Routinoscope: *Collaborative Routine Reflection for Routine-Driven Do-It-Yourself Smart Homes*

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Routines have previously been revealed to be an important design factor in smart homes. However, little research has investigated the utilization of routines in do-it-yourself (DIY) smart home system design. Using routines as a resource for DIY smart homes, this paper suggests the new concept of the smart home system Routinoscope: a routine-driven DIY smart home. Routinoscope is designed to embody collaborative routine reflection among family members. To determine the value of Routinoscope, an in-the-wild study was conducted with 6 households for 3 weeks. The results show that unlike the previous DIY smart home systems, Routinoscope shows different types of user experiences. Routinoscope enabled sensitivity to daily problems and better mediation between routines and smart home features. It also allowed family members to share their conflicts and help each other reduce such conflicts. Based on the findings, 2 design implications for future DIY smart homes are suggested: providing a problem-finding method and considering routine changes over time to maintain the DIY smart home.

Keywords – Design, User Experience, Smart Home, Internet of Things (IoT), Routine, End-User Development.

Relevance to Design Practice – This study suggests a routine-driven DIY smart home product concept designed to embody collaborative routine reflection. Through an in-the-wild user study, we identify design implications to improve the user experience of a DIY smart home product in a domestic environment.

Introduction

With the advent of the Internet of Things (IoT), people can now easily transform their homes into smart homes as small do-it-yourself (DIY) projects. The DIY smart home can be made with products such as Ninja Blocks (see https://www.kickstarter.com/profile/ninja/created), Twine (see http://supermechanical.com/twine/), and SmartThings (see https://www.smartthings.com/). DIY smart home products provide various sensors and actuators along with a rule-based programming environment such as IFTTT services (see https://ifttt.com/).

Because a DIY smart home allows people to select their preferred level of automation and gives them full control of the smart home, these products were expected to solve the problems of previous home automation efforts, such as a lack of user control (Bernheim Brush et al., 2011), the ability to adjust the automation level to satisfy user needs (Mennicken & Huang, 2012), support for a family's chosen lifestyle (Woodruff, Augustin, & Foucault, 2007), and closing the gap between users and smart home developers (Hwang, Liu, Hoey, & Mihailidis, 2013). However, a DIY smart home provides an entirely different user experience than a professionally installed home automation system. With a DIY system, a user must consider what to install, where to install it, what features to create, and how to set up a control program. To determine how users address these questions, previous observational user studies have been conducted to understand user experience of DIY smart homes (Woo & Lim, 2015). In these studies, the participants created smart home rules to support their routines and to remind them of mundane activities. They revised these rules iteratively until the rules perfectly fitted the family routine, and they discovered problems with the rules through self-reflection on their routines to improve their daily activities. From these previous studies, we discovered that users tend to use their routines as resources to generate ideas for their DIY smart home features.

In smart home research, routines have previously been revealed to be an important design factor in smart homes (Davidoff, Lee, Yiu, Zimmerman, & Dey, 2006; Mennicken & Huang 2012; Tolmie, Pycock, Diggins, MacLean, & Karsenty, 2002). Routines play a critical role in DIY smart home user experiences because homes and routines continuously interact with each other when users implement their customized smart home ideas. Since routines enable people to complete their activities of daily living without attending to the details of any moment's activities, people do not pay much attention to the accustomed problems in their routines. This trend makes it difficult for people to identify the problems in their routines. Enabling people to reflect on their routines to discover problems will be a starting point for improving their daily routine using a DIY smart home product (Woo & Lim, 2015). However, little research has investigated the

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utilization of routines in DIY smart home system design, leading to questions such as "How should DIY smart homes be built based on family routines?" and "How can routine-based DIY smart homes provide different user experiences than previous DIY smart home designs?" To answer these questions, we proposed and developed a new DIY system called Routinoscope, which is a routine-driven DIY smart home system.

Routinoscope embodies *collaborative routine reflection among family members. The detail*s of its concept and design will be explained in a later section. A 3-week explorative in situ user study with Routinoscope was conducted. From this study, we discovered that collaborative routine reflection made a difference in the DIY smart home experience. We then proposed design implications for the development of future routine-driven DIY smart homes. Our contributions are 1) a routine-driven DIY smart home concept that applies collaborative routine reflection to the DIY smart home system, 2) the design and development of Routinoscope, and 3) the discovery of how a routine-driven DIY smart home changes the user experience through the in-the-wild study of Routinoscope.

Background

Definitions of Routine

Previous research defines routine as a *pattern of behavior that is repeatedly followed but is subject to change if conditions change* (Winter, 1994), *patterns of interaction* (Cohen & Bacdayan, 1994), and effortful accomplishments (Pentland & Rueter, 1994). A routine contains tacit knowledge (Cohen & Bacdayan, 1994) that is context-dependent, specific, and transferable only to a limited extent (Becker, 2001) because a successful routine always considers the specific context. Since daily activities consist of routine activities, a routine is an important design factor in domestic technology research (Davidoff et al., 2006; Lee, Davidoff, Zimmerman, & Dey, 2006; Tolmie et al., 2002). In this paper, we use the term *routines* to mean groups of activities that are connected sequentially and repeated regularly. Routines help people complete their daily activities without having to pay attention to every detail of activity and instead allow them to focus on the activities that are more important to them. The

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development of routines reduces stress, enhances confidence, and provides people with greater control of their lives (Eagle & Pentland, 2006).

Routines in Smart Home Research

Since routines are a central feature of domestic life and are considered an important design factor in domestic technologies, previous studies have identified characteristics of routines in the smart home environment. Edwards and Grinter (2001) argued that designers who develop new technology need detailed observational information about how new technology changes peoples' routines. Tolmie et al. (2002) introduced characteristics of routines that can be applied in a ubiquitous computing environment. For instance, *describing routines* and actually *doing routines* are different: *describing routines* is significant and remarkable and can be memorable, whereas actually *doing routines* is usually mundane and insignificant. In an ethnographic study of dual-income families, Davidoff et al. (2006) have suggested seven principles for smart home control, such as allowing for the organic evolution of routines and plans and making it easy to construct new behaviors or modify existing behaviors. These principles focused on the importance of preparing for non-repeating routines, routine breakdowns, and routine changes. Davidoff et al. argued that smart home research should focus on how people can manage their lives through domestic technology rather than how easily they can control their smart devices because the goal when using smart devices is to organize one's life, not home technology.

DIY Smart Home Research and Routine

Traditional smart home research has focused on the home automation system. Home automation systems are commonly built by professionals, but the homes made by professionals have limitations and insufficient flexibility to address changing user requirements such as changes in the members of the household. People must constantly change the home automation settings after the professional installation (Bernheim Brush et al., 2011). To address this inflexibility, a new type of smart home system, the so-called DIY smart home system, has emerged. DIY smart home products such as Ninja Blocks, Twine, and SmartThings, enable users to transform their homes into smart homes as a small DIY project. DIY smart home products can be a solution to customize the smart home features to fit the changing needs of users. The DIY smart home product enables the user to proactively solve his or her complex problems and fulfill his or her needs by using ubiquitous technologies (Rogers, 2006). A DIY smart home product is a possible alternative to traditional home automation systems. Users can control what they want by using a DIY smart home product, and it is a possible direction to close the gap between smart home systems and users (Hwang et al., 2013) and interweave the routine of the entire family with the smart home (Mennicken, Vermeulen, & Huang, 2014).

However, our previous study found that current DIY smart home products also have problems guiding users to fit their detail routines with the smart home features. In a previous three-week

observational study of a DIY smart home product usage with eight families, the usage cycle of the DIY smart homes revealed six stages (initial installation, motivation, implementation, use through routine, routinization, and removal) and suggested seven design implications for future DIY smart homes (Woo & Lim, 2015). From these observations, we found some relationships between DIY smart home usage and family routines. Because the participants did not remember the details of every daily activity, they identified these problems through self-reflection on their routines. Based on such self-reflection, the participants could create smart home rules to support their routines. From these observations, we concluded that enabling people to reflect on their routines to discover problems will be a starting point to improve their daily routine using DIY smart home products. These findings inspired us to ask, "What is the way to build DIY smart homes based on family routines?" and "How will routine-based DIY smart homes give a different user experience than previous DIY smart homes?" To answer these questions, we proposed and developed a new routine-driven DIY smart home system called Routinoscope. The results of this research will add a new understanding of the user experience of DIY smart homes when they are designed to integrate family routines, and we will provide design implications for using routines as resources for DIY smart home technologies.

