Scenario-based design

Exploring the effect of explainability on user’s adoption intention of smart home lighting systems

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Scenario-based design: Exploring the effect of explainability on user's adoption intention of smart home lighting systems

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Abstract

Smart home lighting systems aim at increasing the autonomy of the systems and supporting independent living in users' homes (Alaa et al., 2017; Sekulovski, 2013). As intelligent and context-aware as smart home systems can be, one crucial problem is the conflicting requirements between the user's active involvement, and decisions made by the system (Wilson et al., 2014). Although providing explanations about system decisions can be an effective way to increase the users' trust and enhance the system's transparency, little research has been done to explore the explainability of smart home lighting systems (Adadi & Berrada, 2018; Miller, 2019; Mueller et al., 2021; Ribera & Lapedriza, 2019). To investigate how explanations impact users' attitudes in different scenarios and to explore the optimal explanation design, two studies were conducted. In Study 1, 10 scenario-based semi-structured interviews were performed. Four themes regarding the attitude and expectation towards explanation were identified. Two explanation types and three lighting scenarios were developed based on the results for Study 2. In Study 2, the effect of explanation on the adoption intention, along with the perceived control, perceived ease of use, and perceived usefulness, was examined in 3(Explanations: user-centered explanation, system-centered explanation, no explanation)*3 (Scenarios: presence mimic, activity-based mode, lighting assistant) between-subject design. The result showed no effect of explanation or scenarios on the constructs above. However, participants who received a system-centered explanation resulted in a higher satisfaction score than those received a user-centered explanation. The practical implication of the study is to provide explanation design recommendations for future user interaction with smart home lighting systems. Future studies can assess the effect of explanation in a longitudinal design, especially using lighting systems in a real-life environment to fill the gap between users' attitude and actual behaviors and increase ecological validity.

Keywords: explainability, smart home lighting system, perceived control, adoption intention

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Hope you enjoy reading. If not, please let me know how to improve your user experience.

Have fun and carry on!

Cheers,

Kiwi

July 2022, Eindhoven

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1. Introduction

1.1 Lighting systems in the smart home context

Smart home technology and its applications have been widely discussed, adopted, and implemented in recent years (Alaa et al., 2017). A smart home is defined as a residence that provides services responding to the users' domestic needs with connected devices and sensors (Augusto, & Mccullagh, 2007; Balta-Ozkan et al., 2013). Making use of a multitude of internet-connected devices (Internet of Things), smart home applications provide people with benefits and convenience in their everyday lives. For example, smart home applications are used for reducing energy waste, monitoring elderly patients, providing comfort and entertainment, and facilitating everyday basic needs (Alaa et al., 2017).

Smart lighting systems are a major area of interest within the field of smart home research. The lighting system, one of the essential needs in a home environment, plays a role in visual performance, avoiding injuries, improving people's well-being, as well as having an impact on people's mood, behavior, and experience (van Bommel & van den Beld, 2004; Osibona et al., 2021; Hopkins et al., 2017; Summers & Hebert, 2001; Ruyter et al., 2005). The importance of light for human health, well-being and productivity had been well established before the dawn of internet-connected devices.

As smart home technology started to become prevalent, intelligent lighting systems were introduced and adopted in both industries and households (LightingEurope, n.d.). In the domestic context, connected lighting plays a key role in facilitating consumers' life. A UK report in 2020 showed that 5% of smart home tech ownership is lighting products, in third place after audio speakers (11%) and thermostats(6%) (Jackman, 2021). Similarly, approximately 14% of the Dutch population claims domestic usage of lighting, smart plugs, or other systems for smart living (CBS, 2022).

A domestic lighting system includes a number of light sources, sensors, user control devices, as well as the linkages between them in a home environment (Sekulovski, 2013). In traditional domestic lighting systems, control-driven interactions, such as pressing a switch to turn on the light, have been most common in past decades. The interactions nowadays are varied, such as voice control, app control, remote switches, and sensor-based automation. The efficiency and accessibility of controlling domestic lights have changed over time.

