This study aimed at improving the way users would understand device interaction. This final chapter concludes the dissertation by summarizing the findings, evaluating the research approach, and determining the contribution of this research.

8.1 Summary of the research findings

8.1.1 Problem understanding and design implications

This study iteratively reframed the user interaction problem from several perspectives and suggested interface design implications in response to deepening understanding. The user interaction problems in the early phase were stated based on the understanding difficulties associated with performing sequential connection procedures. The problem statement was reframed as I found user difficulties to have occurred in evaluating device interaction status in the connection sequence. The design implications also evolved from providing direct guidance for connection procedure to improving user interpretation and evaluations of device interaction status. The evolvement of the problem statement and design implications are summarized in Table 9:

Table 9. Development of problem statement and design implications

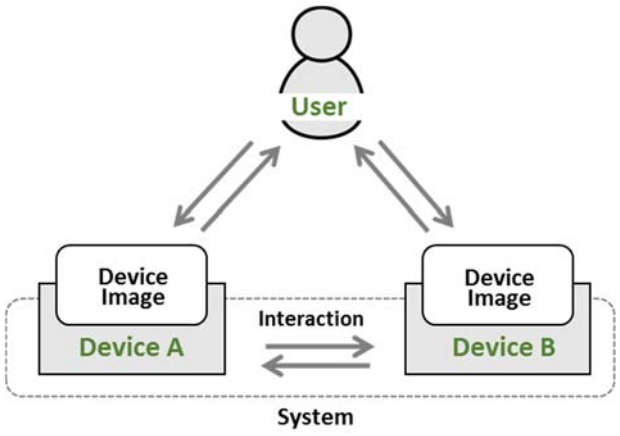
Research phase	Improved problem statement and design implications
Early phase of problem understanding	**Problem statement:** Non-expert users have difficulties handling interaction problems in connecting two devices.

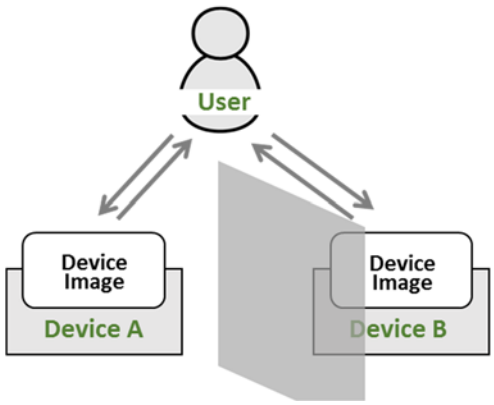
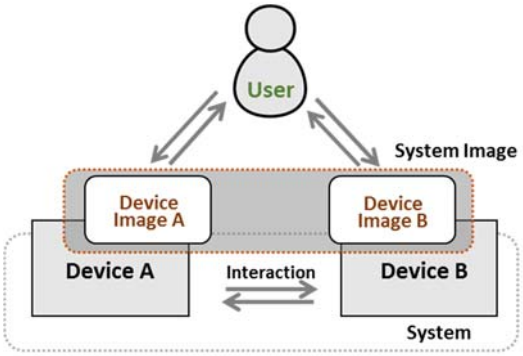
Middle phase of understanding: Gained from exploring sequential connection procedure	**Problem statement:** Non-expert users cannot properly recognize some required sequences of the connection procedure. Current devices do not properly help users handle the connection procedure, including the preparation of the involved devices, discovery of a device from the other device, selection of a targeted device from the other, and connection establishment.
	Design implications: A device's interface should help users handle the sequence of connection interaction. a. A device's interface should provide information to help users perform a sequence for connection, including preparation of the involved devices, discovery of a device from the other device, selection of a targeted device from the other, and connection establishment. b. A device's interface should be designed to reduce unnecessary user action.
Final understanding: Gained from investigating user difficulties in performing action	**Problem statement:** Non-expert users have difficulties with interpreting and evaluating the devices' interaction status regarding the sequence of the connection procedure. When an evaluation problem occurs, they have problems dealing with the required sequence or diagnosing the error in their interactions.
	Design implications: The device interface should provide proper information and feedback, so that users can interpret and evaluate the devices' interaction status regarding the connection sequence. 1) The information and feedback from the devices should not only be clear when operating the devices in user–single device interactions, but should also help the user to evaluate the interactions between two connecting devices. 2) When a user interacts with a connection between two devices, he or she performs a connection sequence that includes device preparation, identification, and selecting and establishing a connection. The devices should provide information and feedback, so that users can interpret the devices' status and evaluate the status regarding the required stages of the connection procedure. 3) The information and feedback should help users evaluate whether the overall procedure has been accomplished and whether the devices are ready to be used, or if the devices require further configuration. b. The devices interface should be carefully designed to require user interaction and reduce unnecessary user action.

8.1.2 Comprehension of user-device interaction

The interaction design problems of two devices are different from the problems of a single-device system. This requires designers to use different approaches when designing user interactions and interfaces. The understood features of user interaction and suggested desirable state are summarized in Table 10:

Table 10. Summary of user interaction features and desirable state

	User interaction with connecting devices
Related issues	Wireless device connection problems face various complexities from different technologies, devices, and interfaces. The complexities are changed depending on whether a device is preconfigured or whether the connection is mediated by another device, or whether connection is accomplished via an initial association procedure or a reconnection procedure. User interactions are also influenced by other devices in the environment or additional information resources.
User interaction with two connecting devices	When a user interacts with a system in which two devices are connected to one another, the user manages not only each device's functions, but also the interaction between the two devices. Users need to handle a complex connection procedure, including preparing the connection, searching, selecting, connecting, and using on the basis of their interpretation of the images on the two devices. 

Feature of design situation	There is a significant design constraint: A device cannot acquire the information necessary to aid the user in the multiple device interaction before there is a connection. 
Suggestion of a desirable state	Through revealing the connection status from both devices, the images of the involved devices work together to provide users with useful information for evaluating the system's status. 

8.2 Rigorousness of study

8.2.1 Integrated theories and methods

When a designer reflects a problem interpretation and generates solutions for an artifact, he or she integrates and contextualizes knowledge from different disciplines and directions (Stappers, 2007). In applying the design research paradigm, this dissertation has referred to various theories and applied several study methods from design, HCI, and other disciplines, as shown in Table 11.

Table 11. Referred methods and theories from design, HCI, and other disciplines

Research objective	Referred theories and study methods
Brief understanding of user interaction and difficulties	▪ Observation methods with various strategies
Initial problem framing (exploration of a sequential connection interaction)	▪ Interview method ▪ Knowledge of network technology ▪ User-system interaction model (Norman, 1988, 2013) ▪ UML sequence diagram
Initial solution generation	▪ QOC (Questions, Options, and Criteria) method (MacLean et al., 1991)
Reframing problem (investigating user difficulties in performing action)	▪ The model of Stages of user action (Norman, 1988, 2013) ▪ Qualitative data analysis method (Analysis with coding)
Generating solution to overcome the design conflict	▪ Innovation by boundary shifting (Jones, 1992)
Expanding research findings to other cases	▪ Observations
Evaluating design solutions	▪ Paper prototype test method

Due to the feature of the Research-through-Design approach that does not specify or limit focus, the thesis started with loosely defined target interactions and three cases, which were observed using various methods. Progressive studies allowed me to narrow and refine the issues studied, and the study methods of additional cases in Chapter 7 were determined with more refined research focus.

The perspective of this research on selecting study methods and techniques is not the same as other research in human-computer interaction (HCI), experimental psychology, or scientific research. The study methods used in this dissertation were carefully decided based on reflection upon what information would reveal the current situation and a possible future of connecting multiple devices. However, the studies in this thesis were not controlled as experiments verifying information. The study methods and techniques cannot be indicators assuring the scientific logic of this dissertation.

8.2.2 Rigorousness by iterative process

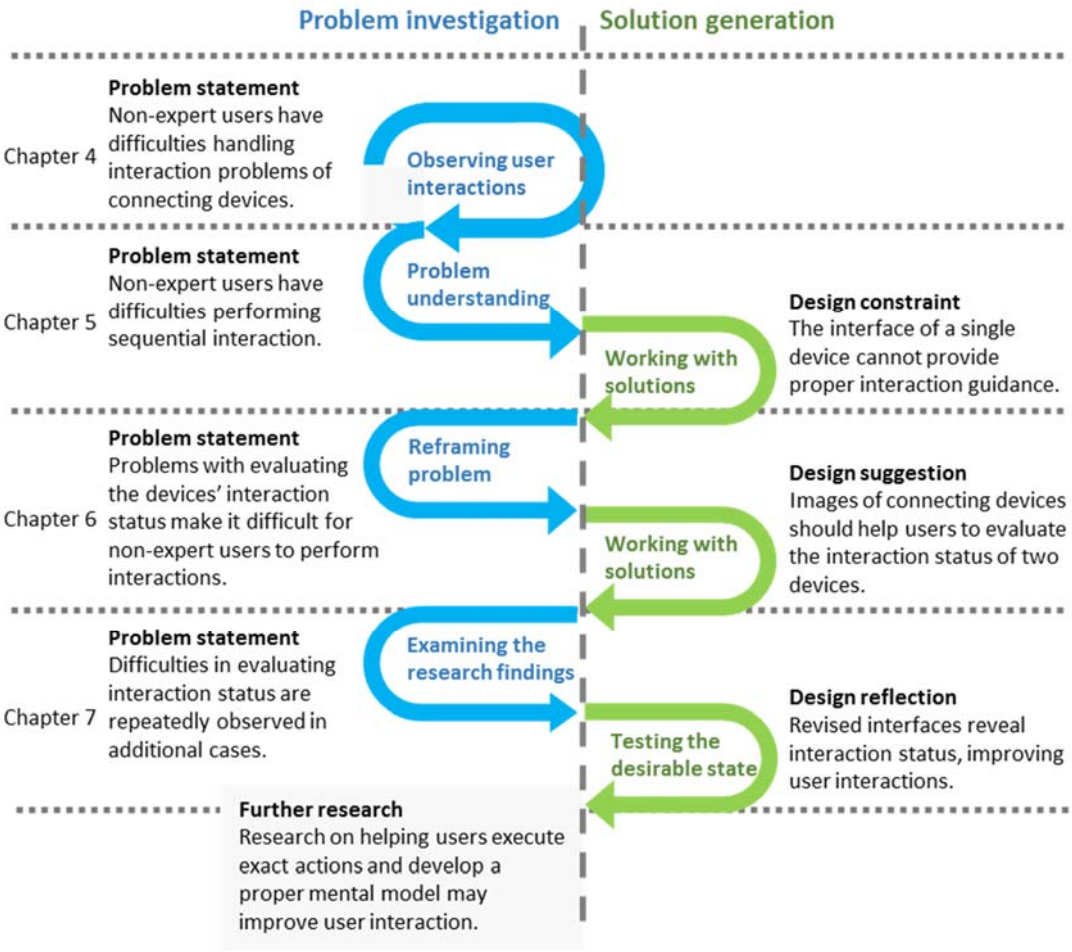


Figure 48. Iterative reflection of the dissertation

The rigor of this dissertation is ensured by the iterative thinking process as shown in Figure 48, by which problem understanding has been continuously reflected via problem investigation and design ideation. The problem statements were iteratively re-framed based on insights about usability issues of the device interface, user difficulties with sequential connection procedure, and reflection upon user difficulties in performing an action. The understanding of user interaction is not only drawn on the basis of observation in various situations, but also reflected with a theory of user-system interaction. The progressing problem statements were tested through design alternatives and examined from the additional user interaction cases using different devices.