Routinoscope: *A Routine-Driven DIY Smart Home System*

Routinoscope is a new DIY smart home system that is based on family routines. The name is a combination of *routine* and *scope*, as the system observes a family's routine. Through this system, users can understand more about their routines and make smart home features to fit the routines. To build Routinoscope, we propose a design concept called collaborative routine reflection.

Collaborative routine reflection is collaborative reflection on routines among family members. Collaborative routine reflection has three factors: collaboration, routine, and reflection. Reflection is the activity that brings the unconscious aspect of the experience to the consciousness (Sengers Boehner, David, & Kaye, 2005). Reflection helps those blinded by unconscious assumptions such as attitude, practice, and values to find new possibilities for conscious choices. Routine reflection is a way of critically thinking about predefined routines and understanding unconscious activities to find new possibilities for creating smart home features to fit the routines. When routine reflection becomes collaborative among family members, it helps them understand all activities in the home. Since it is difficult to understand the whole family routine from the perspective of one member, collaboration is needed. Additionally, collaborative routine reflection will provide an understanding of various values in the family's routines, help adjust conflicts between family members, and help increase variability (Shirouzu, Miyake, & Masukawa, 2002) in creating smart home features.

The need for routine reflection is inspired by the reflection on routines that has previously been mentioned in DIY smart home research (Mennicken & Huang, 2012; Mennicken et al.,

2014; Woo & Lim, 2015). Reflection on routines is important in making DIY smart home rules (Woo & Lim, 2015), as smart homes should fit users' routines and avoid unnecessary work (Mennicken & Huang, 2012), and smart home designers should care about the social values and high-level goals of the inhabitants (Mennicken et al., 2014). Users do not always know about their routines since people become used to routines and do not consider them during their daily activities (Eagle & Pentland, 2006).

One of the family cases in a previous DIY smart home research (Woo & Lim, 2015) is a good example of routine reflection. The mother from this family case made an ad hoc smart home feature when she came up with a new idea without much reflection on the family routine, but these ad hoc features were not working as she planned, and the smart home features conflicted with one another. To solve this problem, she attempted to manage the overall features with her family living patterns. She reviewed the overall family routine, such as the times when the family members departed and returned to the home, their expected behaviors, and the activities that the DIY smart home products could support. After this review, she began to make rules for her family. This reflection on the family's routines helped her manage the current smart home features and find opportunities to create new smart home features. She found similar activities that must indicate the time. She made a series of smart home features that indicate the time to change the kitchen, when the first child should go to school, when the second child should go to kindergarten, and finally when everyone must leave home. Based on this type of an example, we can expect that by providing a guide to remind family members of their routine and a clear vision of how to improve it by the smart home feature, users can build more helpful smart home features and reduce the unnecessary iteration cycle in the DIY smart home product.

In the above family example, the mother performed the routine reflection alone. However, it can be helpful to involve other family members in routine reflection since more perspectives on routines can be identified. For a single person, routine reflection can be an easy process, but when people live with other family members, routine reflection is more complicated. Family members' routines overlap or are separate, and it is difficult to create an overview of all routines (Davidoff et al., 2006). To address the complexity, it is better to create a routine reflection activity with all family members together. We call this collaborative reflection on routines among family members the collaborative routine reflection.

Collaborative routine reflection is the collaborative process of family members to explicitly express the family routine. This process helps remind the user to objectively consider daily problems. Since multiple family members are involved, collaborative routine reflection helps remind them of the various aspects of family routines, including schedules, movement paths, activity areas, family values, and family problems. DIY smart home features can help to solve these problems but do not direct the problems. Including collaborative routine reflection in the DIY smart home product could be helpful in finding what problems should be solved in relation to routines.

For collaborative routine reflection, Routinoscope provides Family Note, which is a step-by-step guide for explicitly expressing family routines. Previous research has shown some examples of expressing routines through a calendar (Mennicken, Kim, & Huang, 2016), movement visualization (Crabtree & Rodden, 2004; Crabtree & Tolmie, 2016), and activities (Fahim, Fatima, Lee, & Lee, 2012). Based on previous studies, Family Note provides reflections on the temporal, spatial, and social aspects of routines. In addition, the routines are constantly changed and broken down (Davidoff, Zimmerman, & Dey, 2010). Understanding the current state of smart homes and routines is essential for further development (Desjardins & Wakkary, 2016). Therefore, providing regular sessions for collaborative routine reflection will help users maintain an understanding of the status of the smart home and the family's routines. To support regular collaborative routine reflection sessions, Routinoscope provides a guide that displays the current smart home features and a guide for weekly collaborative routine reflections to check the current living status. Additionally, Routinoscope hardware is designed as tea table-shaped hardware to enable all family members to sit together in the living room and naturally discuss family routines. To support the collaborative routine reflection described above, Routinoscope provides three

components: 1) Family Note for a step-by-step guide for reflection on routines, 2) a web client to cooperatively manage the smart home system, and 3) tea table-shaped hardware to support family discussion in the living room. The detailed implementation of Routinoscope is described in the next section.

Implementation of Routinoscope

Routinoscope (Figure 1) is composed of three parts: Family Note, a guide to reflection on routines; a web client; and a wooden table. Family Note provides a reflection session for family members to reflect on the temporal, spatial, and social aspects of their routines. Family Note also includes a guide for regular collaborative routine reflection sessions. The web client is the component that creates smart home features in Routinoscope. It provides an interface to create smart home features with If This Then That (IFTTT) style and displays current smart home features in the calendar view. Last, the wooden table is designed as a tea table that can be installed in the lounge. This wooden table is designed to enable all family members to sit together around Routinoscope to discuss family routines. The detailed design components of collaborative routine reflection in Routinoscope are described in Figure 2.

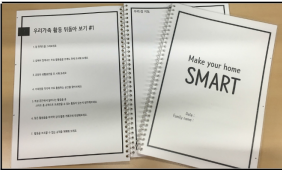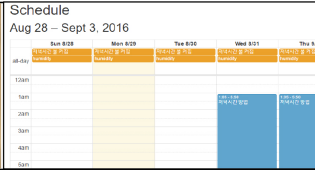**Figure 1. Routinoscope:** a routine-driven DIY smart home system.

	Routinoscope Family Note	Routinoscope Web Client	Routinoscope Hardware
Shared routine reflection	• Guide for reflection on routine floorplan and timetable. • Guide for reflection on routine for managing & extending smart home features	• Calendar-style trigger-action rules based on time properties	• Tea-table-type hardware shows current smart home status with touch interface

Figure 2. Design components of Routinoscope to apply collaborative routine reflection.

Family Note

Family Note (Figure 3) is the main design component embodying collaborative routine reflection in Routinoscope. Family Note is the guidebook for reflection on the routines of all family members to provide an understanding of family routines among the family members. Family Note is designed to guide the reflection on routines step by step, to help users recall unconscious routines and to guide them to think about their daily activities one step at a time. Family Note is provided in a paper book form in which members can freely draw and write.