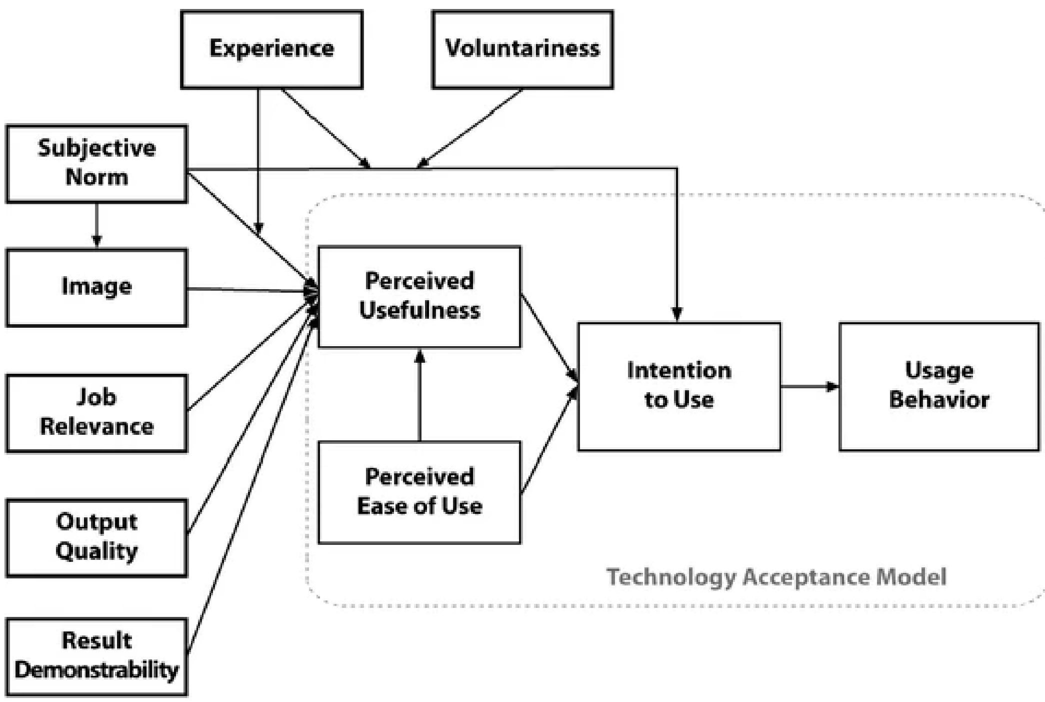
However, the current lighting systems are mostly control-driven. Compared to the control-driven domestic lighting systems, a smart home lighting system focuses on the interaction with the user and context, creating adaptive lighting effects utilizing a set of intelligent, context-aware algorithms (Sekulovski, 2013). The concept of a lighting system in a smart home context is usually based on LED-based lighting systems that could become increasingly context-aware and adaptive in the near future (Aliakseyeu et al., 2011). A context-aware system means the system has the ability to use context to provide relevant services or information (Ibarra et al., 2016). In terms of a smart home lighting system, being context-aware and adaptive means learning and adapting to the home context, and providing the most suitable lighting based on the user's needs. As the applications of context-aware and intelligent lighting systems are increasingly available to customers, explorations on the relationship between such systems and the user become even more important.

1.2 User's acceptance towards new technology

Investigating the acceptance of products or services is one of the key activities to evaluate the quality of the products or services. Therefore, a number of theoretical models have been implemented to assess the acceptance. One of the most prevalent and acknowledged models is the Technology Acceptance Model (TAM) by Davis et al. (1989). In the TAM model, the user's acceptance related to information technology is impacted by both perceived usefulness and perceived ease of use. Davis et al. (1989) suggested that perceived usefulness is likely to be influenced by perceived ease of use. Based on the relationship between perceived usefulness, perceived ease of use, and the user's acceptance, Venkatesh (2000) proposed an extended theoretical framework of the technology acceptance model with additional anchors and adjustments, see Figure 1. Several past studies have suggested and validated the technology acceptance model as a crucial framework for offering an explanation of technology usage (Lee, Kozar, & Larsen, 2003).

Figure 1

Theoretical framework of the Determinants of Technology acceptance model (Venkatesh, 2000)



1.3 Automation and perceived control in smart homes

To build increasingly context-aware and intelligent lighting systems, research on automation needs to be discussed and considered. One of the key considerations of building control-based systems, such as lighting systems, is automation (Karjalainen, 2013). Home automation refers to home systems that are able to autonomously make decisions in order to support independent living. A case in point is a robot companion designed for the elderly assisting domestic tasks (Gross et al., 2015). A human-centered smart home system aims to learn user behavior and facilitate user’s everyday life by providing context-aware automation.