The design implications and framework were suggested on the basis of the

comprehension of user interaction difficulties. As the problem statement has been reframed and detailed, the design implications have evolved together. The solutions were also tested by users in paper prototype tests.

The acceptance of produced knowledge from design research is not assured by research methods, but is assured by repeated reflection on the current state and experimentation with a possible future (Löwgren & Stolterman, 2004). The iterative investigation and ideation spiral, in which understanding of the devices' connection problems are continuously reflected upon from different perspectives and tested through design alternatives, make certain the claims of this study.

8.3 Evaluation and contribution of the dissertation

8.3.1 Evaluation of Research through Design

This study is not aimed at testing a hypothesis relating to one specified phenomenon, but rather aims to provide a design framework for interpreting and resolving complex and ill-controlled user interaction problems. Therefore, traditional criteria are not appropriate for evaluation of this design research. Instead, this design research can be assessed with the four criteria Zimmerman et al. (2007) suggested for qualifying Research through Design. The accomplishments and contribution of this research are reflected based on the four criteria: process, invention, relevance, and extensibility.

Process: This dissertation described research progress, covering the detailed process of early problem framing, evolution of understanding of interaction problems and design situation, articulation of design implications, vision of desirable interaction, and assessment of research findings and design suggestions. In documenting the process, rationales for study methods and data analysis were described in detail. The diligent documentation of the research progress helps readers judge the quality of the research contribution and rigorousness.

Invention: This dissertation addresses the complex interaction design problem with novel integration of design grounding and ideation methods and several theories and knowledge from the interaction design and HCI fields. Advanced knowledge was produced regarding differences in user interaction between multiple-device and single-device systems. This study also produced design implications, an

understanding of the design situation, and a design framework, to which designers may refer while creating their designs. The design insights were described not only through documentation but also via revised interfaces and user interaction changes.

Relevance: Design research should be evaluated on whether it properly articulates what is real and what is preferred rather than what is true (Zimmerman et al., 2007). In this dissertation, user interaction difficulties were framed based on close observations of several user interaction cases involving an MP3 player, a notebook computer, smartphones, an iPad, audio devices, an office printer, and a mobile pocket printer. The desirable state of device images is developed based on thoughtful reflection upon observed user interaction problems, and the vision of this dissertation is examined through revised interface cases and paper prototype tests.

Extensibility: This dissertation formulated the research findings as applicable and extensible knowledge for interaction design by examining its findings from several user interaction cases. It generated a problem statement, design implications, and a framework, that have been applied for understanding and improving the three user interaction cases, and it assessed its research contribution as knowledge of common device connection problems.

8.3.2 Contribution of the dissertation

This study formulated knowledge to which designers can refer in their designs for connecting devices: how to comprehend user-system interaction, how to interpret user difficulties and how to approach the design problem, and what a desirable state is for the future. This thesis made four major contributions to that knowledge:

1) It provides understanding of user-system interactions when associating two devices. It explains how different user interactions with multiple devices compare to user interactions with a single device. It also found that a single device cannot provide sufficient guidance for users during a connection procedure.

2) This study provided interpretation of user difficulties. Through framing the problem from different perspectives, it found that non-expert users cannot properly recognize some required sequences of connection procedures. It also found non-expert users had difficulty interpreting and evaluating the device

interaction status, and users had difficulty in carrying out the required sequence of interaction. These findings can provide important insights to interaction designers coping with user difficulties.

3) This study developed design implications which solve the framed problems, and a design framework for connecting devices is searched to overcome conflict between the interface that is provided and what is desired. A design solution was suggested to reveal each device's status regarding whether it is ready for connection or already connected.

4) The study not only provided design implications and a framework, but also provided examples of a desirable state of user-system interaction. Through the example interfaces and tests, the dissertation presented how the suggested interface design revisions improved user interaction by helping users to evaluate the devices' interaction status.

This research contributes to Research through Design as an example of manipulating interaction design knowledge. With reflection through the repeated process of problem understanding and ideation, it demonstrated how Research through Design constructs comprehension of the complex problem of interaction design.

This dissertation generated knowledge for designers who must deal with user interaction problems of current technology. This thesis contributes options for user interaction improvement realizable with current technology, rather than proposing techniques requiring advanced technologies. However, this study does not criticize or ignore the benefits we can get from technologically advanced association techniques, which the HCI field has endeavored to develop. Rather, this study contributes to broadening probable solutions for user interaction improvement. Better understanding of the current devices' connection problems would provide important insights for future association techniques as well.

8.4 Further studies

Further studies are required in order to leap forward into more preferred user interaction. First, in addition to the suggested framework and interface examples, broad design alternatives must be explored and examined. In order to improve the framed problem further, explorations searching for probable design solutions and

discussions of benefits and costs of each design alternative will be crucial for the advancement of user interaction.

Second, further studies are required to develop design example cases and test them in real user interaction situations. The paper prototype tests from this study have assessed the benefits of the suggested design implications but could not evaluate the application of the design framework to design practice and assess it with real user interaction cases. Suggested interface revisions should be implemented with thoughtful reflection upon the different context, situation, and related issues of each device's unique situation. Assessment of the improvements in real interaction situations would require lengthy studies but would provide important further insights.

Third, further comprehension and solution ideas are required for the remaining problems, of which user execution difficulties are particularly important. It has been observed that users had difficulty recognizing the exact execution method when they performed it on multiple devices simultaneously, such as tapping two devices. Even though the difficulties did not make users confuse the overall sequence of interaction, such execution difficulties are still important problems that interaction designers and researchers should resolve to improve user interaction.

Fourth, this study defined several related issues, but only some issues were intensively investigated. Disconnection and reconnection occurred during functional usage, other devices influenced the interaction situation, and identification problems among multiple devices occurred; these are important issues of user interaction, which require further studies to increase understanding and improvement.

More importantly, the interaction model should be developed further. The graphical model and device signals of revised interfaces helped users to explore device interaction status and evaluate the result of their actions, such that design suggestions helped users determine how they should proceed with the connection sequence. However, we need continuous investigations for advanced models that can guide users to build a better mental model of the connection sequences and structure, as well as help user evaluation of device interaction status.

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Appendix A: Transcribed protocols and diagrammed interactions (from Chapters 4 and 5)

In these examples, inconsequential protocols and the moderator's reactions were removed or shortened for smoother reading and marked with ellipses.

Example 1: P5 (a male participant) connecting earphones to an MP3 player

He connected an MP3 player and earphones for the first task and tested the connection between the MP3 player and a speaker for the second task.

I turned on Bluetooth on this MP3 player.

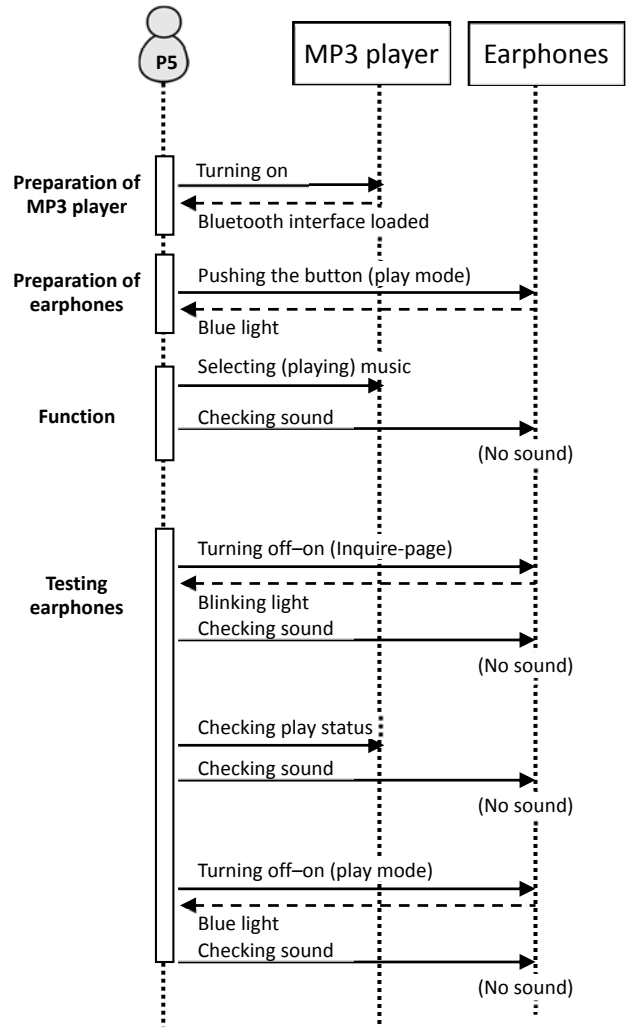
At first, I would tap (the earphones' button) and go onto the blue state.

Is Bluetooth turned on? Now, I go to listen to a song. Is this song playing? It seems that the Bluetooth is not connected because the song is not playing (from the earphones).

I pushed the button longer (on the earphones). Two lights (are blinking). I cannot hear the sound (from the earphones).

Let me check if the song is playing properly (from the earphones). A song is being played (on the MP3 player), but I hear no sound.

Now, I will turn it off again. Let me think about what to do. I will try again. The (earphones') blue light is turned on, but sound is not coming out again.



I guessed that there was a problem with the volume, so I raised the volume to check, but it still doesn't work. I tried to slide (move) to the next song, but that didn't work either.

It does not seem to run (function of connection) yet. I will try again in this state. I figured that the red is the off state, as I expected.

I pushed the button (on the earphone) for longer. Heck! It still doesn't run.

It is definitely playing music but it (the sound) doesn't function, so let me try again. I am looking around for other controls.

I pushed the state once more. What would happen if I pushed it gently again? Uh, the blue (light) is on. Ha, let me press it once more.

Can sound be heard when something comes close (to the MP3 player)? It is so hard to hear. Let me push it once more. I still cannot hear it.

Um, I turned it off again.

Let me push it long again. Now, both lights are on. Once again, I still can't hear it.

Something is acting weird. Let me tap it once. There are no specific changes.

(He activates the MP3 player's screen.)

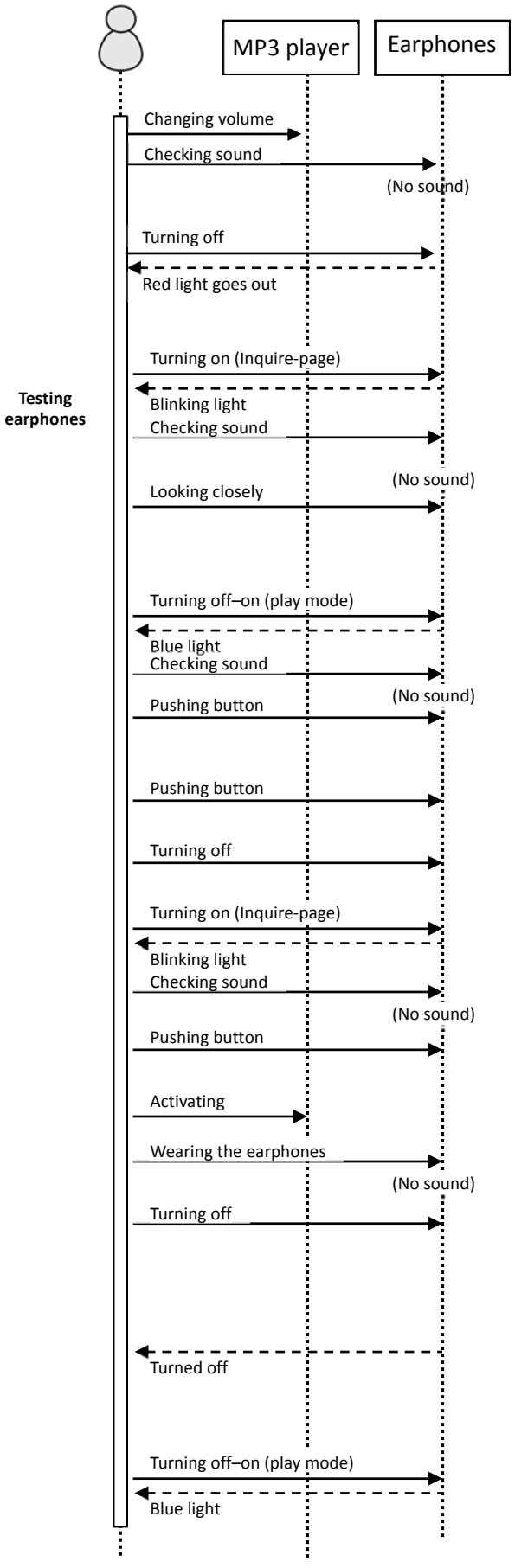
I will wear (an earphone) on the left side.