Family Note has five parts. The first three parts help users recollect family activities to identify problems in the temporal, spatial, and social aspects of their routines. In these parts, the users are expected to reflect together on family routines and to understand and discuss social problems that may emerge during this reflection process. The fourth part helps in planning smart home feature creation for the activities identified in the previous parts. Last, when the DIY smart home features are implemented, Family Note helps users keep track of the status of the smart home features and suggests questions for rule extension depending on the current status of the smart home. Family Note provides furniture icon stickers to help users easily draw a floor plan. The first part of Family Note is shown in Figure 4. Following the question guide, users are reminded of their routines and to complete the Family Note to identify problems in their daily lives.
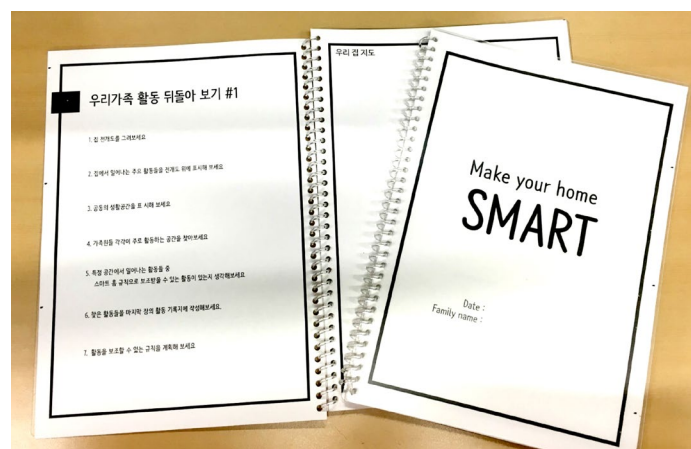
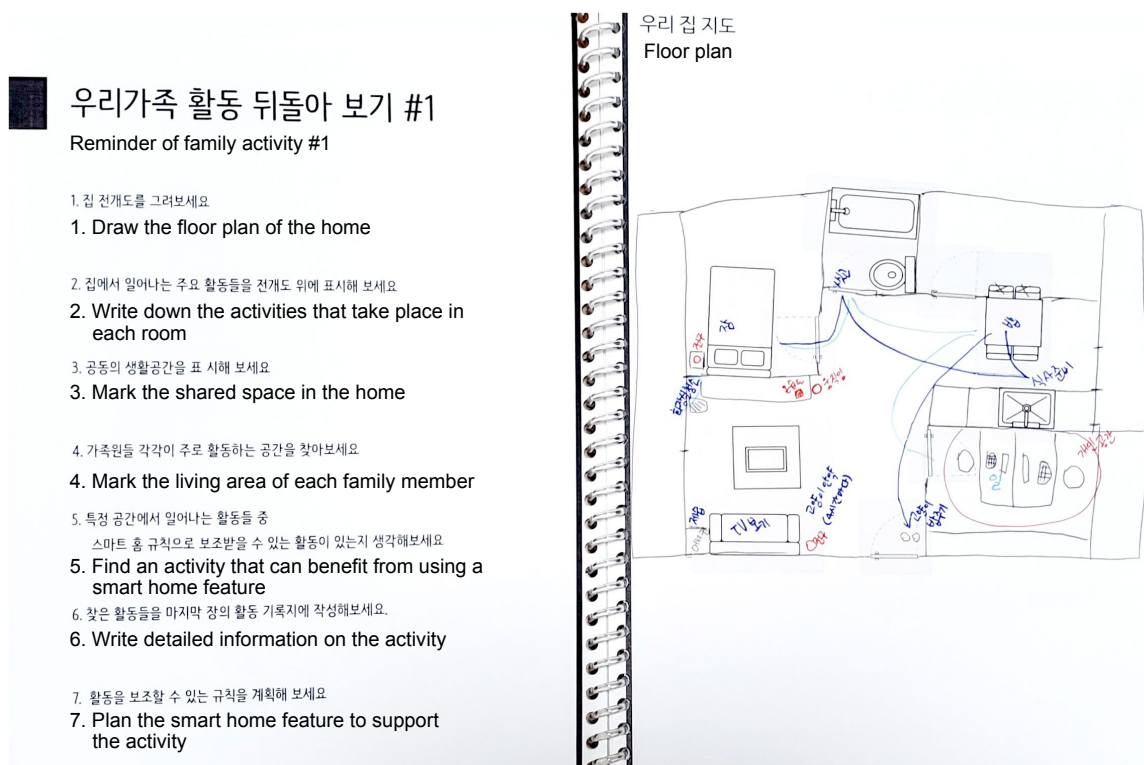

Figure 3. Family Note in Routinoscope.

Figure 4. Example of the first part of Family Note used for reflection on routine through a floor plan (Household 2 in the user study).

The second part of Family Note supports reflection on the temporal aspect of family activities. A timetable is provided, and family members fill out this timetable with their daily routines. Through this process, the family reflects on their activities, particularly those dependent on time. The guidelines on Family Note are shown in Figure 5.

The third part of Family Note involves the social aspect of family routines (Figure 6). A series of questions are provided to reflect on social order, promises, and household chores.

The fourth part of Family Note provides guidelines for writing the details of each activity and the smart home rules (Figure 7). The first page of the fourth part helps users recollect
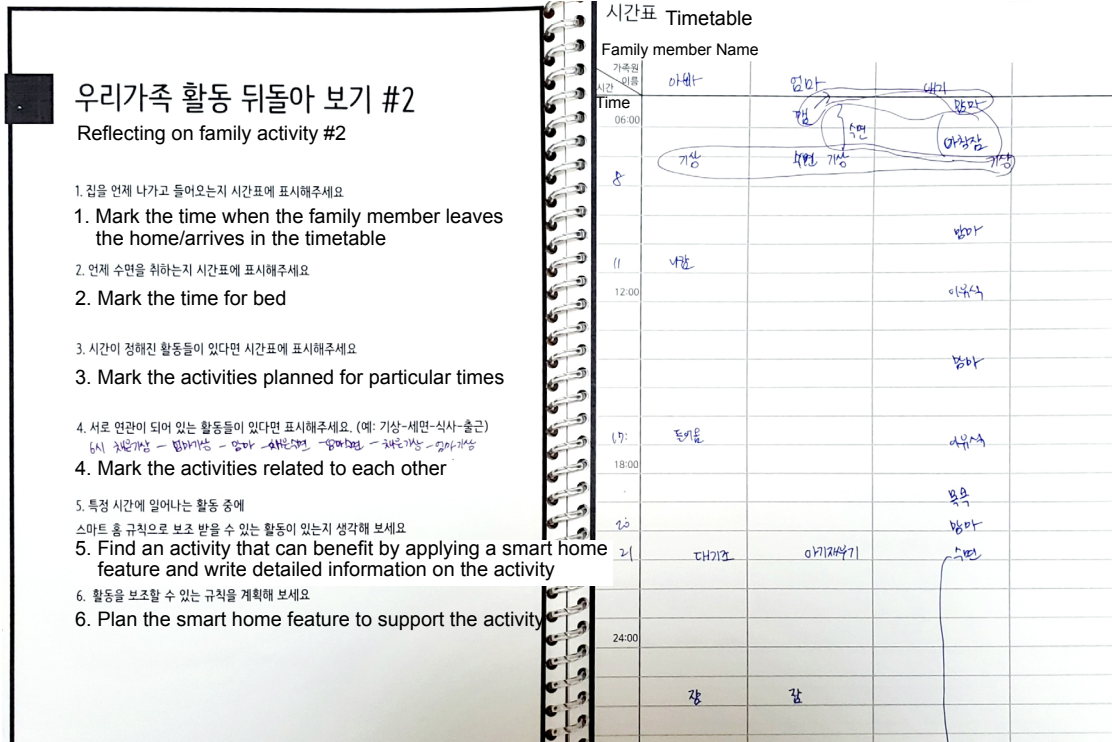

Figure 5. The second part of Family Note for reflection on routine through a timetable (Household 4 in the user study)**.**
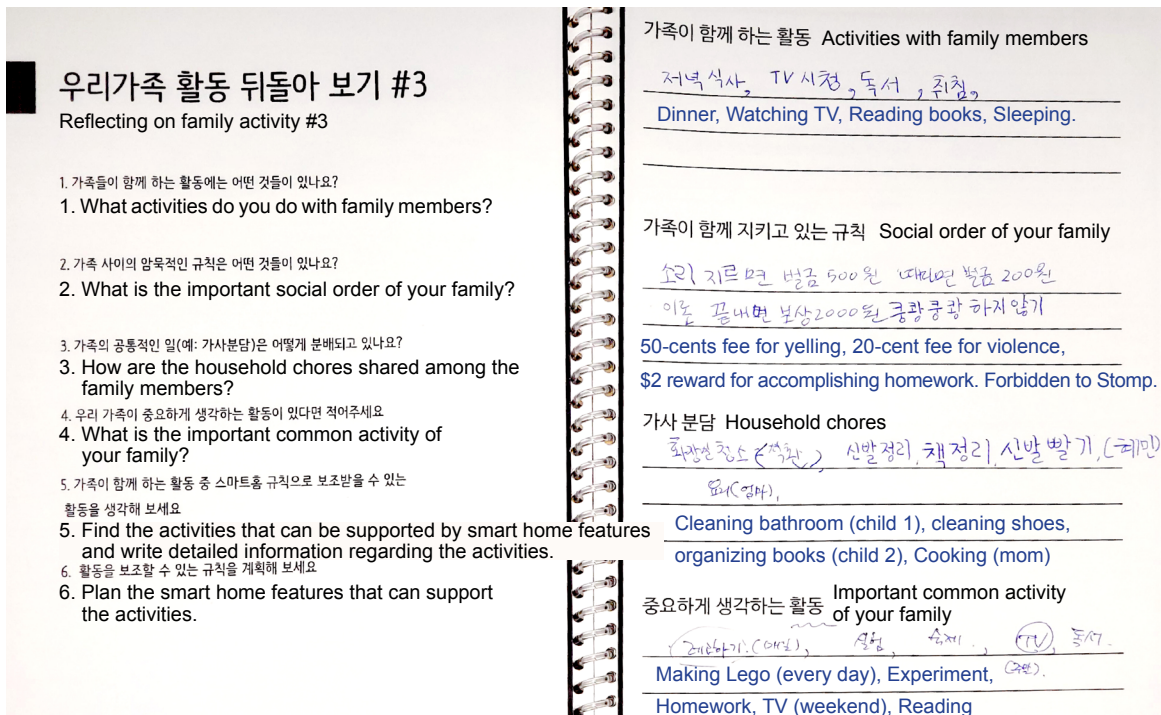