However, bringing automation doesn't guarantee the satisfaction of users. There are many possible ways in which systems may be designed to allow for varying levels of user control. One most common approach is the four stages of automation functions: 1) information acquisition; 2) information analysis; 3) decision and action selection; 4) action implementation (Parasuraman et al., 2000). A fully automated system may result in less trust and less adoption intention of the users (Karjalainen, 2013; Sauer & Rüttinger, 2007; Meerbeek et al., 2014; Yang et al., 2018). Karjalainen (2013) pointed out that the mistrust of full automation may be related to the naturalness to control in special qualities of the domestic environment. A study by Yang et al.(2018) conducted an online survey about the general concept of a smart home to investigate the relationship between automation and controllability. They proposed a structural research model of how the adoption intention of users is impacted by perceived automation, perceived controllability, perceived interconnectedness, and perceived reliability in a smart home context. The result of the study demonstrated that a fully automated system is not desired because a home is safe and represents the user's personal space. The concept of "smart" indicates that users expect the right level of intelligent control of the home systems, rather than everything being decided for them. The study also indicated that users require a system to optimize the controllability, which could be similar to a limited form of automation. Similarly, in the study of Sauer and Rüttinger (2007), participants were invited to read the description of three products (a vacuum cleaner, a refrigerator, and a television set) with different automation levels and fill in a questionnaire about perceived complexity, perceived risk, and overall appreciation. The goal was to investigate the impact of product autonomy on the user's appreciation. The results showed that users regard highly autonomous items as more complex and risky than those with lower levels of autonomy. Users expect that highly autonomous systems are more difficult to learn and more likely to experience malfunctions, thus leading to a lower appreciation. The authors indicated that this could be solved by designing the products with more consideration taken. For example, the system can offer feedback to the user on the current task. The system could also provide more information on how the new product works and what the benefits are.

An automated smart home system can receive and process environmental inputs to deliver optimal outcomes without human intervention. Compared to current IoT-based services or applications that simply allow users to control devices remotely, providing intelligent automated assistance can be greater long-term interest. The potential capabilities that intelligent home systems carry can be enormous, such as monitoring automated home appliances at a distance, changing services based on users' activities, notifying caretakers about behavioral abnormalities of the elderly, and providing assistance to users in independent living (Kumar & Pati, 2016; Das et al., 2021; Ghayvat et al., 2018; Morris et al., 2013; Makonin et al., 2013). One of the basic scenarios is a person who is absent from his/her home can fully automate basic home functions including monitoring and controlling his home appliances (Adedoyin et al., 2020). Another potential capability is home automation based on activity recognition (Das et al., 2021; Makonin et al., 2013). A study of Das et al. (2021) investigated the possibility of adaptive home lighting based on activities of occupants for the interest of sustainability. The study proposed a design model for energy saving based on activity detection from a technical feasibility perspective. The several proposed possible home automation can be of interest for envisioning future lighting scenarios.

As intelligent and context-aware as smart homes can be, one crucial question is the conflicting requirements between the user's active involvement, and automation or decision made by the system (Wilson et al., 2014). Hence, it is important to understand how much control the user is willing to hand over to the systems (Shneiderman & Maes, 1997; Yang et al., 2018). The perceived control refers to how users perceive the easiness and naturalness when performing a particular activity (Park et al., 2017; Lu, Zhou, & Wang, 2009). As mentioned earlier, as domestic lighting used to be control-driven, it is increasingly important to investigate the users' perceived control of a smart home lighting system.

Several studies have combined perceived control with the technology acceptance model (van Dolen et al., 2007; Elwalda et al, 2016; Lu et al., 2009; Park et al., 2017). For instance, Lu et al.(2009) investigated the Chinese users' acceptance of instant messaging by measuring perceived ease of use, perceived usefulness, perceived (behavioral) control, and behavioral intention. Lu et al.(2009) proposed a framework combining perceived control with the technology acceptance model. The result showed that perceived control positively affects behavioral intention and actual behavior. In addition, it resonates with the original model in the relationship with perceived ease of use, perceived usefulness, and acceptance. However, although it provided an extended framework of the original TAM model with perceived control, the context of the study does not apply to the smart home domain. A study by Park et al. (2017) explored the main determinants of user acceptance of IoT technologies in a smart home environment. They conducted an online survey with more than 1000 participants who had experience with IoT technologies in a smart home environment. The study investigated a research model suitable for smart home technology adoption with the most relevant factors, such as perceived connectedness, perceived enjoyment, perceived compatibility, and perceived control. The study found that higher perceived control contributes to a higher score in the perceived ease of use, thus increasing users' intention to use, which serves as an extension of the original Technology Acceptance Model (Venkatesh & Bala, 2008). Similar results of earlier studies also showed a strong positive correlation between perceived control and perceived ease of use, but focused on the e-commerce context (van Dolen et al., 2007; Elwalda et al, 2016). Several aforementioned studies indicate that assessing perceived control can assist understanding the acceptance of a smart lighting system that is able to make decisions. However, there are only few studies investigating the relation between perceived control and adoption intention in smart home lighting systems.