Well, now it does not even turn off.

Weird. Were the manipulation methods wrong? It is not turned off.

Now, it seems turned off. Still, sound cannot be heard. The songs have changed twice already.

I am starting to doubt whether the MP3 player has a problem (with operating). Let me analyze this. If I



push it (the button on the earphones) once, the right light goes on. It is still not connected.

In this state, it is now blinking. Let me push it once more. Again, it is blinking. If I push it longer, will it be turned off? Ah, but there is no sound.

Now. (He touches a magnifier icon on the MP3 player, and the graphic image moves.) Oh, is this it? I am happy, but why can't I hear the sound?

Well, it seems the device has searched for 001b42. But still, sound is not coming out.

Then, let me check whether it (an icon on the MP3 player's screen) disappears if I turn these (earphones) off. Search again! Ah. (The icon is not shown.) I found it is a status: (The earphone is) turned on.

Then, I will check what happens if I push (the button on the earphones) once. Now, only the blue light is on. (The icon is not shown on the MP3 player.) Now, the blue light status is not for Bluetooth. The blinking status is for Bluetooth.

Well, it entered the Bluetooth state now. It has been found.

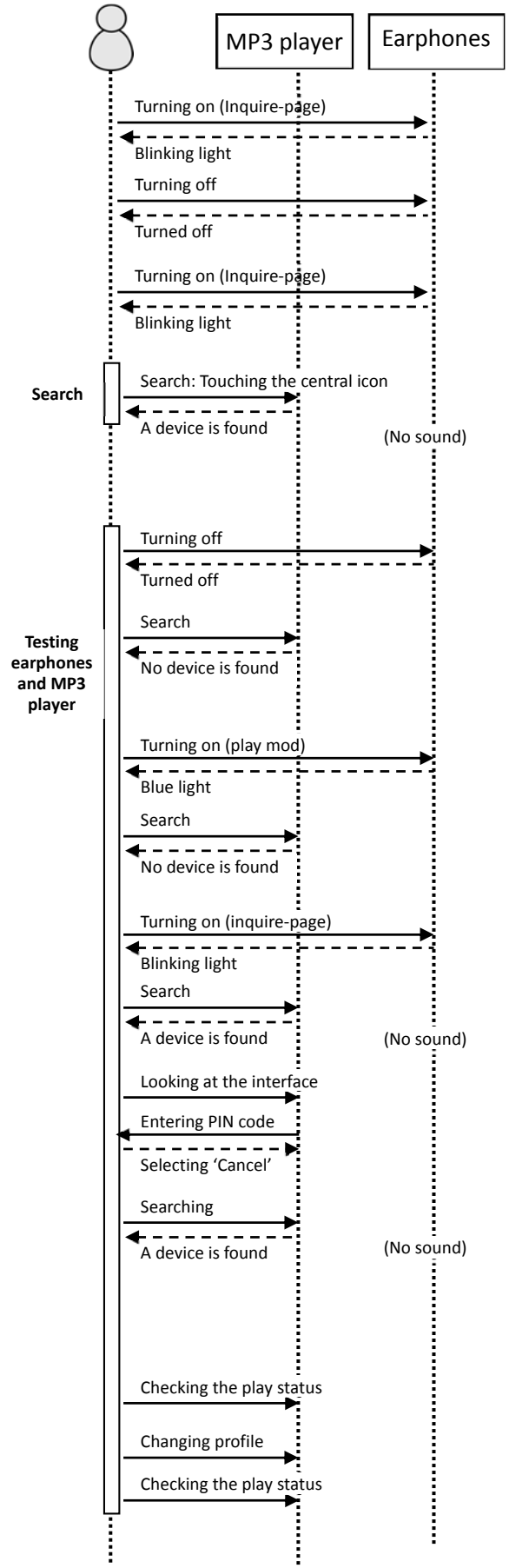
Options, Headset, may be not File transfer. (He goes through options of the MP3 player) Device information—I think (I should look around) the device information.

Well, it was found, but why is it not functioning? Bluetooth is functioning. It had been done.

If I go back, will the Bluetooth work?

The earphones do not have a problem now. Gee. It says there is a Bluetooth (device), but (it is) not connected.

(Search, Option, File transfer. (He reads off options on the MP3 player) A



song is still playing, but (I cannot hear it).

They (earphones) became blue. Strange. Argh. Now, (it became) undetected too. I would stop this (search).

Now, it is turned off. In the off state, it should not be detected.

It does not search either now.

(He changes the search options for the headset.) Now, one (device) is detected again.

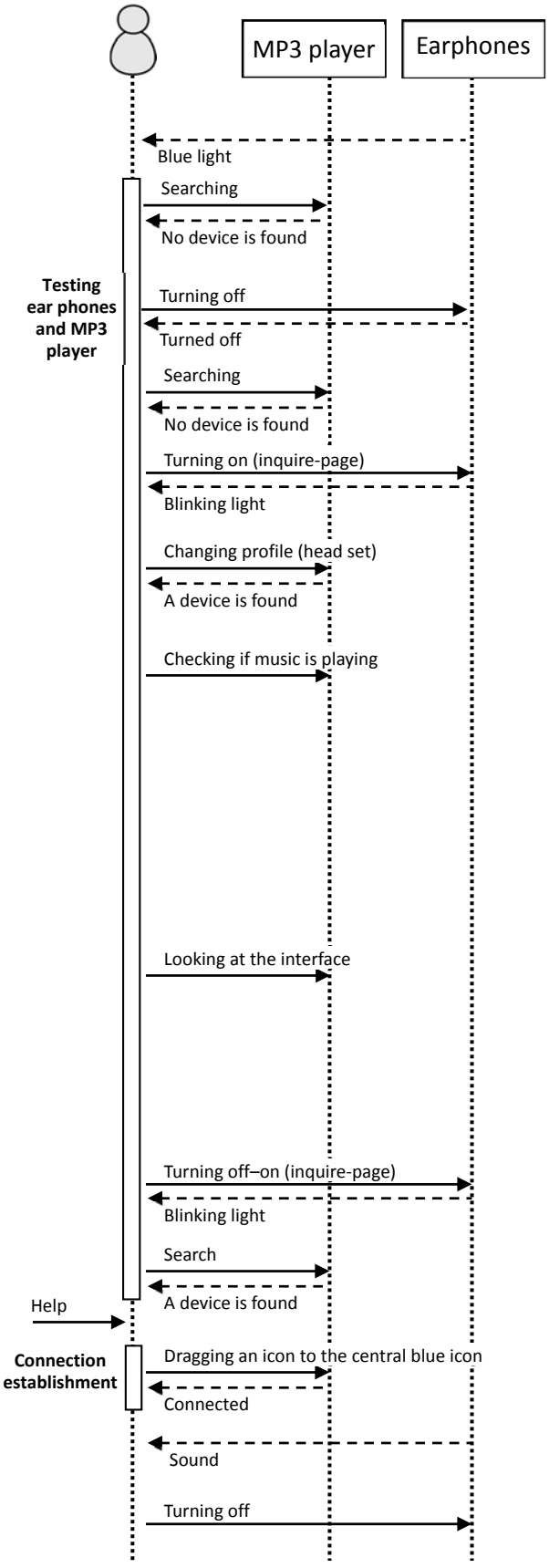
Okay, now I need to play this song. The song is still playing (on the MP3 player). Let me play my favorite song. Well, it was detected, but why is it not functioning? Now that it is detected, it seems that there is a way to connect them, but I don't know how to do it.

It says Bluetooth is on. Oh, it is initialized. Oh, ridiculous. Was it broken?

I will try everything. Information about my device—I tried this before, and Search Options, Headset, and Bluetooth. Oh, it (Bluetooth) is for on or off. I started to become bored.

How can I make them work? Give me a hint. I really want to hear a song. ... I know how to make it search for the (earphones). I think I should turn it off and then turn it back on. This is really uncomfortable. Ok. The search is done.

(The moderator informs P5 to drag the earphones icon to the blue icon at the center.) Wow! Well, I started to hear the voice of Jo Kwon (singer's name). It (MP3 player) has a secret. Now, I'll turn it off because I don't like the earphones. Unbelievable.

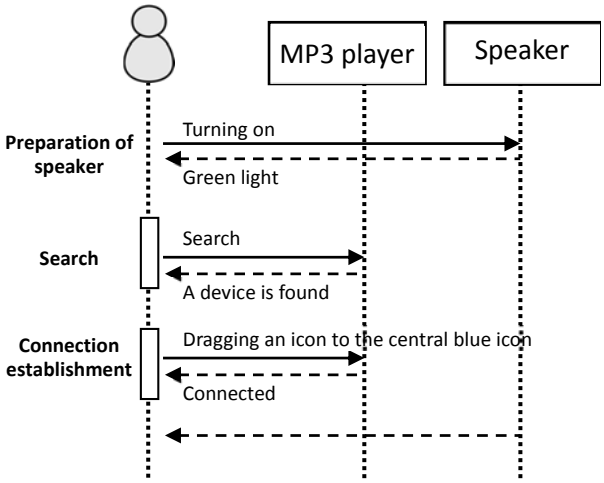


Connection between the MP3 player and a speaker

I'll observe (the speaker) first. It doesn't have such features (like the MP3 player). I don't think I should activate anything separately. I'll search right away.

Uh, the light is on. It's very easy.

Well, the connection was done immediately.



Example 2: T3 (two male participants) connecting a printer and a notebook computer

P1 controlled the devices, and P2 assisted with the interaction verbally.

P1: Let's turn on the power (of the devices). Wait, it's not the notebook I used. Uh (He finds the power button). Uh, it's on! It's amazing! I guess it turns on when I lift it up. (He types the password.)

P2: The power on the printer does not work either.

P1: Do we have to connect the power (cable)? I'll find where the power port is.

P2: Here is the (printer's) USB port. I don't know what it's for.

P1: "Tara, Tara"; Oh, it is turned on.

P2: Is it turned on?

P1: (He reads the display panel of the printer.) "Preparing. Please wait," it says. One-touch networking! (He reads the text on the printer.) "Push the WPS button for two seconds, and push the WPS button on the router for two seconds."