Figure 6. The third part of Family Note for reflection on routines to understand family routines (Household 3 in the user study).

the details of the activities that were identified and recorded in the previous parts. The user must fill in the activity name, time of occurrence, related family members, location, and a detailed description. The next page provides guidelines for planning the smart home rules. The user fills in the activity name, the sensors and actuators expected to be used, and the operation time of the rule. Stickers are provided for the sensor and actuator icons. Each part is carefully designed as a step-by-step tutorial to guide the user to reflect on the spatial, temporal, and social aspects of the family routines. After this step, the user creates the rule on the Routinoscope web client.

After the participant has created and used the smart home features for some time, the last part of Family Note can be used to manage and extend the existing smart home features (Figure 8). The final part of Family Note is designed to help users understand the status of the smart home and extend the smart home features based on the present state of the home. This section was included for regular collaborative routine reflection sessions during the study period. The timetable and floor plan are provided to the user for reviewing the current smart home feature rules and installing sensors and actuators.

Web Client

The web client is the component for creating a smart home feature in Routinoscope. The web client comprises a calendar view and a rule creation view. In the calendar view, all created rules are displayed (Figure 9). In the rule creation view, the list of rules is displayed, and the user can create rules and revise them in that view. The main page of the web client shows the calendar view. The user can review

Figure 7. Section for recording routine issues in Family Note
(left part for activity issues, right part for planning the smart home rules; example of Household 1 in user study).

Figure 8. Smart home feature extension guide in Family Note (Household 2 in the user study).

all the smart home rules in the calendar view, which is designed to support routine rule management. Each rule in the calendar provides a hyperlink to the rule creation page. On the rule creation page, the user can revise the rules and review the history of rule events. The web client is designed to show only the generated rules to reduce unnecessary information in calendar-style smart home rule management (Mennicken et al., 2016). After recalling their routines through Family Note, users create rules with the web client, preventing the web client from displaying unnecessary information.

The Routinoscope web client was designed for predictable rule creation (Figure 10). Previous research has shown that in the case of trigger-action programming, ambiguous conditions arise when a rule is triggered during a specific period. For example, if a rule to turn on the light is triggered between 10 p.m. and 11 p.m., should the light be turned on or off after 11 p.m.? Huang and Cakmak (2015) showed that no common mental model exists for these cases. To address these issues, the IFTTT service (see https://ifttt.com/) removes the use of periodic conditions in the case of triggers. It allows only instant triggers to be specified, that is, an exact triggering time for the rule, such as *turn on the light at 10 p.m.* and *turn off the light at 11 p.m.* This type of trigger-action

programming facilitates the anticipation of the actuator's action. The Routinoscope web client supports a predictable rule depending on the time period, 24-hour period, and specific time rules. A time-period rule is a rule that operates during a period, a 24-hour rule operates for the full 24 hours, and the specific time rule is triggered only once at a specific time.

After the user decides the rule type, he or she can select the appropriate sensor and actuator for the rule. Routinoscope provides four types of sensors: door contact, motion, wireless switch, and temperature/humidity sensors. The door contact sensor, motion sensor, and wireless switch are radio frequency (RF) sensors because they use the RF 433 Hz frequency for wireless communication. Seven actuators are provided in Routinoscope: text messaging, three Hue bulbs, email, a wireless socket, and Ninja eyes. On the web client, the user can decide the details, such as the body text font for email, the color of the Hue bulbs, and the on/off status of the wireless socket. The technology underlying Routinoscope does not use newly emerging sensors but uses sensors and actuators similar to those already on the market; thus, the participants could compare this system with previously experienced commercial smart home systems (Figure 11).
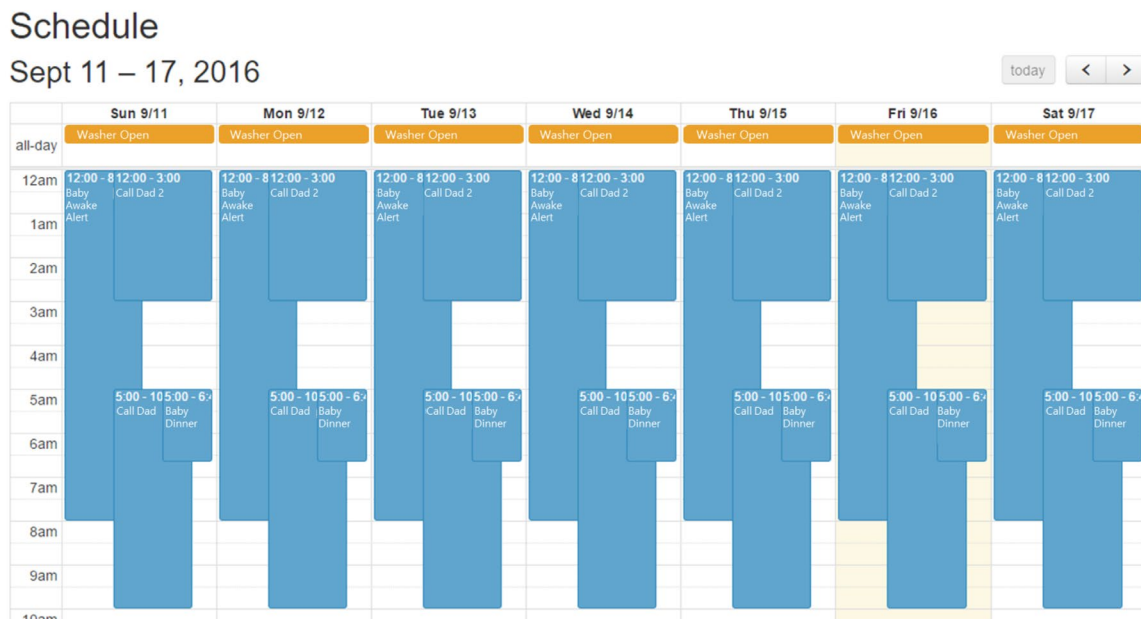

Figure 9. Routinoscope web page calendar (Household 2 in the user study).
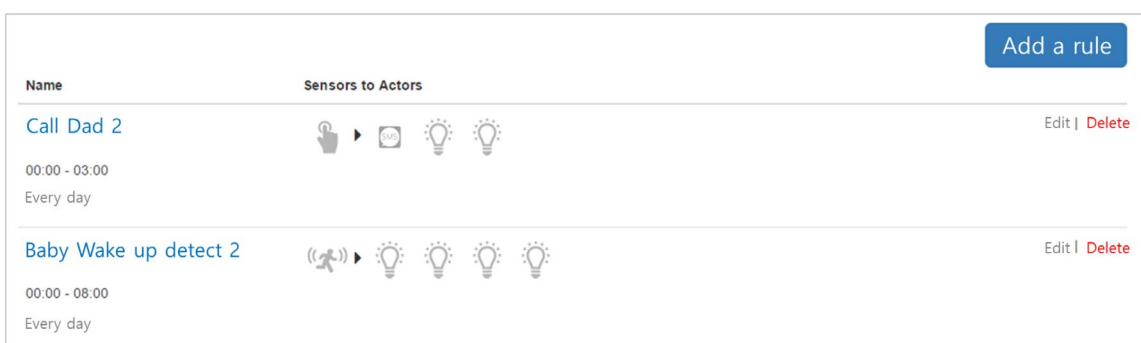

Figure 10. Rule creation page (Household 2 in the user study).