1.4 Explainability in smart home systems

With a lack of perceived control, users may mistrust, misuse, or abandon a system if there is a mismatch between what the user expects and how the system behaves (Lim et al., 2009; Meerbeek et al., 2014). One of the most applied solutions for the dilemma is to provide useful information and feedback about system decisions to users (Sauer & Rüttinger, 2007). This information aims to assist users in understanding how the system works. To be more specific, explainability represents how well a user can understand the decisions in a given context (Wilson et al., 2014). Providing explanations about system decisions is an effective way to increase the users' trust and enhance the system's transparency (Adadi & Berrada, 2018; Miller, 2019). Miller (2019) argued that a deviation from expected behavior prompts the need for explanations. Miller (2019) also suggested the reason people expect explanations is that they try to understand the system behaviors by narrowing the causes and forming a model for future predictions.

There is still a lot of discussion over how to deliver explanations in a clear, precise, and understandable way to users. One trade-off about explainability is that the more complex the model, the more difficult it is to interpret and explain, and the less accurate the explanation will be (Adadi & Berrada, 2018). Explanations should be contextual, timely, experiential, and explorative (Brézillon, 1994; Alam, 2020; Mueller & Klein, 2011; Lakkaraju et al., 2017). There are several general perspectives aiming to formalize explanation types. One commonly mentioned format is the explanation focus. The explanation focus consists of two aspects: global (how the system works on a general level) and local (why it made a particular decision)(Wick & Thompson, 1992). Another approach is logical rationales, which means the explanation involves the verbal and logical description of reasoning for a decision (Lim & Avrahami, 2009; Swartout, 1977). Another perspective is examples and cases, which give users practical cases of system decisions. The example-based approach is used frequently (Doyle et al., 2003). In addition, visualization is also a powerful way to make explanations more understandable for users (Adadi

& Berrada, 2018). A previous study by Alam (2000) showed that a combination of the different aforementioned formats has also shown to result in high satisfaction in a medical AI explanation system. The study showed that compared to rationale text, users showed higher satisfaction when presented with the integrated rationale with examples or visual content.

One explanation design approach by Ferreira and Monteiro (2020) is applied in the current study to define the research scope. Three dimensions of the explanation should be considered when evaluating explanation designs: 1) in which context the explanation is presented, 2) who receives the explanation, and 3) why that explanation is needed. In the current study, the context is smart home lighting systems. This system can make context-aware decisions for home lighting, such as switching on and off the lights at a specific time, controlling a group of lights simultaneously, or changing the lighting scenes based on the activity of users. The receivers of the explanation are end users, who control their home lights and may be confused by the system's decisions. In this sense, the reason to provide the explanation is to improve the trust of the users, and to avoid concerns about the system, thus increasing the possibility of system acceptance.

However, while most studies of explainable systems are focused on technical aspects, such as the algorithm and network structures, insights from the perspective of human-centered approaches remained less investigated (Mueller et al., 2021). Similarly, industry applications, including health, recommender systems, and e-commerce with expert explanations, have received more attention than everyday consumers in this domain (Alam, 2020; Doyle et al., 2003; Swartout, 1977; Schafer et al., 1999). Far too little attention has been paid to the smart home context, especially studies on end users' perspectives (Ribera & Lapedriza, 2019). There are few smart lighting systems articles that address the aspect of explanation of the intelligent decision in a smart home lighting system. However, designing explanations in the context of smart lighting may have different requirements than explanations in other contexts. For recommender and e-commerce systems, the explanation focuses on decisions selection between different alternatives. The explanation types are usually tag-based, or preference-based, such as top-N lists, or tag clouds (Gedikli et al., 2014). A previous study showed that users strongly prefer natural language explanations rather than tag-based explanations in smart home systems (Das et al., 2021). The result indicates that user may have different expectations for explanation in smart home systems than in other systems. In addition, most explanations of other systems, such as e-commerce or recommender systems, focus on the automation level of decision and action selection. Users were recommended with recommended options, but the actual action, such as choosing a movie or buying a product, needs to be implemented by the user. Smart home lighting systems focus on action implementation.

Another aspect often overlooked in the field is the differentiation between different explanation receivers and their needs. In other words, studies on explainability, especially in the field of explainable AI, are mostly focusing on explaining “black-box” algorithms to experts. A study by Ras, van Gerven, and Haselager (2018) pointed out that explanation methods or interfaces for end users are missing. The research of Ribera and Lapedriza (2019) pointed out the lack of attention of the target explanation receivers in the explainable AI domain and proposed implications for lay user explanation design. Ribera and Lapedriza (2019) classified explanation receivers into three main groups (developers or AI researchers, domain experts, and end users). Each group has its unique goals, limitations, and preferences. As the final recipients of the decisions, their study indicated that end users should receive brief explanations in plain language. In addition, satisfaction questionnaires can be used to evaluate the satisfaction with the explanation for end users. Researchers also find that users with less expertise would prefer a mixed-method explanation with visualization and text (Szymanski et al., 2021). However, the context of the study by Szymanski et al. (2021) was mainly focused on AI algorithms. Another study by Narayanan (2018) implied that when explaining to end users, the complexity of explanation increased response times and decreased users’ satisfaction. The study focused on recommendation systems, hence needs to be verified in the smart home context.