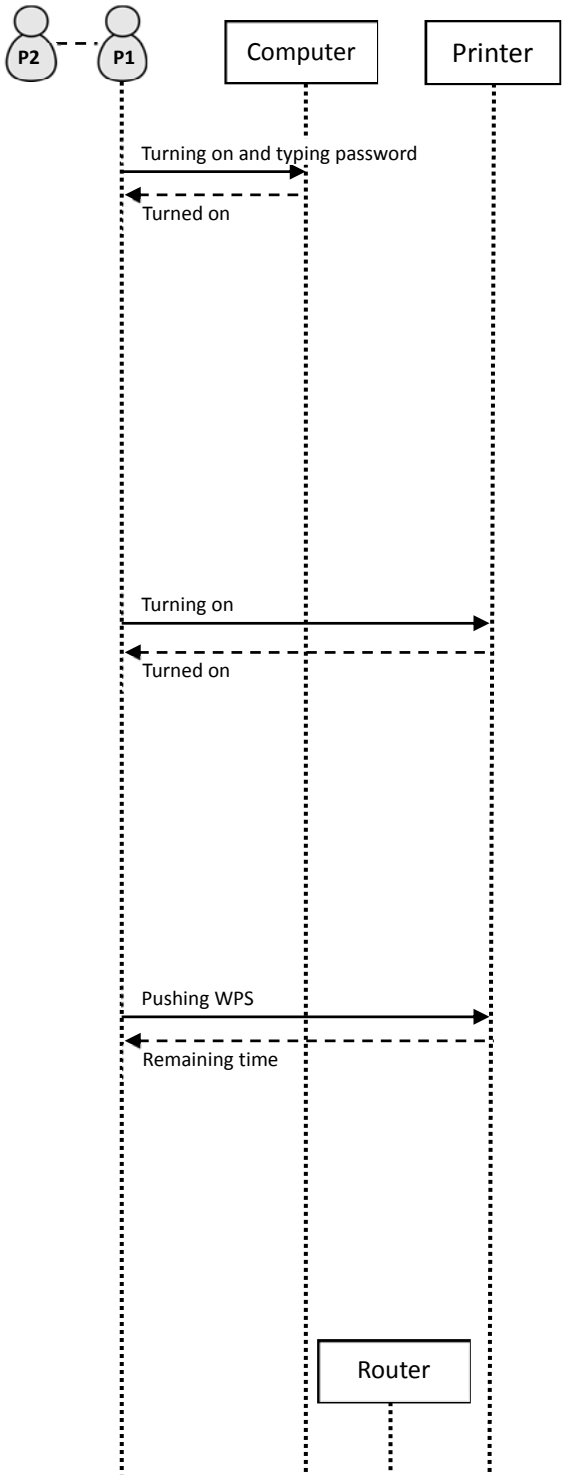
P2: Push this for two seconds.

(P1 pushes the WPS button on the printer.) P1: One, two. Where is the router?

P2: Uh, we don't have one.

… (He moves to get a router and turns it on.)

(P1 connects the router's power cable . P1 connects the printer and a router physically with a cable.)



P1: Push this (the printer's WPS button) for two seconds: one, two. Push here (the router's WPS button): one, two. Is it done?

P2: Ah, a connection. It (the printer LED) is blinking. Good!

P1: I am smart!

P2: Let's find the file to print from the notebook.

P1: Should we print the file to finish the task?

P2: Uh. It is still connecting.

P2: What is this? The printer is CLK3185WK from Samsung.

P1: Different firm? (I select) Add a printer.

P2: Eh? There are a lot.

(P1 searches the list of network printers.)

P2: But it doesn't have a Samsung.

P1: The wireless connection isn't done.

P2: Push the button again. What is the ipTime address?

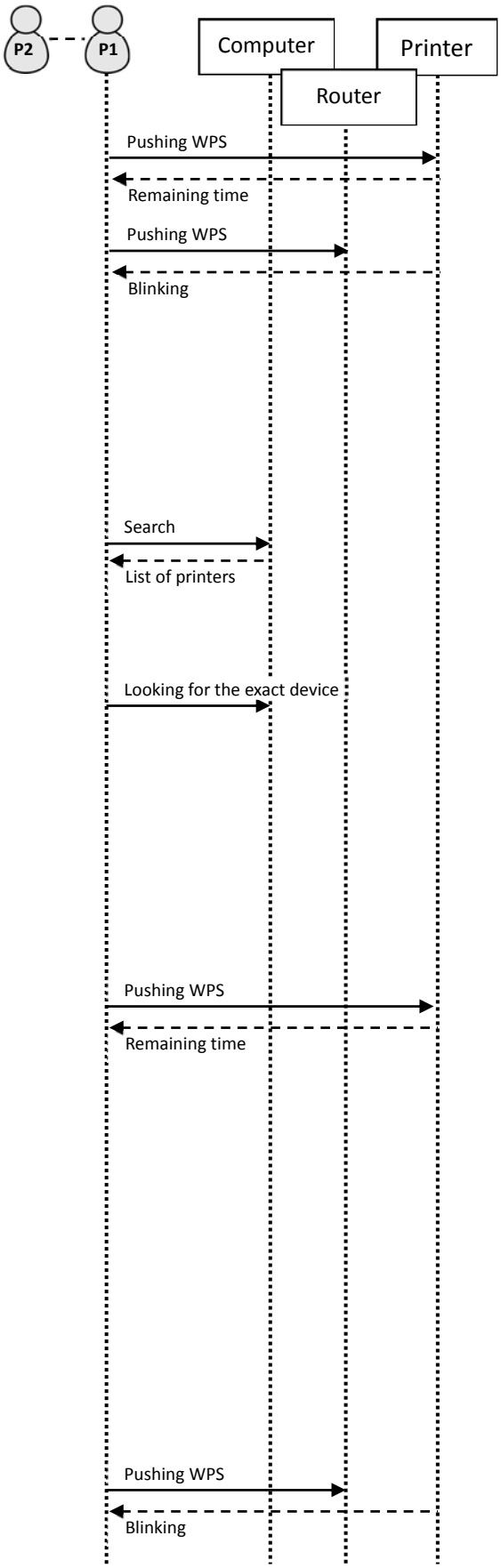
P1: (He checks the written information again.) Push the WPS button.

P2: Is there anything (additional guidance on the configuration sequence) above (the printer's WPS instructions that are covered by a notebook computer)? Hold the laptop. Nothing there?

P1: How? Hold the laptop?

P2: Under the (notebook). Nothing there. (P2 reads the written information.) A dedicated button for fast wireless installation.

P1: It says to push the WPS button, and I pushed it.



P2: Remaining time. The remaining time is shown. Do we have to wait? Push WPS for two seconds of time. Did you push it?

P1: Uh.

P2: “Connecting”.

P1: It showed “Connecting” inearlier, but it didn’t work.

P2: Fail. Did it show “Fail” earlier?

(Five minutes passes from the beginning, and the moderator passes them a printed manual. P1 reads the printer manual.)

P1: Through away the useless things (of the manual). Infrastructure mode, support, and.

P2: Should the LAN cable be plugged in here?

P1: Should it not?

P2: Is it not written there in the manual?

P1: Oh, ah, it’s not. (He murmurs.) I thought that I should connect a LAN cable that is connected to the Internet (to here). Then, it will be from Internet to Internet. But, it seems not to be the case.

P2: Let’s do whatever.

P1: Go, go! The manual is very unfriendly. Annoying! Let’s do as it (manual) says. Press the Menu button (on the printer). It doesn’t have one!

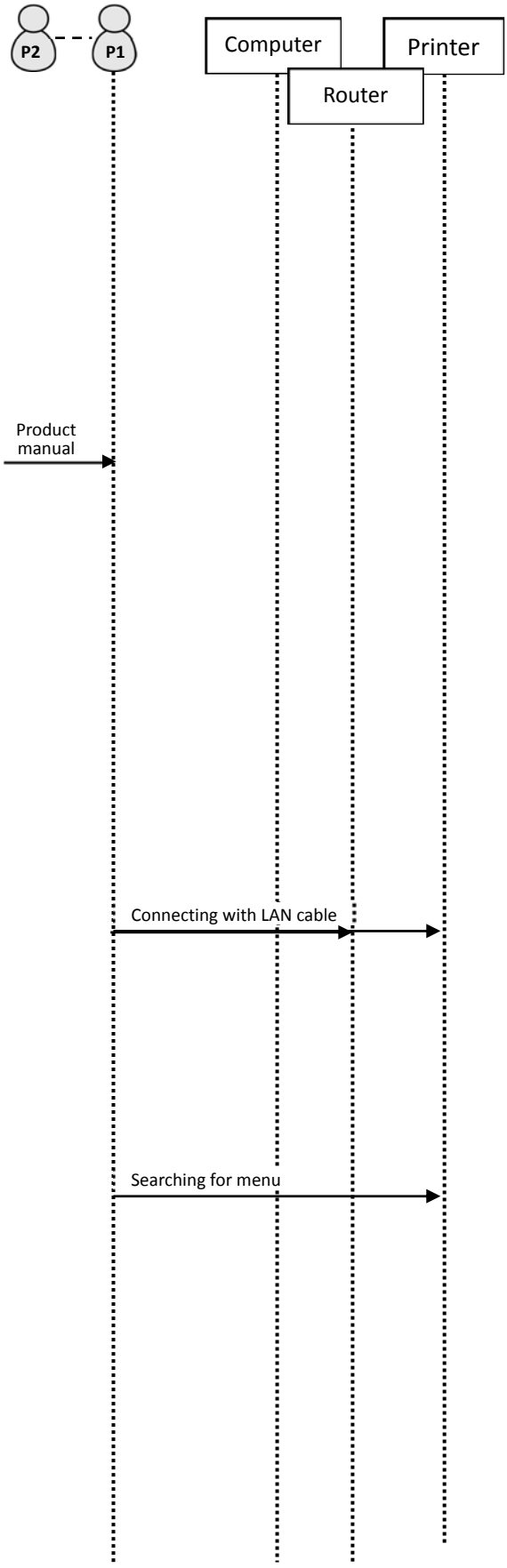
P2: Network? Is it lying?

P1: Yes. It does.

P2: There are only ‘Scan’ and ‘Copy.’

P1: Eh? I found it. IP menu.

P2: But, (we are not looking for) copy but for print.



P1: Copying and printing may be the same.

P2: But we trying to print. Does it not really matter?

P1: (He points the page on the WPS mode in the manual.) We are doing what it says. PBC seems to be right.

P2: It is saved. (He reads the manual.)

P1: Uh.

P2: Press it (the WPS button on the printer).

P1: I don't think this is the one (I am looking for).

P2: Do you think it is not the right one? Why don't you press this one (on the router)?

P2: By the way, if the two are connected with the cable, there's no reason to push the WPS button on the printer or the WPS button on the router.

P1: There's no meaning. So, it seems (the cable) should be plugged somewhere else. Throw this away. (He disconnects the cable.)