Figure 11. Sensors and actuators in Routinoscope (from left):
temperature-humidity sensor, wireless switch, motion sensor, door contact sensor, smart light bulbs, wireless socket.

Routinoscope Hardware

Routinoscope is packaged in a 90 cm × 90 cm wooden table, made of white birch plywood, for collaborative routine reflection (Figure 1). It is designed as a tea table that can be installed in the lounge. This wooden table is designed so that all family members can sit together around Routinoscope to discuss family routines. A tablet PC or iPad is also considered part of the hardware of Routinoscope; however, a tablet PC alone cannot provide the space for sharing information among family members or for the storage of the hub, sensors, and actuators.

The Routinoscope system consists of a single web server and multiple Node-RED applications (see http://nodered.org/). Node-RED is a visual programming tool for the IoT developed by IBM Emerging Technology using Node.js. BeagleBone with a Ninja Blocks shield as the microcontroller, as in the Ninja Blocks system. Node-RED controls all sensors and actuators, such as the RF sensors and wireless sockets, through the RF433 Hz transmitter/receiver. The Web API is used to control Philips Hue bulbs, Twilio (see Twilio website, https://www.twilio.com/) text messaging, and email (Figure 12). Through these implementations, we expected that Routinoscope can integrate family routines with the DIY smart home system by 1) providing guidance for reflecting on routines to understand their problems, 2) providing space for collaborative routine reflection to facilitate communication between family members, 3) managing the current status of the smart home, and 4) guiding the extension of current smart home features.
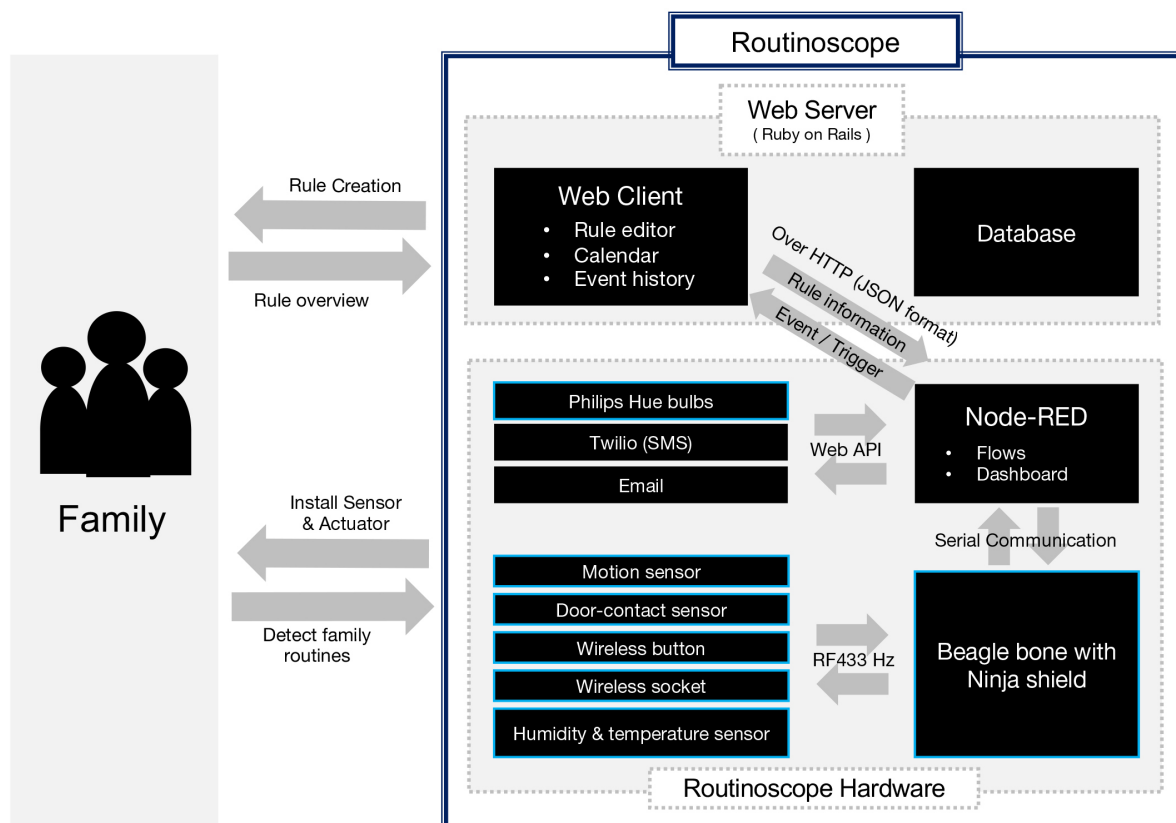
Figure 12. Implementation diagram of Routinoscope (blue-outlined boxes show physical forms that the user interacts with).

User Study

User Study Goal

The goal of the user study was to understand the value of Routinoscope in terms of its accommodation of the *collaborative routine reflection* design. In detail, what unconscious problems will the users find in a collaborative routine reflection session before creating DIY smart home features, what will be the differences in smart home features created after a collaborative routine reflection session, and what value will be added for users by the collaborative routine reflection of Routinoscope? To achieve these goals, we conducted an in-the-wild (Brown, Reeves, & Sherwood, 2011) user study with Routinoscope. The study setup was designed to compare previous DIY smart home experiences (Woo & Lim, 2015) by recruiting participant families who had previously experienced DIY smart home systems. Additionally, we used the same sensors and actuators and the same study period for this study.

Participants

Our goal was to understand the value of Routinoscope in terms of collaborative routine reflection design. To understand the difference between Routinoscope and other DIY smart home systems, participants who had previously experienced DIY smart home products were recruited. The participants 1) had previous DIY smart home experience and 2) had the motivation to use DIY smart home products. Six households that agreed to participate in the user study were recruited, and each of the family households received a reward of approximately $150 in local currency after they finished the study. Detailed information about the participants is listed in Table 1.

User Study Setup

In Routinoscope, four sensors (temperature/humidity sensor, door contact sensor, motion sensor, and wireless switch) and four actuators (text messaging, email, smart light bulbs, and a wireless socket) were provided. The participants could create smart home rules through the web client, and all rules were recorded in the web client. Moreover, an individual diary was provided to each participant to record individual user experiences of Routinoscope. The participants wrote in their individual diaries about how they used Routinoscope and how they felt about it. The diary is a component of the study that differs from Family Note in Routinoscope and was used only to record the user's experience. The participants were encouraged to record photos and videos of Routinoscope usage, for example, when they created a new rule and when family members used Routinoscope.

The study was conducted for three weeks as an in-the-wild user study that tested new systems with groups of users in relatively unconstrained settings outside the laboratory (Brown et al., 2011). The three-week user study is the same time period as that for a comparative observational user study (Woo & Lim, 2015). We compared the differences between previous DIY smart home user experiences and Routinoscope experiences. The moderator visited each household three times. All family members participated in the meetings with the moderator, and they listened carefully when the moderator explained the user study process. In addition, the moderator interviewed the participants. The visits required approximately 1 hour and were recorded by video and audio. The in-the-wild user study was conducted from August to September 2016.

In the first visit, the moderator installed Routinoscope in the participants' homes and explained the user study. After the introduction, all family members sat together and followed the guide for Family Note on Routinoscope. They reflected together

Table 1. Participants and their living situations [F (father), M (mother), S (son), D (daughter); for example, H1_F stands for father in H1].