1.5 Current study and research question

To summarize, with increasing automation and its applications in smart home systems, the potential capabilities of systems are expanding (Kumar & Pati, 2016; Das et al., 2021; Ghayvat et al., 2018; Morris et al., 2013; Makonin et al., 2013). When system decisions mismatch the expectations, users may perceive a lack of feeling in control, leading to mistrusting and abandoning the system (Karjalainen, 2013; Lim et al., 2009; Meerbeek et al., 2014; Yang et al., 2018). Providing explanations can be a helpful way for users to understand how the system works and enhance trust (Adadi & Berrada, 2018; Miller, 2019; Sauer & Rüttinger, 2007). However, although the explanation design is widely discussed in industry applications, there are few studies that address the aspect of explanation of intelligent decisions in a smart home lighting system, especially for end users (Alam, 2020; Doyle et al., 2003; Ras, van Gerven, & Haselager, 2018; Ribera & Lapedriza, 2019). The assumption of a potential transfer of findings resulting from work in other smart-home related domains to lighting systems neglects the difference in system processes that alter the need for specialized explanations. As opposed to other systems, lighting systems do not aim at offering a wide range of alternatives for the selection of users. On the contrary, lighting systems explanations put focus on explaining the current decision (action implementation) to the user rather than offering alternatives (decision and action selection). The current study therefore aims to add to work in the field, by providing insights on explanations in highly automated smart home systems which lack the necessary research in order for practitioners to give tailored explanations to users.

Therefore, the current explorative study aims to investigate what types of explanations could increase explanation satisfaction of users and which could affect a user's adoption of smart lighting systems in different scenarios. Hence, the main research question is:

To what extent could the explainability affect the adoption intention of smart home lighting systems?

In the first part of the study, the focus is on users' attitudes and understanding of smart home lighting systems in different lighting scenarios, and how to deliver a clear and understandable explanation of smart home lighting systems to the users. In addition, another goal of Study 1 is to choose proper stories with corresponding light scenarios for Study 2 by the feedback of participants. Hence, the sub-research questions for the first study are:

- SQ1.1. What is the attitude of users when receiving an explanation of a smart home system decision and why?

-SQ1.2. What are the core factors of the explanation that would affect users' satisfaction with the smart home lighting system?

-SQ1.3. Which format of explanations would users consider most optimal and why?

Based on the first study, lighting scenarios with different aspects of explainability will be created and tested in an online experiment in the second study. Hence, the sub-research questions for the second study are:

- SQ2.1. To what extent can the format of explanations and proposed lighting scenarios impact users' adoption intention?

- SQ2.2. To what extent can the format of explanations and proposed lighting scenarios impact users' perceived control, perceived ease of use, and perceived usefulness?

- SQ2.3. What is the relationship between the explanation satisfaction, adoption intention, perceived control, perceived ease of use, and perceived usefulness?

- SQ2.4. Which proposed explanation would be preferred in different lighting scenarios?

2. Study 1

2.1 Method

2.1.1 Design

A qualitative study using in-depth, semi-structured interviews was performed. The goal of the interviews was to gain insights into people's understanding and expectation of explanations in smart home lighting scenarios, and to choose proper stories with matching lighting scenarios for Study 2. Semantic analysis was used in this study (Braun & Clarke, 2006). This study has been approved by the Ethical Review Board of both the Concept Creation Lab of Signify Netherlands B.V. and the Human-Technology Interaction group at the Eindhoven University of Technology.

2.1.2 Participants

For the study, 10 participants (7 male participants, 3 female participants) were recruited through convenience sampling. Five participants were employees of Signify and the other five participants were recruited externally from the Hue user community. Participants were aged between 24 and 64 years old (M = 36.80 years, SD=11.38 years). Since they had to be available via Teams with a computer for an online interview, people with visual, auditory, and motor impairments were not asked to participate. Participants should be able to understand English well and communicate fluently in English. Participants all required to have experience with Hue lights and home automation. In addition, participants should be at least 18 years old.

2.1.3 Settings and stimulus materials

Lighting scenarios design.