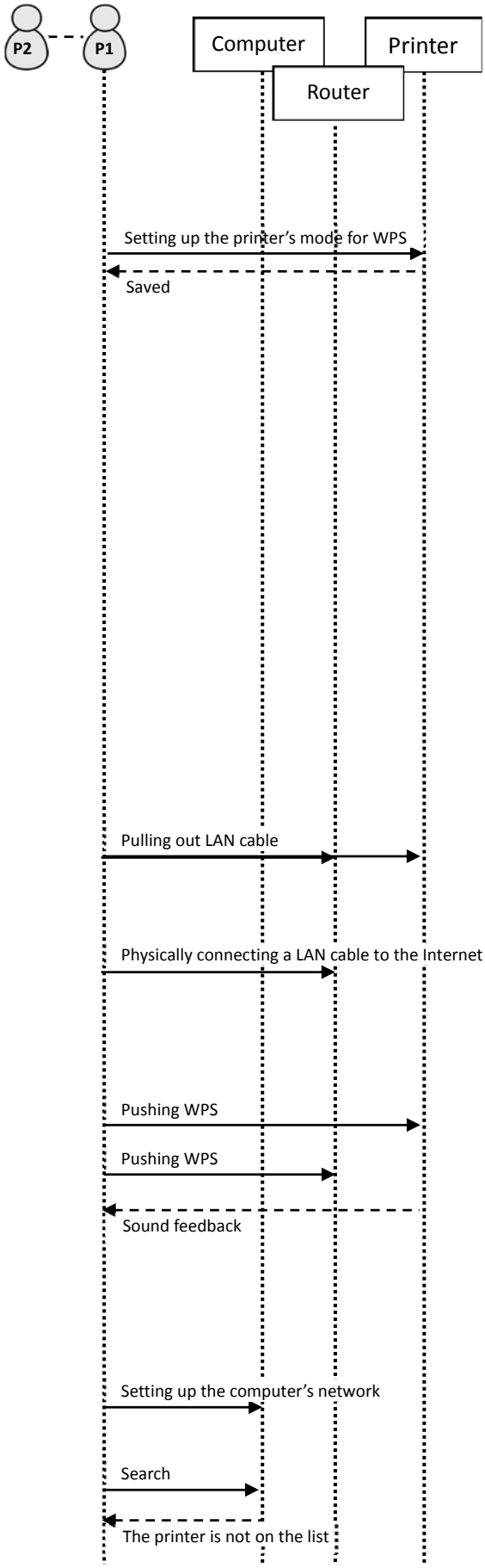
P2: We should connect this (printer) with the notebook (with a cable), shouldn't we? It seems not. The notebook identifies the network that the printer is sending.

P1: If the laptop sends the signal, this (router) will receive it and should send the signal to this (printer) again. …

P1: Push (WPS) again. (He pushes the router.) Oh, please "Tara."

(Printer gives sound feedback, "Tara, Tara.")

P1 & P2: "Tara"!



P1: (On the computer) ipTime. (He configures the computer's wireless network connection. He searches for the printer from the computer.)

P2: Wireless, show Samsung.

(The printer is not found.)

… (P1 configures the computer's network connection again.)

P2: Ah, it is done. Did you connect to 'iptime' or 'KAIST' (the school network)?

P1: 'KAIST'. This (router) is connected to 'KAIST'. Is this connected to another? It (the printer) has not been identified.

P2: Each router forms a network, doesn't it? It is not 'KAIST.'

P1: This (router) is connected to 'KAIST.'

P2: Ah, that is right.

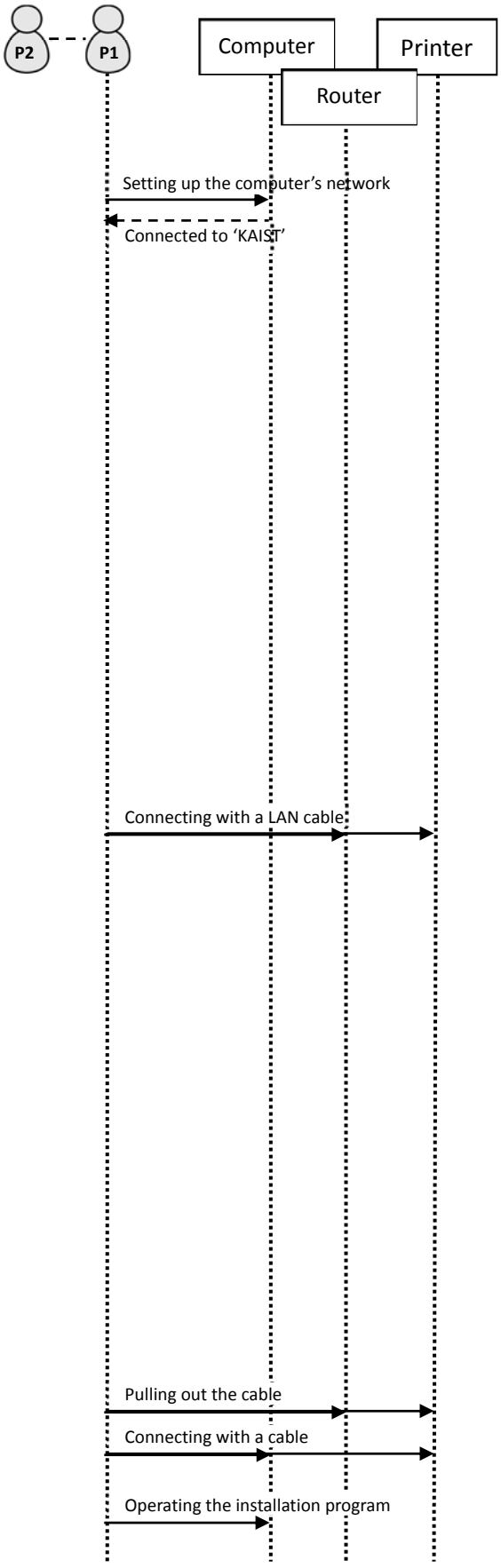
P2: Oh, it takes much longer than I had thought. (He reads the manual). ipTime is on the network. (He watches P1 connect the computer and router with a cable.) Uh, we should not connect them like that. Otherwise, it becomes a wired connection.

P1: I know. Do we have to configure the wireless network from this computer? Why don't we try an ad-hoc connection?

P2: Why can't we do that with ipTime?

P1: Let's do it with the ad-hoc connection. Ad-hoc is here. (P1 reads the manual.)

P2: Did you find (the part of the manual)? There are up to sixteen orders!



P1: Let's do this. Check whether the USB cable connects to the product. (He connects the printer and computer with a USB cable.) I turned the computer and the printer on. Now, the software is here, then I click 'set up.'

… (They talk about their previous ad-hoc experience when playing a game.)

P2: By the way, do we have to plug the USB (cable)? Can we use a USB cable?

(The moderator answers that the ending status requires a wireless connection but that they can use a USB cable during the task.)

P1: But why does the set-up window not show up? I turned it on.

(AP has been found on the screen. He selects 'wireless network.')

P1: Next, would it work?

P2: Connecting to the network. (He reads the information on the screen.)

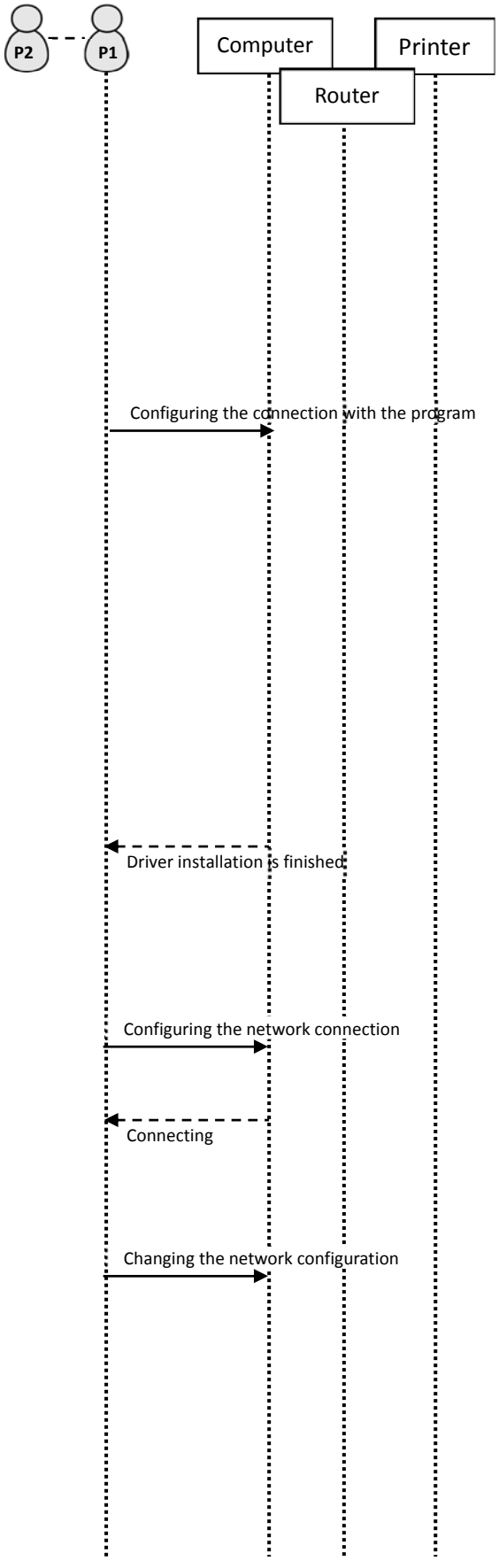
P2: The commercial said it is one touch. It seemed like it would end up just for 4 seconds. 2 seconds (on the printer), 2 seconds (on the computer). It is best to ask an engineer (to configure the device) if I buy a product.

P1: Oh? It's done. The network is communicating with the printer. (He reads information from the screen and opens the SSID window of the computer.)

P2: Is it that one?

P1: Yes. (He configures the wireless network connection; it shows 'connecting.') It seems like it isn't working again.

P1: In order to connect the printer and the notebook computer, both should have fixed IPs or both should have dynamic IPs. So, I am trying to



configure (both) as dynamic.

P2: It takes longer than I thought.

P1: (I would say) Just use it via the cable.

P2: I'll definitely use it plugged.

P1: Uh, isn't it right? (P1 checks the SSID from the computer window and compares it to the manual.)

P2: Connection failed! PC connection error.

P1: Start a new installation. It looked right. I did everything just like (the manual) ordered. Huh, why does it not work?

P2: Let me guess.

P1: I did as it ordered.

P2: I don't know what ad-hoc is, so let's find another way. (He reads the manual.) Use the WPS button. Let's start from here.

(P1 looks at the menu on the printer.)

P1: Why does it work like that? It is right, isn't it? The manual explained that the computer and the printer should be set up for dynamic IP, and then they should be shown on the program. I changed both to dynamic (IP) but here (program) it says the configuration is not properly done and to do it again.