	Participants (gender, age, occupation)	Living situation
H1	H1_F (male, 34, Researcher) H1_M (female, 28, Graduate student)	Flat with a kitten (two months). H1_M remained in the home with the cat most of the day.
H2	H2_F (male, 30, Graduate student) H2_M (female, 29, Graduate student)	With an infant (female, 1). H2_M remained in the home with the infant most of the day.
H3	H3_F (male, 60, Researcher) H3_M (female, 62, Housewife) H3_D (female, 31, Graduate student)	Flat. H3_M remained in the home most of the day, and the other members were present from night to morning.
H4	H4_F (male, 30, Graduate student) H4_M (female, 30, Housewife)	Flat. With an infant (male, 3) and three cats. H4_M remained in the home with the infant most of the day, and H4_F was at home from late night to morning.
H5	H5_M (female, 42, Graduate student) H5_F (male, 40, Researcher) H5_S (male, 9, Schoolchild) H5_D (female, 8, Schoolchild)	Flat. Dual-income family. The parents stayed at home from night to morning with their daughter (female, 8) and son (male, 9).
H6	H6_F (male, 37, Researcher) H6_M (female, 41, Housewife)	Flat. With daughter (female, 7) and son (male 5). H6_M stayed at home with the children most of the day. H6_F was at home from night to morning.

on the temporal, spatial, and social aspects of their routines. Based on Family Note, the participants created a plan for their smart home features. After the planning session, the tutorial for the Routinoscope web client was conducted. The moderator provided the Routinoscope web client guidebook and explained in detail how to create the rules. After the tutorial session, the participants formed the rules that were planned in the Family Note sessions. After all sessions, the moderator asked the participants about their experience of the Family Note sessions and rule creation.

After one week, the moderator visited each household again. The moderator asked how the family had used Routinoscope in the previous week, what rules they had made, and where the sensors and actuators were installed. After the interview, the moderator explained how smart home feature extension could be performed using the last part of Family Note. The participants wrote all rules on the timetable and drew the installed sensors and actuators on the floor plan. They subsequently followed the smart home feature extension guide on Family Note. After the sessions, a semi-structured interview was conducted to ask the users about the roles of the web client and calendar and how Family Note affected the user experience in the DIY smart home.

Three weeks after the user study started, the moderator visited the households to conclude the user study. The moderator asked about the users' favorite rule, frequently used rules, the roles of the family members, and, more importantly, the main difference between the users' previous experience of a DIY smart home and the experience of using routine-driven rules.

Data Collection and Analysis

The study data were collected through Family Note, rules, interview recordings, photos, videos, and diaries. The web client recorded the rules that the participants created, modified, triggered, and removed. Approximately 16 hours of interviews and video recordings, 15 diaries covering three weeks, 98 photographs and 5 videos were collected. A total of 146 smart home rules (time period rule: 51, dependent rule: 23, 24-hour rule: 31, specific time rule: 41; average 24 rules per household) were created over the three weeks. All interviews were transcribed and iteratively coded based on the initial research questions: the main difference between the routine-driven DIY smart home and the previous DIY smart home, what problems the users found when a family had a collaborative routine reflection session before creating DIY smart home features, what were the differences in the smart home features created after the collaborative routine reflection session, and what value was added by the collaborative routine reflections of Routinoscope. The data were analyzed using iterative processes to generate, refine, and verify the themes that emerged. The themes were supported by the diaries, rules, photos, and videos to triangulate the findings.

Findings

Our research questions were: "What is the way to build DIY smart homes based on family routines?" and "How will routine-based DIY smart homes give a different user experience than previous DIY smart homes?" All participants previously experienced using DIY smart homes, so they could compare the Routinoscope experience and their previous DIY smart home experiences. From the user study, we found different user experiences between Routinoscope and previous DIY smart homes.

Providing Critical Perception to Identify Daily Problems

During the collaborative routine reflection session with Family Note, the participants (H1, H2, H3, H4, H5) were reminded of their daily routines. They felt that some of the routines were uncomfortable but not treated as problematic since there was no better solution for improvement. However, with Routinoscope, the participants were critically reminded of these routines and found problems that could be solved with new smart home features. For example, the participants in H2 claimed that Routinoscope helped them discover problems in their routines that they had not noticed previously. After they found a problem, they could solve it by creating smart home features. They felt motivated to seek out and address other problems in the routine through the DIY smart home features. When H2_M tried to get her baby to sleep at night, she held her baby in a dark, quiet room. However, sometimes she needed her husband's (H2_F) help. She could not make noise or leave the room since the baby was sleeping. She tried a small knocking sound by tapping the door with her foot to call her husband. However, the knocking sound was so low that H2_F usually did not hear it.

H2_M remembered this problem during the Family Note session on their first day of using Routinoscope. She attempted to solve this issue by creating a rule named *Call husband* that turned on a blinking red light bulb when the wireless button was pressed. After they had made the rule, H2_M brought the wireless button with her when she tried to put her baby to sleep. When she needed her husband's help, she pressed the button. H2_M and H2_F had thought their problem could not be solved. However, when they found a possible solution with Routinoscope, they learned that there were problems in their routine.

> Once I experienced the new possibility, it showed me that I was in an uncomfortable situation. After that, I thought, 'I can fix that routine too' (…). I felt uncomfortable, but I did not have a better solution at that time, so I just embraced it. However, when I had new possibilities with these tools, I could think about new ideas to fix this problem. (participant H2_M)

The members of H2 divided their household to create a baby room after they used a rule related to caring for their baby. H2_M and H2_F usually lived and slept in the same room with their baby. However, the H2 parents experienced that any noise they made at night would wake the baby. When they found that the smart home rule enabled them to know whenever the baby woke up, they planned to create a separate room for their baby and installed a motion sensor to detect the baby's awakening. The H2 parents installed the motion sensor in front of the baby's bed, thus, when the baby moved, the motion sensor sensed the baby's movement, and the light bulb in the parent's room blinked (see Figure 13).

Figure 13. Motion sensor, wireless switch, and humidity/temperature sensor in the new baby room (H2; from H2_M diary).

After devising the new smart home feature, sometimes immediately after making a loud noise outside the baby's room while the baby was sleeping, the baby would possibly wake up. The signal for such a situation would be detected by the motion sensor in the baby's room, and would notify the parents by the light bulb blinking in the parents' room. Before the baby fully awakes, the baby can sleep again when the parents no longer make noise. In other words, the blinking light bulb indicates to the parents that they must be quiet so as not to wake the baby. Before H2 made these rules, they had to sleep with the baby, which meant a lot of noise being created that often woke the baby, which was not a good condition for the parents and the baby. After they had adopted the new smart home rule, they could divide their household into the parents' bedroom and the baby's bedroom. These living area changes improved the sleeping condition of both parents and baby.

> I decided to divide H2_baby's room, moving H2_baby to the small room with the motion sensor, and the lamp in the bedroom blinks together with the lamp in the study. When the baby stayed with us in the bedroom, the baby would wake up when we were moving around. Therefore, we had to move carefully. However, now H2_baby is in the small room, so I felt free and comfortable. (participant H2_M's Diary)

Based on the example of H2, Routinoscope made the participants critically examine their existing routines and consider the hidden problems in their lives. Through shared routine reflection, Routinoscope allowed the participants to challenge existing problems that they had become accustomed to. Based on the discovered problems, the participants applied their lifestyle adjustment to new smart home features.

However, the current *collaborative routine reflection* method in Routinoscope has a limitation in readily discovering what core value people care about in terms of what they come up with. For

example, the H2 parents needed two steps to build the baby's room: first, making the *call husband* rule and, second, dividing the baby's room. They did not come up with the baby room idea at first when they reflected on the routines in Family Note. The H2 parents made the *call husband* rule to call the husband while H2_M tried to put the baby to sleep. As for the superficial value of the *call husband* rule, H2_M used changes in the color of the light bulb to call H2_F for help, but the core value of this feature was to make the H2 baby sleep well. After they had made this rule, the H2 parents divided the baby room to obtain the same core value, which is to get the baby to sleep well. The H2 parents required two steps to revise the smart home features to configure the core value that they attempted to solve with the DIY smart home feature. Thus, the current Family Note must be improved to remind the core value that people want to achieve from the smart home features. To overcome this limitation, the guide for reminding the user of the fundamental problem and core value to achieve by using the smart home features can be helpful to the user in planning these features. When the user is supported to remember the core value and fundamental problem to solve by smart home features in the collaborative routine reflection, the user can directly approach these issues to create a smart home feature for their routine. For example, Family Note can add a new chapter after the planning of smart home features that reveals the core values: "What is the value that one wants to achieve by this smart home feature?" "How can this smart home feature help your routine?" "Is this smart home feature the best method for achieving that value?"