Three lighting scenarios with six user stories were prepared for the study to evoke discussion. The design of the hypothetical lighting scenarios follows the principles of scenario-based design and experimental vignette (Carroll, 2000; Carroll, 1997; Aguinis & Bradley, 2014). Storyboards were used in order to keep participants interested and avoid fatigue (Erfanian et al., 2020). All lighting scenarios were not existing feature and was not used by any of the participants. The first scenario is Presence mimic. When the presence mimic is activated, the lighting system will make decisions on turning on and off certain lights at home when the users are away from home based on the previous data, mimicking their presence. The second scenario is Activity-based mode. Based on the current activity of the user and the user habit data, the lighting system makes decisions about turning on and off certain lights for users or switching to proper lighting scenes. The third scenario is Lighting assistant. The system collected not only the sensing data including the level of activity, but also the surrounding data including the weather, humidity, etc. The system can keep learning about users' habits and routines. In this way, the system can predict the most suitable lighting. The three scenarios are practical applications of context-aware and adaptive smart home lighting systems based on the original Philips Hue lighting system. These three scenarios were based on current Philips Hue lighting services and features, see Appendix A.

Story design.

In total, six stories were presented during the interview, see Appendix A. The stories were co-created by experienced Philips Hue users and developers based on the corresponding scenarios. All the stories followed a four-step scenario design. First, the story introduced a fictional person and a short process of how the person adopted a smart home lighting system. Second, the illustration briefly depicted the main function of the system and how it works from a systematic perspective. Third, there was a specific home situation related to the lighting system autonomous decision that was happening to the fictional person. Last, the fictional person expressed his/her confusion about the current situation. The situation was designed as a manipulation to confuse or annoy the participant.

Explanation design.

In this section, the focus was on designing different explanations that will explain the confusion or frustration in the stories. In other words, why they were receiving certain light settings in the scenarios. Adopting the principles for Human-AI systems, the following design guidelines were considered for all variants of explanations:

- **Simple and short**: The information provided to users should be short, simple, and in plain language (Ribera & Lapedriza, 2019). Reducing complexity of the explanation is essential to increase users' satisfaction (Narayanan et al., 2018). In the explanation design, the length of the explanation was shortened to one sentence.

- **Visualization with supporting text-based information**: Using a combined explanation format with visual and textual elements leads to higher ease of use and understanding (Szymansk et al., 2021). In the current explanation design, an informative icon with explanation was provided.
- **Timely**: Explanations are only useful in crucial situations, such as status changes, and need to be offered in a timely manner to remain relevant (Alam, 2020). The explanation was given after the scenario stories happened via the Hue app notification.
- **Relevant:** Relevant occurrences, such as anomalies or expectation violations, require an explanation (Sørmo et al., 2005). The explanation is only given when the participants experience confusion or annoyance by unexpected lighting.
- **Contextual**: The notification gives the user the context of the system behavior (Doyle et al., 2003). Additionally, a system status was provided.
- **Local/global**: Considering the context and scenario given to the users, we focused on the particular decision that is made. A study of Kulesza et al.(2013) suggested that the completeness of explanation is important for users to understand the system. Hence, a short global explanation is given in the scenarios to the participants.
- **Logic / why**: The explanation involves reasoning for a certain decision (Swartout, 1977; Miller, 2019).

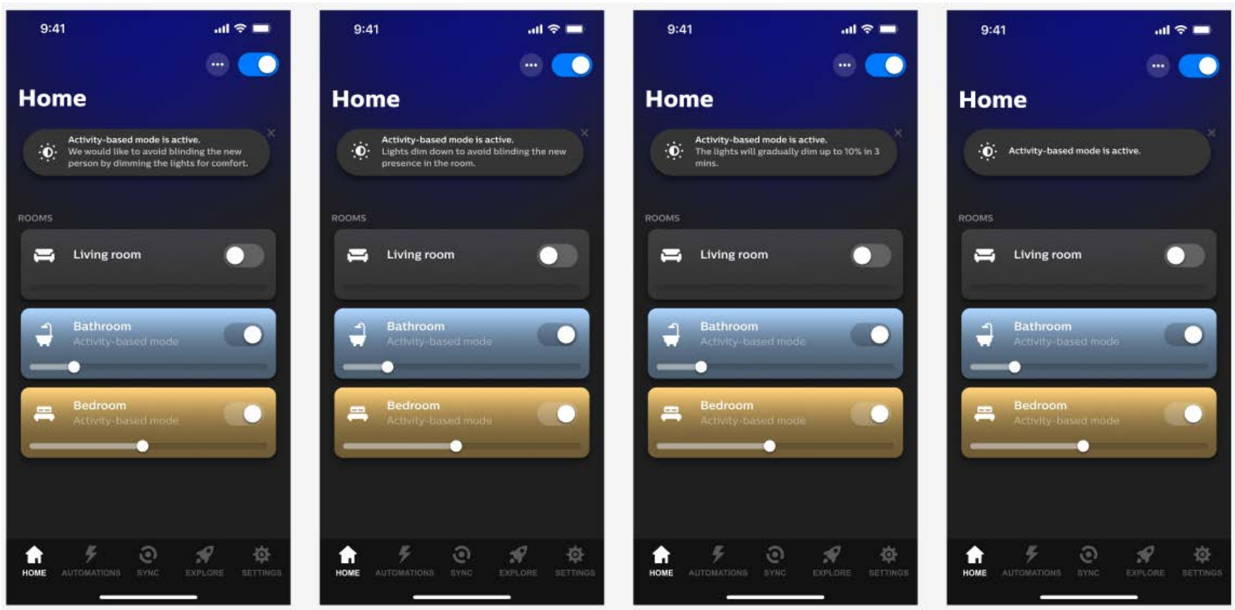
All principles above were applied to all different types of explanations. The notification interface was designed based on the existing interface of the Hue app. For all the options, there was the same icon with the same system status message in the notification. Next, based on the guidelines, there were four different types of information on a notification page for participants as follows, see Figure 2. The four variants of explanations were chosen by the consideration of Signify.