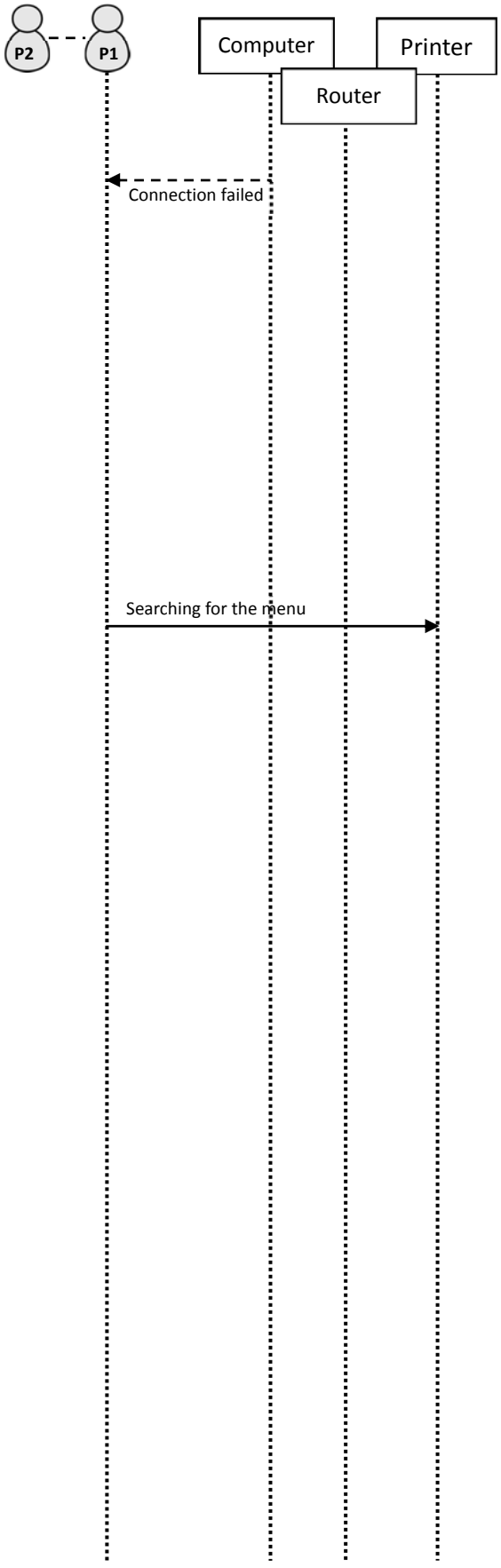
P2: Why don't we try WPS once more?

P1: Should we?

P2: If you want to do (what you are doing) more, go ahead.

P1: Here, it looks really easy. (He points to the written guidance on the printer's surface.) This (printer's LED) is done.

P2: That (printer) is connected to this (router), isn't it?



P1: Is it? It seems so. I did it right.

P2: Let's do WPS once again.

P1: OK.

P2: Do you want to try one more time?

P1: It doesn't seem to work. I did as it ordered. Uh, there is (a found printer).

P2: Let's pull this out. If we pull this out...Oh, it disappeared.

P1: It disappeared, yeah.

P2: Ah, the computer stopped

P1: It seems possible. Try it. (The printer's) Properties are not available. (He checks the printer's properties, as shown on the computer.)

… (P1 complains about the manual.)

P1: The printer, uh, its seems like it was probably connected.

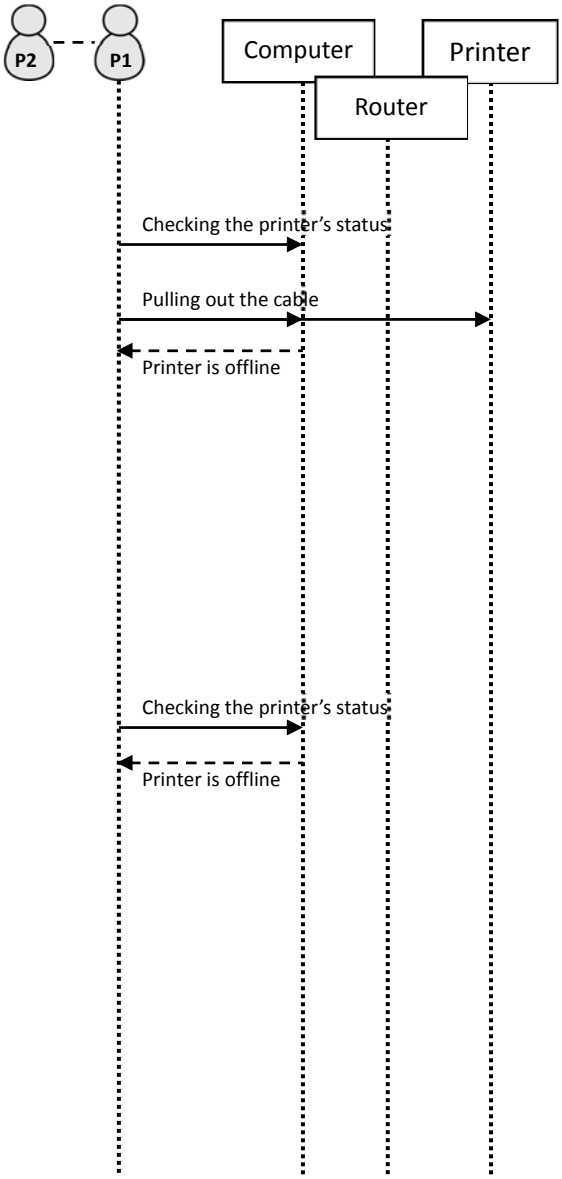
P2: Was it done before?

P1: It's offline. It isn't connected.

P2: Fail. Uh, it's so sad. We haven't been able to do it for an hour.

P1: The biggest problem is the manual. It's really unfriendly. When I tried to install the program, I did what it said but it made an error. I fixed the error and tried once more but it made an error too.

P2: The biggest problem is that I cannot infer what the problem is. I cannot find any clues.



Appendix B: Analysis codes of observations (from Chapter 6)

Connections of audio devices to MP3 player

Summary of participants

Participant (gender)	First task	Second task	Other features
P1 (F)	Connection of a set of earphones	Connection of speaker	
P2 (F)	Connection of speaker	Connection of a set of earphones	The devices were reconnected during the earphones connection, but she ignored the reconnection and performed the connection during the general connection procedure (of initially connecting the devices).
P3 (F)	Connection of a set of earphones	Connection of speaker	The devices were reconnected during the earphones connection, but she ignored the reconnection and performed the connection during the general connection procedure.
P4 (F)	Connection of speaker	Connection of a set of earphones	She connected the speaker via the reconnection procedure and connected the earphones during the general procedure.
P5 (M)	Connection of a set of earphones	Connection of speaker	

User interaction codes for connecting an MP3 player and a set of earphones

User actions were described in time order.

	Connection step	Quote	Problem with performing action
P1	Device preparation	(She looks for a way to set up the earphones' inquire-page) It (the status for inquire-page) seems like it is blue (light). Doesn't it?	Evaluation (interpretation): She could not determine which status was for Bluetooth connection (inquire-page mode).
		I pushed the blue one (on the earphones), but nothing is loaded here (on the MP3 player). Then, the blue button (of earphones) seems not for Bluetooth.	Evaluation: She tried to evaluate the earphones' status through information gained from the MP3 player.

	Device preparation - search	Why can't it (the MP3 player) search for them (earphones)?	Evaluation: She could not evaluate the interaction between the two devices and had difficulty determining what caused the problem.
	Device preparation	What is the button for Bluetooth?	Execution: She searched for a way to prepare the earphones.
		Here (earphones) should be some signals that Bluetooth is available. It seems like blue or red (light), but (I don't know).	Evaluation: She looked for feedback about the earphones' Bluetooth status, but the feedback from the earphones was not properly interpreted.
	Search	This (magnifier icon) and this (blue circle at the center) seem like the same function.	Execution: The graphic icons' functions were not clearly recognized.
	Connection	Is it finished (connected) after finding?	Evaluation (interpretation): The connection was not established yet, but according to the graphical interface she confused the devices' interaction status.
		(She moves to the screen for music play and plays a song.) Uh? Sound is not coming out. What is this? Is the volume too low? (She increases the volume but no sound is heard.) Isn't this? It's stifled.	Evaluation: The connection was not established yet, but she evaluated that a connection was established and searched for the cause from other problems.
		Was this disconnected when I got out of the Bluetooth screen? Or, was this not connected originally? Ah, so complicated	Evaluation: She could not evaluate the devices' status and was confused about the interaction.
		Is there a separate thing to do for a connection?	Execution (sequence): She suspected the interaction sequence and searched an execution method after she spent much time to recognize he needs to perform an action for making devices to connect.
	Others	By the way, what is the red (signal)?	Evaluation (interpretation): She could not interpret the signals of the earphones until the end of task.
P2	Reconnection	I don't know what 'pairing,' is so I would select 'No'.	Evaluation (interpretation): She could not interpret a sudden message, so she didn't know the message is associate the intended connection.
	Preparation-search	It (earphones) is not searched, so I would turn it off and on.	Evaluation (result): She could not evaluate why the device was not searched and repeated the action.
	Connection (during reconnection)	Is it ('pairing') mean pair? By the way, this (speaker) is turned on and here is only one (icon). It seems to pair with this (speaker), so I should not select it. I would search again.	Evaluation (interpretation): The icon on the screen represented earphones, but she could not interpret it.
	Device preparation	If there is a blue light (on earphones), that means it's turned on (status for Bluetooth),	Evaluation (interpretation): She could not interpret the earphone signal. Blue state was not for Bluetooth inquire page.

		isn't it?	
	Search	(She moves MP3 player's position.) If I move the position, it may search (earphones).	Evaluation (result): She could not evaluate the interaction status and problem cause. As result, she suspected other problems.
P3	Connection	(She touches blue icon at the center of the MP3 player. When the blue icon shows wave, she moves to play a song.) Uh? If (sound is) not coming, is it (connection) not accomplished?	Evaluation: She evaluated that the devices were connected from the graphic feedback.
	Reconnection	What is 'pairing?'	Evaluation (interpretation): She could not interpret a sudden message, so she didn't know the message was associated the intended connection.
	Device preparation	Is there a difference between pushing (the earphone button) long and short?	Execution: She could not recognize the correct execution method.
	Connection	(An icon is loaded on the MP3 player.) Uh? Is it done? (She moves to play a song.) I don't know what (state) it is. It seems they (devices) are connected, but (they do) not function. (Moderator informs her the connection is not established.) Was not accomplished?	Evaluation: She evaluated the devices were connected from the graphic feedback.
		Uh? What is the problem?	Evaluation: She could not evaluate the connection status.
	Device preparation	Why this (earphones) becomes blue again?	Evaluation: She could not evaluate why the status changed, but she could perceive the change of status.
P4	Reconnection	(When a message asking pairing is loaded, she closes the message window.)	Evaluation: She didn't think the message was associated with the intended connection.
	Connection	(I don't know) The connection failure means either these failed (earphones) or this failed (speaker).	Evaluation: She was confused about which device was related to the message.
	Connection	(She touches the blue icon at the center of the MP3 player. When the blue icon shows waves, she checks sound from earphones out.) No sound is coming out. Should sound come out? It is being played, but (sound is) not coming out.	Evaluation: She evaluated the status from the graphic interface that devices were connected, but they were not.
	Connection	It seems like it's not connected. If they are connected, then there should be some feedback. Are they not connected?	Evaluation: She had difficulty in evaluating the devices' interaction status. She looked for feedback to evaluate the interaction status, but she could