Mediating between Routines and Smart Home Features

The participants commented that Family Note in Routinoscope played the role of a mediator in their adoption of new technology in their routines. They commented that Family Note assisted them in

viewing problems in their routines, where the smart home features played the role of a mediator between smart home features and routines. With Family Note, participants could make more essential smart home rules compared to their previous DIY smart home.

> When I used DIY smart home before, the most useful rule was something like wake-up lighting. That was the best rule. But with Routinoscope, it helped to make rules with schedules. So it is like... a mediator between daily life and the DIY smart home. And this mediator worked well for me. Apparently, I used the DIY smart home more than before. (participant H1_M)

> Filling in the timetable and then filling in the floor plan helps when thinking about daily activities. Maybe it depends from person to person, but I do not think I could plan my activities without these tools. These tools were helpful reminders (for the activities). (participant H1_F)

As the users explicitly mentioned the word *mediator,* *R*outinoscope provided a different user experience from the existing DIY smart home systems. If the previous smart home features were created around experimentation and fun values, Routinoscope was made for practical and necessary values. Family Note plays the role of a helpful reminder,

> Routinoscope was more essential than the previous DIY smart home. The previous model was more focused on fun, or toy-like usage; it did not have necessary features. (participant H2_M)

> Many of the previous smart home features made for fun and curiosity. But this time (with Routinoscope), I considered it more for practical use. (participant H3_D)

> Routinoscope is like you can do like this with the floorplan. but the previous DIY smart home is like 'try your best.' Previous DIY smart home had a lack of storytelling so the only people who already familiar with it can handle it. (participant H2_M)

The Family Note provided a step-by-step guide to find the daily problems and guide the participants to make smart home features to solve the found problems through the web client. This step-by-step guide helped to design their DIY smart home. The *storytelling* part was helpful to the participants to make smart home features for their current problems.

The participants reflected on their routines with their family members and shared problems with the family. After they had shared their problems, they tried to solve them together. For example, H2_M usually cared for her baby and performed almost all the household chores. H2_F did not understand the problems involved in the house chores in detail, so there was a conflict between them due to the lack of a common understanding of the house chores. After they reflected on their routines through Family Note, H2_F understood the inconvenience and difficulty of H2_M's household chores and started to help H2_M more actively. They also made rules to solve these problems together.

> H2_M apparently knew the problems, but I did not. I think I should write down all of the routines on Family Note to be aware of them. (participant H2_F)

After the H2 family had reviewed the routine together, they made a rule: *washing machine is open*. H2_M often blamed H2_F because H2_F did not remove the finished laundry from the washing machine until late at night. To solve this problem, they made the rule *washing machine is open*, which sent a text message to both H2_F and H2_M that the laundry was finished (see Figure 14). H2_M expected H2_F to remove the laundry more frequently before she complained about it. Both H2_M and H2_F commented that the rule strongly contributed to reducing arguments, conflict, and disharmony in the home. Collaborative routine reflection in Routinoscope provides the opportunity to remind all family members of existing problems, after which they can make smart home features to reduce family conflicts. For instance in family H2:

> They contributed to the peace of the family. There are two rules that contribute to the peace: the washing machine door and the switch. In the past, when the washing machine rang when it finished, I usually did something else, like putting the baby to sleep or doing house chores. At that time, H2_F was free, so when I found that the laundry was not taken out, I became really angry. H2_F had the time to do it, so I blamed him for not doing it. I made a rule to give an alert about this for both of us. (...) There was no fighting after I made the rule. (participant H2_M)

Enhancing Sensitivity to Other Family Members' Routines

The participants tried to understand other family members' problems and make rules for them. H3_D commented that the timetable in Routinoscope web client reminded her to think about other family members' routines. Because all the participants in

Figure 14. The door contact sensor attached to the wall and the washing machine door from H2 (left)**. Two hours after starting the washing machine, H2_M and H2_F received the text message** (right)**.**

H3 were adults, they had individual schedules and did not fully know other members' schedules, and because H3_D wanted to know about other family members' routines, she made rules to share important schedules within the family. These rules included an alert for medicine once a week for H3_F, an alert for all family members to attend church on Sunday mornings, an alert for when H3_D was late returning home, and an alert for H3_F to go home from work to prevent him from staying late at work (Figure 15).

> I liked that it organized all of the important schedules, such as for Mother to leave for Seoul on Monday, Tuesday and, Thursday, for other family members to go to church on Sunday mornings and the time for my father to return home. ... I think this is related to the scheduler on the web page. I thought only about myself in the previous usage of the DIY smart home, but Routinoscope shows the other family members' schedules, which made me think more broadly than before. (participant H3_D)

Not only H3 but also other participants created smart home features inspired by other family members' routines. H4 made a rule to remember to feed their cats (Figure 16 left), and H5 installed a lamp with a motion sensor for their son in the bookshelf where their son usually read in the dark (Figure 16 right).

Enhancing Collaborative Usage and Requirements for Discussion Space

Compared to their previous DIY smart home system, participants commented that the table-shape hardware enhanced the discussion with other family members. Their previous DIY smart home required the use of a laptop to manage smart home features, so mostly one main user created the smart home features. However, Routinoscope has the table, where other family members easily gather around and share their opinions on the smart home features.

Name	Actor
약알람	SMS
07:00	
목	
약드세요 아빠아~비싼 약 먹었으니 오늘도 건강관리 *^^*	
성당 알람	SMS SMS SMS
10:00	
일	
성당갈 준비를 하세요	

Medicine alarm
07:00
Thursday
Take medicine daddy. You took expensive medicine so today also take care of yourself.

Church alarm
10:00
Sunday
Be ready to go to church

Figure 15. The rules for other family members' routines (made by H3).

Figure 16. The door-contact sensor attached to the cat-food bag (H4; left).
The desk lamp installed in the bookshelf, with H5_S reading a book under the light (H5; right).

Thus, the table shape is not for personal usage but for multiple users, so the users show more collaborative usage gathered around the table shape. H1_M and H1_F said that when H1_M made a rule, H1_F could provide an opinion for the smart home feature being created while sitting on the sofa nearby.

> If I need to use a PC, the discussion could be hard. but it is in the living room, I just sit on the near sofa and gave opinions... (participant H1_F)

However, H3_D gave a different opinion on the table. H3 family normally do not have time together in the living room or watching TV. H3 family did not gather near the tea-table during the test period because they usually did not gather in the living room where the Retinoscope was located. From this case, depending on a family's lifestyle, the method to enhance discussion must be changed. To address this limitation, H3_D suggested a mobile application that contains a virtual discussion place where other family members can receive the smart home feature information and provide feedback about the features.

> In fact, we did not make a smart home rule together in the Tea-table. Usually, we did not stay at home at the same time. (...) If I revise the rule, the notice could deliver to the other family members' phones and they can give feedback about it. That kind of the virtual home style application is more suitable for these days. (participant H3_D)

Design Implications

From the in-the-wild study with Routinoscope, we aimed to understand how user experience of the DIY smart home had changed with Routinoscope. From the findings, we derived design implications to apply routine-driven DIY smart home features to future systems, focusing on providing a problem-finding method in the DIY smart home system and maintaining smart home systems.

Need for a Problem-Finding Method for DIY Smart Homes

The main difference between Routinoscope and previous DIY smart home systems is that Routinoscope addresses family routines in practical ways, unlike previous DIY smart home systems that focused more on fun and experimentation. Some participants mentioned that Routinoscope contributed to discovering problems in the current routines and helped solve them with DIY smart home features.

When designing a DIY smart home system, it is necessary to provide a solution and a problem-finding method to help users discover their needs. We use the term methods since these methods can be a process or physical toolkits to find daily problems. In Routinoscope, we use the collaborative routine reflection as problem finding methods. Routinoscope provides the Family Note, Web Client, and the tea-table style hardware as a toolkit for the problem-finding methods, as well as providing a detailed guide on how to use these methods, which are tightly connected from problem finding to creating solutions. Since the DIY smart home is usually used in the home for the benefit of family members, *collaborative routine reflection* is a more suitable method for problem finding for Routinoscope. The home context is the co-living space with all household members, so that the *collaborative* aspect of the routine reflection must understand the holistic view of the routines in the home.