- **User-centered explanation**: As suggested by Li and Mao (2015), creating a sense of human touch of a virtual advisor has a positive influence on the user. Systems with a communication style that matches the user's language habits are able to arouse the user's trust and enjoyment. In addition, adding a pronoun in communications could enhance trust. The use of "you" and "we" pronouns is recommended by customer service communication to emphasize the customer (Bacal, 2011). Therefore, the message was based on the interest of the user in the first plural person, offering explanations with a personal touch to the participants.

- **System-centered explanation**: Compared with the user-centered explanation, the system-centered explanation provides the same amount of information, but in a less social, more matter-of-factly way. Providing participants with explanations in a neutral manner, the explanation focused on the functionality of the system.
- **Plan-based information**: Compared to explaining what happened in the past situation, this notification focused on the possible future impact of the system.
- **No explanation**: In this notification, only the system status was provided as well as all the other options. This is the control group.

Figure 2

Notification page with explanations in story 2 with scenario activity-based mode (See Appendix A)



(1) user-centered (2) system-centered (3)Plan-based (4) No explanation

Note. the explanation is linked to the story that when the user was present in the bathroom in the morning, the lights dimmed down when his/her partner entered the same room.

Philips Hue lighting system.

The scenarios were based on the original Philips Hue lighting system with the cooperation of the Concept Creation Lab of Signify Netherlands B.V. ("Slimme verlichting," n.d.). The explanation and notification page was in line with the design of Philips Hue app. The original Philips Hue system is a domestic connected lighting system with sensors, bridges, and lighting points. The current lighting system contains multiple control methods (physical switch, remote, app, and sensors), and only includes basic automation that is configured by the user.

2.1.4 Procedure

When participants were recruited, they received the informed consent form and were given enough time to read it. They were asked to digitally sign the consent form if they had no questions about the study and agreed on the terms on the consent form. When the participants joined the online Teams meeting, they were welcomed by the researcher and were given a short introduction about the goal of the study. Participants were allowed to ask questions at any time during the study and were allowed to quit at any time. Then the video recording started.

The participants received an online semi-structured interview, see Appendix B. In the interview, after a short introduction, they were asked to talk about the general usage of their sensors, Philips Hue lights, and Philips Hue automation at home. They were asked to share their past experience with lighting automation at home. Then they were presented with scenarios and stories via the shared screen by the researcher (see Appendix A). They were asked about their expectations for the situation, their level of confusion or annoyance, and how relevant these feel to their own case. Then, four explanations for the specific story were presented to the participants at the same time. They were asked which explanation they preferred and the reasons for the explanation preference. In addition, they were requested to modify the existing explanation in terms of formatting, phrasing, and the user interface. Following the same steps of each scenario and story, participants were asked which story explanations they considered most beneficial. Moreover, they were invited to co-create the whole story with the researcher by combining their own experience. At the end of the interview, participants were thanked by the researcher for their voluntary participation.