			not gain it.
	Device preparation	Is this turned on?	Evaluation: She had difficulty evaluating the device preparation.
P5	Device preparation	(He turns on the earphones.) Is this Bluetooth turned on? Now, I go to listen to a song. Is this song playing? (But sound is not heard.)	Evaluation (interpretation): He had difficulty evaluating the earphones' preparation.
		It seems that the Bluetooth is not connected because the song is not playing (from the earphones).	Evaluation: He tried to determine the device interaction status by checking whether sound was coming out.
		I push the button longer (on the earphones). Two lights (are blinking). A song is being played (on the MP3 player), but I hear no sound. The (earphones') blue light is turned on, but sound is not coming out again.	Evaluation (interpretation): In order to determine the device status, he tested how the device's changing status changes the device's action.
		I guessed that there was a problem with the volume, so I raised the volume to check, but it still doesn't work.	Evaluation (result): He could not evaluate the status, and he suspected other problems.
		I will try again in this state. I figured that the red is the off state, as I expected. I pressed the button (on the earphone) for longer. Heck!	Evaluation (interpretation): In order to determine the device status, he tested how the device's different statuses change the devices' action.
		It is definitely playing music but it (the sound) doesn't function, so let me try again. I am looking around for other controls. Can sound be heard when something comes close (to the MP3 player)? Weird. Were the manipulation methods wrong? I am starting to doubt whether the MP3 player has a problem (with operating).	Evaluation (result): He could not evaluate the status, and he suspected other problems.
		Let me analyze this. If I press it (the button on the earphones) once, the right light goes on. It is still not connected. In this state, it is now blinking. Let me press it once more. Again, it is blinking. Ah, but there is no sound.	Evaluation (interpretation): In order to determine the device status, he tested how the device's different statuses change the devices' action.
	Search	Now. (He touches a magnifier icon on the MP3 player, and the graphic image moves.) Oh, is this it? I am happy, but why can't I hear the sound?	Execution: He found the way to execute a search. Evaluation: He evaluated the connection was made.
	Device preparation	Well, it seems the device has searched for 001b42. But still,	Evaluation (interpretation): In order to determine the device status, he

		sound is not coming out. Then, let me check whether it (an icon on the MP3 player's screen) disappears if I turn these (earphones) off. Search again! Ah. (The icon is not shown.) I found it is a status: (The earphone is) turned on. Then, I will check what happens if I press (the button on the earphones) once. Now, only the blue light is on. (The icon is not shown on the MP3 player.) Now, the blue light status is not for Bluetooth. The blinking status is for Bluetooth.	tested how the device's different statuses change the devices' action.
	Other	Options, Headset, may be not File transfer. (He goes through options of the MP3 player) Device information—I think (I should look around) the device information.	Execution: He had difficulty understanding the interface.
	Connection	Well, it was found, but why is it not functioning?	Evaluation: He could not evaluate why the connection was not made.
		Bluetooth is functioning. It had been done. If I go back, will the Bluetooth work?	Evaluation: He could not be sure of the device's status.
		It says there is a Bluetooth (device), but (it is) not connected. A song is still playing, but (I cannot hear it).	Evaluation: He could not evaluate why the connection was not made.
		Now that it is detected, it seems that there is a way to connect them, but I don't know how to do it.	Execution: He searched for a correct execution method.
		I will try everything (every action).	Execution: He tested each menu to know a correct execution method.

Codes of user interaction on connecting MP3 player and speaker

	Connection step	Quote	Problem with performing action
P1	Device preparation	I don't even know how to turn it on.	Execution
	Other	Are these (earphones and MP3 player) connected now?	Evaluation: She could not evaluate the status of the involved MP3 player, whether it maintained a connection with another device.
	Device preparation	This (speaker) should have something to turn it on (Bluetooth). It seems to have nothing.	Execution: She expected that the speaker could require a sequence of actions to prepare it.
	Device preparation	(She searches for a device from the MP3 player. A speaker icon loads.) Oh, this (speaker) turned on automatically.	Evaluation: She determined the status of the speaker from the reaction of the MP3 player.
P2	Connection	How to connect? Should I just click it?	Execution: She could not recognize how to execute an action to trigger a connection.
P3	search	Why isn't it working?	Evaluation: She could not evaluate the cause of the problem.
	Other	I don't know what this means. Stereo headset, file transfer. Isn't that it (the one I am looking for)?	Execution: She could not find an execution method.
	Connection	(She tries to drag an icon on to the central icon (MP3 player).) Why isn't it working? (Moderator informs her that the icon is the wrong device.) Oh, Is this (icon) that (earphones) one? What should I do?	Evaluation: She had difficulty in recognizing the device representation. She tried to connect the wrong device (earphones instead of speaker).
P4	preparation	How can I turn this (speaker) on? Is this have something (required to operate) to connect? (She looks at the speaker.)	Execution: The interface is not easily understood.
	Search	(The MP3 player loads a new icon.) Now it is found! (She waits for a while.) It found it, but why isn't there any sound coming out?	Evaluation: She thought the connection had been accomplished but it hadn't.
	Connection	(Does the problem occur) because this (earphones) is identified? (She pushes the earphone far.) I thought the two devices (earphones and speaker) were confused (so the speaker could not function).	Evaluation: She could not evaluate that the connection was not made and suspected other problems.
		(She checks the interface	Execution:

		elements and tries different ways like dragging or tapping other things on the MP3 player for a while.) I don't know (why they are not functioning).	She could not find the correct execution method.
P5	He accomplishes the connection very easily.		

Connection of printer and computer

Summary of participants

Team (gender of participants)	Feature of interaction
T1 (Two male participants)	They accomplished wireless connection of devices by connecting them with a physical USB cable. One of the participants has engineering experience.
T2 (Two female participants)	They could not accomplish the task.
T3 (Two male participants)	They could not accomplish the task.

Codes of user interaction

Participant	**Connection step**	**Quote**	**Problem on performing action**
T1	Preparation: Connecting the printer to network through WPS buttons	P2: Push two seconds on the router! P1: Is there any change on the printer? Do I (my hand from the router)? (They look at the printer together.) P1: I don't understand what it means. The wireless connection (light) is blinking. Did you check this (how it appeared) before? P2: No, I didn't. (P1 turns off the printer and turns it back on to check the original LED status.)	Evaluation (interpretation): They actively interpreted the device signal responding to their action, but signal was not clearly interpreted. It was not even clear whether it was meaningful.
		P1: What is that (message of printer to wait two minutes)? Did you check this before?	Evaluation (interpretation): Printer's message was not clearly evaluated.
		P1: Let me check the (printer's) wireless connection status. By the way, its (LED) color is yellow. It looks strange.	Evaluation (interpretation): The printer's signal is not clearly interpreted.
		(P1 changes printer's network configuration.) P1: It's done. Push WPS. (He pushes the WPS button on the printer)	Evaluation: The quotes show how the participants evaluated the printer's

		P2: It's blinking (P1 pushes WPS button on the router.) P2: It's done. (Moderator asks how he knows it.) P1: It said "connecting." P2: It didn't say "connecting" before. It is done.	status.
	Search: After the printer is connected to a network	P1: If this (printer) is connected, that means it is connected to the router. P2: What IP is the router assigned (to printer)? Ha-ha. P2: Can we check it from the router?	Evaluation: The participants tried to evaluate the device's interaction status.
		(They see a message that "No printer is found" on the computer.) P2: What is this? Uh? The Internet is disconnected! P1: What should we do? (Should I) Push the reset button (on the router)? P2: I think restarting from the beginning would be better than pushing the reset button. (P1 turns the router off and configures all devices again.)	Evaluation: The participants could not evaluate what caused the problem and repeated the sequence
		(When P1 searches for the printer from a computer, he finds a fail message.) P1: Ah, What can I do?	Execution (intention): The participants could not determine next sequence
		(P1 reboots the router and re-configures the computer.) P1: Its (printer's) wireless connection (signal) is lighted. Should I disconnect the connection (of printer)? P2: Let's do not touch it.	Evaluation: The participants evaluate device connection status from device signals.
	Configuring a connection with a USB cable	(They read a connection using a USB cable from manual and tried it.) P2: Uh? It is loaded. It may be the first order (of sequence). We may have to do this first.	Execution (sequence): They tried to infer the proper sequence of action.
		(Installation program guides to connect a computer to wireless network.) P1: We are not connecting to a wireless network. P2: Uh? It is connected, isn't it?	Execution: They tried to compare their sequence to the guidance of the installation program.
		P2: We do not need to do this (access a network), do we? It's already connected. Isn't it? P1: It seems to be connected, (and) these (the computer and the printer) are connected through the USB. P2: It is asking to connect through a (wireless) network. Is this (the printer) sending a signal?	Evaluation: They could not evaluate the devices' interaction and depended on their guess.

		P1: Maybe it is, but what is it (the name of the signal)? Terrible. P2: Um, It is lighted (on the printer).	
T2	Preparation: Connecting the printer to the network through WPS buttons	P2: Should we try this? Should we push this? P1: WPS? P2: I don't know what it means. P1: I would try WPS. (She pushes printer's WPS.) It (wireless connection signal of printer) looks like it's blinking, doesn't it? … P1: If this is blinking, does that mean the wireless printer isn't ready? Should I push this first?	Evaluation (Interpretation): Participants could not interpret the terminology and the blinking signal. Execution (sequence): They tried to infer the sequence of action.
	Configuring a connection with a USB cable. (search)	(They watch a fail message from the computer screen.) P1: Um, What should I do? Was the connection wrong? P2: Cancel it, and go back.	Evaluation (result): They could not evaluate whether the connection was right or wrong, so they could not determine what to do.
		P1: Is there a specific one (I should choose)? Or should I just do an advanced configuration?	Execution: The participants had difficulty recognizing the correct execution method.
		P1: Is it not connected? P2: Let's do it again. (P1 carries out installation procedure again.) P2: Wireless network? P1: It seems to say select SSID, but what should I select?	Execution: The participants had difficulty recognizing the correct execution method.
		(They watch a fail message from computer.) P1: Uh, Why is it this? Should I retry? P2: Let's do it again.	Evaluation (result): The participants could not evaluate the situation and the cause of the problem and repeated the sequence.
		(P1 configures the wireless network connection of the notebook computer.) P1: (From the printer installation program running on the notebook computer) Can I select 'next?' Did I do something wrong? P1: It says 'unidentified network.' P2: Not connectable. P1: We followed the manual exactly, didn't we? I thought there were no problems. … P2: Why don't we go back to the original status and try again? P1: How do we go back?	Evaluation: The participants tried to perform sequence as manual guided, but they had difficulty in evaluating whether their action and device situation were the same as in the manual.
		P1: I don't know what it means (from the manual). P2: It says to match with the computer's	Execution: They could not recognize the correct execution