Previous DIY smart homes allow the user to install the sensors and actuators, without first finding the existing problems, and use them in their daily life. However, the Routinoscope guides the user to find the problems in their daily routines as the first step, whereby users can investigate the current problems in their routines and have the opportunity to think about their problems first. After they find the problems, users can develop solutions with the Family Note, create smart home features with the Routinoscope web client and have all the family members discuss the solutions around the Tea-table. After a new smart home feature is created, it re-affects the family's routine, and the new family routine is understood through the next collaborative reflection. It would be an improvement if DIY smart home products provided the problem-finding process as the first step of the device use, similar to what Routinoscope provides. In addition, providing a C*ollaborative routine reflection* for the DIY smart home product can help to find appropriate day-to-day problems in a family's routines.

Since the collaborative routine reflection guides the user, a perspective is required to find the daily problems and create smart home features process-wise. The following steps should be considered in the *collaborative routine reflection* process: (individual family members) reflecting on routines, reviewing with other family members, and connecting solutions to problems related to the routines to smart home features (Figure 17). The first step (reflecting on routines) is an individual session wherein the individual reflects on family routines within the general guidance from the DIY smart home product. The DIY smart home product should guide the way of reflection depending on the created smart home features, types of sensors, and actuators in the product. Based on the system characteristics, the DIY smart home product must guide the users and remind them of the routines in the guidance. The second step is reviewing the found routines with other family members. Because each family member has a different perspective on the same routine, thus, the users must verify the routines with each other and add any missing aspects of the routines. Through this collaborative step, the users should discover the core family values and fundamental problems, which would not be otherwise found with only a single user controlling the system. Last, the third step: connecting to the smart home features. Users must create smart home features depending on the family's daily routine problems. DIY smart home products have an interface to create the smart home features, i.e., through IFTTT style programming. However, not all end-users are familiar with creating smart home features with the provided programming interface. This step must guide the users to create smart home features from the found family routines to device smart home solutions. These three steps are an example of the collaborative routine reflection in the DIY smart home product. Since the process of collaborative routine reflection can vary depending on the context and components of the DIY smart home product, the collaborative routine reflection process is not limited to these three steps.

Collaborative Routine Reflection Process		
1. Reflecting on the routine	2. Reviewing with other members	3. Connecting to the smart home features

Figure 17. Collaborative routine reflection process.

In addition to the reflection method provided in Routinoscope, there should be other methods to provide problem-finding methods for routines and smart home features. For example, in addition to the reflection on routines suggested in Routinoscope (temporal, spatial, and social aspects), activity-based reflection on routines could be an additional approach. These activities should be related to the mechanisms of the sensors and actuators. Therefore, the users can be reminded of activities that can be observed by the sensors and activities that can be affected by the actuators. For example, the door-contact sensor can sense not only the opening of a door to a room but also activities in other parts of the home, such as opening drawers, the refrigerator door, the pet-food bag, and the washing machine door. Depending on the product category, it is expected that a problem-finding method can be provided in a form focused on a specific domain. For example, security-related IoT products could provide guides/toolkits to exhaustively identify places in the home that are a problem for crime prevention.

Consider What Changes over Time to Maintain the DIY Smart Home

During the user study, H4 reported an interesting incidence. H4_F made a rule to check his son's restroom timing. If 5 hours had passed without a button being pressed, a text message was sent to the parents. The first time, H4_F pressed the button after H4_S used the restroom. After 2 weeks, H4_son learned to press the button himself after using the restroom (Figure 18). This is a good example of a family routine changing over time. Children grow and learn.

DIY smart homes are not made for instant use; they live with people, evolving and changing with the users' routines. As explained in H4_S's restroom example, DIY smart home users also change over time. There are design points to consider depending on the users' routines and how the users and the DIY smart home evolve organically. Considering changes over time, users, routines, and DIY smart home systems are three important design factors for DIY smart homes.

First, family members change. Family members grow, new family members are born, and sadly, other members leave or die. Each such change causes an atypically large change in routines, which is accompanied by changes in the surrounding environment, which causes users to make changes in the DIY smart home. For such situations, users may reflect on their routines themselves, but they may not be prepared for changes, such as having more children and new family members. In such scenarios, the DIY smart home system may suggest the necessary relevant features to adopt by referring to other users' cases. This could be a new design opportunity, as it presents a great need to users who have not yet prepared for a new routine (e.g., suggesting smart home features to care for their children).

Second, as the users change, so do their routines. As time goes by, lifestyles and the rules related to them also change (Cho, Lee, & Lee, 2019; Davidoff et al., 2010). Smart home features are usually revised through ad hoc repairs that fix malfunctions, depending on how the given routine has changed. Therefore, collaborative routine reflection should be performed on a monthly or seasonal basis to understand the current status of the household. In this step, the DIY smart home should display all the rules and prompt the users to examine the overall status of the smart home. For example, a pop-

Figure 18. The baby of H4 learned that he had to press the button after using the restroom; in actuality, he pressed the button himself in the last week of the user study.

up message is an easy way to remind users to manage the rules. This method of management gives the users a chance to control the entire system, prevent possible conflict between rules, understand the current state of the DIY smart home system, and create more rules. In addition to managing, the DIY smart home system can suggest feature extensions. For example, it can propose a new rule for the installed sensor/actuator to apply rules to different routines.

Last, the DIY smart home system must change over time. After users have become familiar with the whole DIY smart home system, they may well be prepared to learn the complex programming environment. Hence, in the early stages of use, it is important to have an easy way of programming–for instance, trigger-action programming–so that the users can quickly adapt to changes in the household. Therefore, as users become familiar with the system, they will demand a more complex programming environment to create customized rules. Accordingly, the DIY smart home should provide a different programming environment for users who are still learning about and adapting to the system. At first, users can start with simple rules, but they will soon need more complex rules. This is similar to how DIY smart home users educate themselves regarding programming. They learn about the programming, make applications for themselves, and use them daily. These evolving programming environments make the long-term use of the DIY smart home system possible. Long-term usage will enhance users' ability to shape their environments and create smart home features that are suited to their routines.

Changes in family members, changes in routines, and changes in users from being beginners to experts are closely related to changes in the home environment. In the DIY smart home, three factors that change over time (routine, expertise of the user, family members) should be considered so that a DIY smart home can consistently respond to the needs of the users.

Conclusion

Previous studies have suggested the demand for future smart home products to close the gap between user routines and interweave the family routine and the smart home. The *Routinoscope* product described in this study can integrate a family's routines with the smart home system through collaborative routine reflection. The in-the-wild user study conducted with six families identified findings related to how the users' experiences changed through Routinoscope. The findings show that the users' experiences changed from their previous DIY smart home experiences. Routinoscope enables users to have a critical perspective of their own daily problems and an enhanced sensibility of the routines of other family members, thereby reducing family conflicts through smart home features created using Routinoscope. These findings provide empirical insights into routine-driven DIY smart homes, wherein the DIY smart home product uses the family's routines as resources for the DIY smart home. Our contributions are 1) providing a routine-driven DIY smart home concept that applies the collaborative routine reflection to the DIY smart home system, 2) designing and developing Routinoscope, and 3) discovering how a routine-driven DIY smart home changes the users' experiences through the in-the-wild study of Routinoscope.

However, our study has limitations and requires further investigations, one of which is the regional limitation. This study was conducted in South Korea, where many people live in flat-type apartments, and all participants lived in this type of apartment. Since the cultural background and house structure are highly influential to family routines, different cultural backgrounds and house types will be associated with different problems and concerns. Another limitation is the diversity of sensors and actuators. This study used 5 types of sensors and 3 types of actuators. Since the possible smart home features highly depend on sensors and actuators, different or advanced sensors and actuators can also show different user experiences with DIY smart home-usage. In addition, new types of smart home products have been introduced in the market, such as trackers (see https://www.thetileapp.com/en-us/) and cars (SmartThings, 2020, January 8). These types of products can be integrated into the smart home product to expand its boundary beyond the house interior. The authors intend to further pursue this area of study to investigate *how to reflect on outdoor activities* and *how the user can manage devices inside the home when outside.*

In the era of the IoT, which will have a pervasive influence in every future home, the smart home should involve the adoption of emerging technology and ways to evolve to fit users' lives. The family is the master of the home, they are the experts in their home context, and they already know their problems, although not always consciously. Therefore, there could be new design opportunities in allowing them to consciously understand their problems. We hope that our findings and suggestions will provide a new perspective on DIY smart home product design, which includes new solutions and problem-finding methods by reflecting on the routines of the users.

Acknowledgments

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