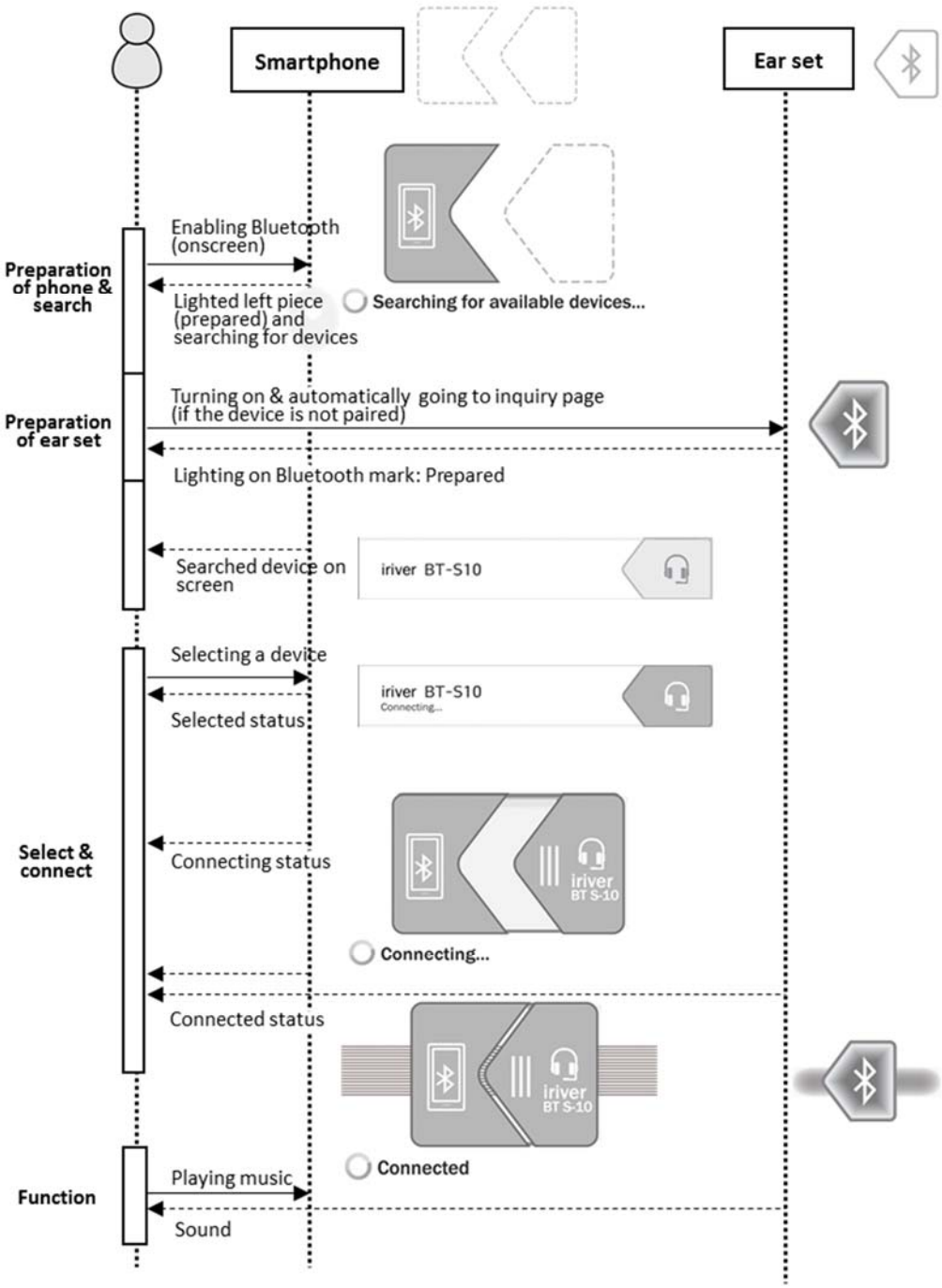
		network. It says the PC's network should match the printer's network configuration in order to connect them. (I don't know) what configuration it says.	method.
		P2: It (printer) is blinking and says that the copier is available, printer seems be ready (to be connected.)	Evaluation (interpretation): The participant evaluated the device's connection status based on the device signal.
		P1: 'Change' means select a different network from the original one. I did it before and it didn't work. How (should I do that?) Should I change everything? P2: Change it. P1: It says to choose this ('portthru'). I don't think so.	Execution: Participants tried to perform the correct execution as manual guided, but had difficulty recognizing proper execution.
		P1: It failed again. That's annoying. Did I turn it on? Next (on the install program)? I did this (before)!	Execution (sequence): The participants tried to perform the sequence as the manual guided.
		P1: I want to have help (guidance), like "If you see this, you should do this." I want to get help to diagnose the situation.	Execution, Diagnoses: Thoughtful evaluation and execution guidance are desired.
		P1: I did this before…. P2: It seems we tried all of these. P1: Is this related, like an unsecured network?	Execution (sequence): The participants tried to perform the sequence as manual guided.
	Connecting the printer to a network through WPS	P1: Pushing (the button) on the router for two seconds, that is step 2. Does it (router) have a button? I should push it after I push the WPS there (on the printer). P1: Step 1 is this, and step 2 is pushing this (the router's WPS) P1: we didn't do this before.	Execution (sequence): The participants tried to perform the sequence as the manual guided.
T3	Connecting the printer to a network through WPS	P1: "Tara, Tara"; Oh, it is turned on. P2: Is it turned on? P1: (He reads the display panel of the printer.) "Preparing. Please wait," it says. One-touch networking! (He reads the text on the printer.) "Press the WPS button for two seconds, and press the WPS button on the router for two seconds." P2: Press this for two seconds. (P1 presses the WPS button on the printer.) P1: One, two. Where is the router? P2: Uh, we don't have one. (He moves to get a router and turns it on.)	Execution: The participants followed the manual without evaluating the status or considering requirements.
		P2: Ah, a connection. It (the printer LED) is blinking. Good! P1: I am smart!	Evaluation (interpretation): They interpreted the

		P2: Let's find the file to print from the notebook. P1: Should we print the file to finish the task? P2: Uh. It is still connecting.	signal that the printer was connected, but the printer was not connected.
		P2: Is there anything (additional guidance on the configuration sequence) above (the printer's WPS instructions that are covered by a notebook computer)? Hold the laptop. Nothing there?	Execution (sequence): They looked for complete information about the sequence.
		P1: It says to press the WPS button, and I pressed it. P2: Remaining time. The remaining time is shown. Do we have to wait? Press WPS for two seconds of time. Did you press it? P1: Uh. P2: "Connecting". P1: It showed "Connecting" in earlier, but it didn't work. P2: Fail. Did it show "Fail" earlier?	Evaluation: They compared their actions and the device's status to their earlier actions.
		P1: Let's do as it (manual) says. Press the Menu button (on the printer). It doesn't have one! P2: Network? Is it lying? P1: Yes. It does.	Execution: The participants had difficulty finding the correct menu.
		P2: We should connect this (printer) with the notebook (with a cable), shouldn't we? It seems not. The notebook identifies the network that the printer is sending. P1: If the laptop sends the signal, this (router) will receive it and should send the signal to this (printer) again.	Execution (sequence and mental model of connection): They tried to determine the required interaction.
		(Printer gives sound feedback, "Tara, Tara.") P1 & P2: "Tara"! P1: (On the computer) ipTime. (He configures the computer's wireless network connection. He searches for the printer from the computer.) P2: Wireless, show Samsung. (The printer is not found.)	Evaluation: From the printer's feedback, the participants thought that printer was prepared and could be searched from the computer.
		P1: Is this connected to another? It (the printer) has not been identified.	Evaluation: When the printer is not searched, participants could not evaluate printer's status.
	Connection with USB	P1: Let's do this. Check whether the USB cable connects to the product. (He connects the printer and computer with a USB cable.) I turned the computer and the printer on. Now, the software is here, then I click 'set up.'	Execution (sequence): The participants tried to check the sequence carefully.
		P1: Uh, isn't it right? (P1 checks the SSID	Evaluation:

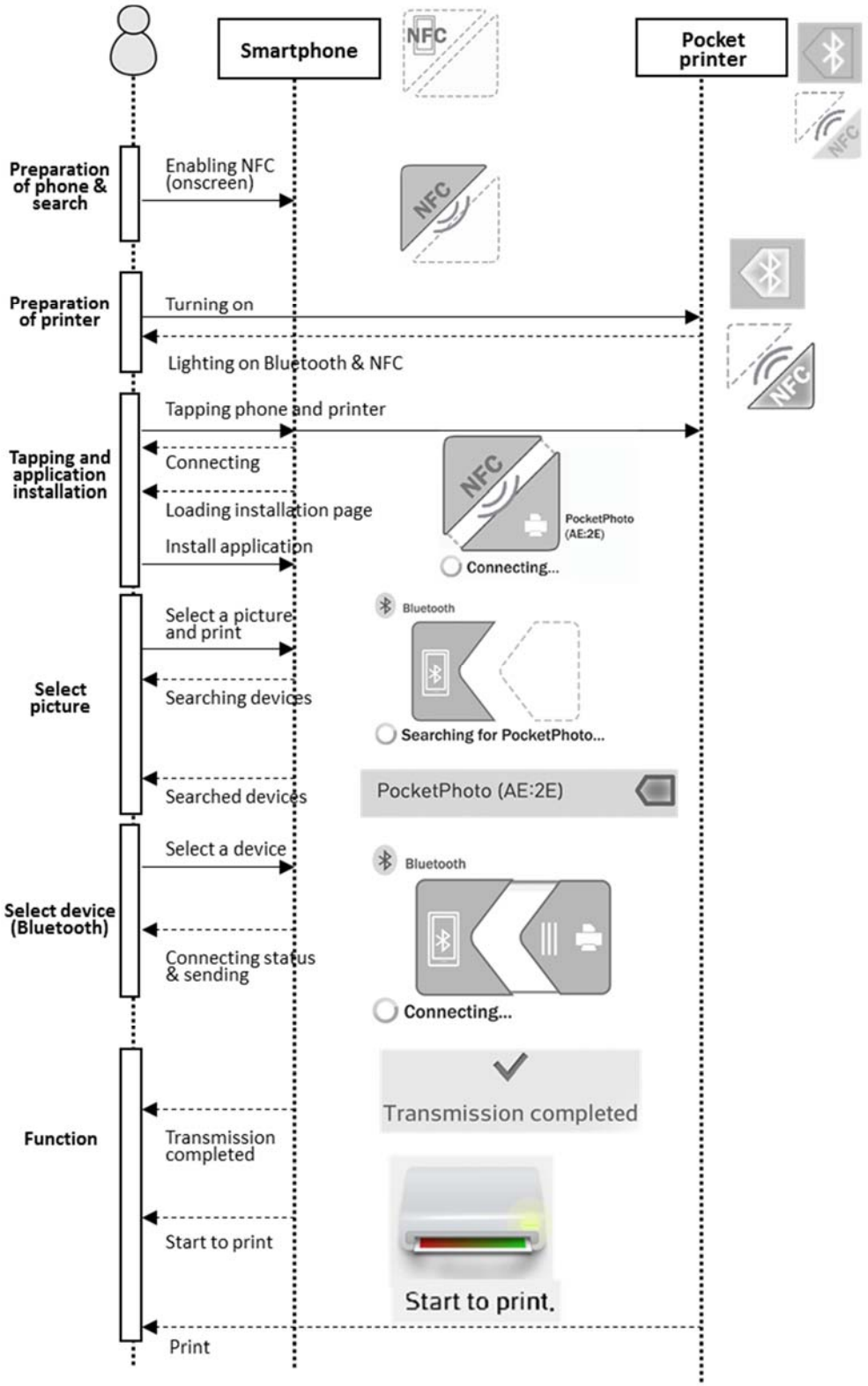
		from the computer window and compares it to the manual.) P2: Connection failed! PC connection error. P1: Start a new installation. It looked right. I did everything just like (the manual) ordered.	The participants had difficulty evaluating the devices' interaction status and compared it to the manual's guidance.
		P1: Huh, why does it not work? P2: Let me guess. P1: I did as it ordered.	Evaluation: The participants could not evaluate the cause of the problem.
		P1: Why does it work like that? It is right, isn't it?	Evaluation: Participants could not evaluate the cause of the problem.
		P1: The manual explained that the computer and the printer should be set up for dynamic IP, and then they should be shown on the program. I changed both to dynamic (IP) but here (program) it says the configuration is not properly done and to do it again.	Evaluation: The participants could not evaluate the cause of the problem.
	Connecting the printer to the network through WPS	P1: This (printer's LED) is done. P2: That (printer) is connected to this (router), isn't it? P1: Is it? It seems so. I did it right.	Evaluation: The participants had difficulty evaluating the devices' interaction status and compared their interaction to the manual's guidance.
		P2: The biggest problem is that I cannot infer what the problem is. I cannot find any clues.	Evaluation: The participants could not evaluate the cause of the problem.

Appendix C: Interaction sequences of revised interfaces (from Chapter 7)

Connection between a smartphone and an ear set



Connection between a smartphone and a pocket printer



Connection between a printer and iPad connection