2.1.5 Data analysis

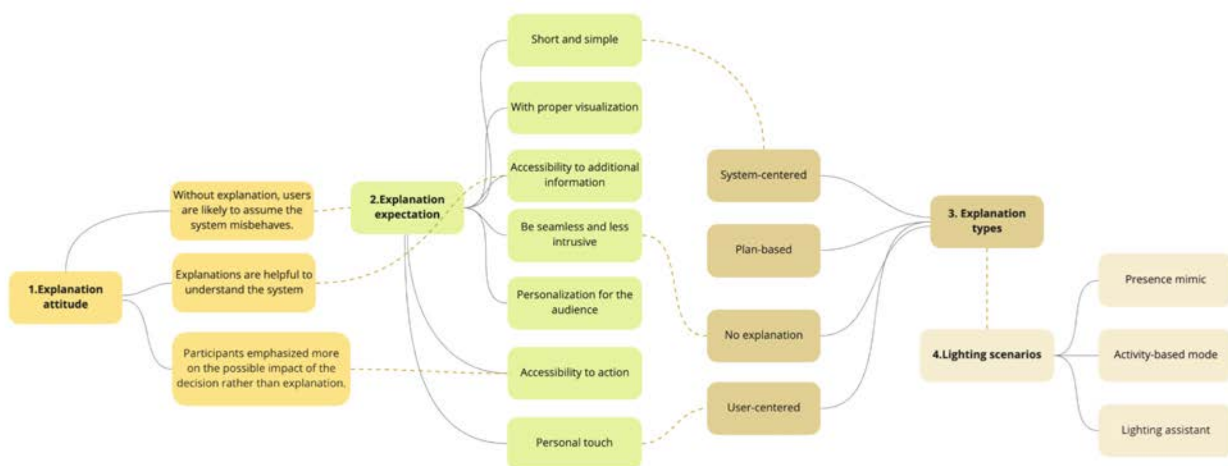
The data acquired through the interview was transcribed from video recordings and analyzed with the thematic analysis method. The study followed the thematic analysis procedure suggested by Braun & Clarke (2006). During the procedure, Miro was used as the whiteboard software tool. There were several coding stages during the analysis. First, the author generated initial coding based on the transcripts and original recordings. In the next step, potential themes were identified by reading and re-reading the transcripts. Higher-level sub-themes and overarching elements were created. The research question about the explainability of the smart home lighting system informed this process. At the next stage, quotations were matched to corresponding themes. Themes were defined and renamed in this stage. In the last step, themes were finalized.

2.2 Results

In this chapter, the results of the thematic analysis are presented. First, an overview of the themes was produced, see Figure 3. Four themes arose from the analysis, which are explanation attitude, explanation expectations, explanation types, and lighting scenarios. These four themes will be discussed in more detail below.

Figure 3

Main themes and sub-themes of the analysis



2.2.1 Theme 1: Attitude towards explanation

The first insight is that when experiencing confusion, users are likely to assume the system misbehaves. Participants reported experiencing confusion or frustration in all stories. Eight participants assumed the system misbehaved or performed poorly. Some remarks are: *"I would be wondering if the system is actually working" (P1, P4, P6, P7); "I think the system wasn't robust. It could annoy me. I would want a system that takes away my responsibility, not that I have to babysit it." (P5)*

The second insight is that all participants consider explanations helpful in understanding the system. All participants acknowledged the usefulness of having an explanation, such as assisting them to understand how the system works. Some remarks are: *"An explanation could be handy. Otherwise, I might be doubting is it picking the wrong scene."(P1, P7); "I want to see the logic, how it works."(P2, P10); "If I understand why this is happening and I know how to change it, even if I don't like it, I might still appreciate it."(P8).*

Furthermore, all participants emphasized the importance of having control of the decision alongside explanation. Some participants clearly paid more attention to how to possibly have an impact on the decision, including switching the service off, switching back to the previous lighting state, or overriding the system. Participants started to talk about all possible ways to impact the decision without being reminded. Some remarks are: *"The explanation is great. But I would also give the option to override it, like to impact it somehow."(P1, P3, P4, P9); "I think a sense of control is very important. Aside from the explanation, I would like to have an option to change the behavior, turn off the feature or change the settings, like a small click here to change" (P8).*

2.2.1 Theme 2: Expectation for explanation

Participants expected the explanation to be short and simple. Eight participants mentioned that they prefer less text to read with the same amount of information. The message should be simple to understand, only including the critical information of the decision. Some users' remarks are: *"For me the sentences are complicated, I've been reading the text for the fourth time"(P6); "Being simple, make it easier to understand."(P10); "I don't want to read too much, so as simple as possible. Better not too many lines."(P2)*

One important remark is that all participants proactively mentioned the possibility in controlling the system to alter the decision along with the explanation. Some remarks are: *"The way you write it here makes sense to me. But it's not the way I want it. I would also like to change the settings."(P9); "I also want an action to change, like a button next to the* *explanation."(P3); " I do trust the system, maybe I would not do much, but I would like to have the option to override with the explanation."(P6)*

The visualization with text in explanation could make the explanation easier to digest. Six participants commented on the icon in a positive way. They mentioned that having an icon helps to attract attention and understand the information. However, several participants also mentioned the accuracy of the icon with the context. Some remarks are: *"The icon is good, it catches my attention. It makes sense to me."(P4); " The icon can give you info, so it's great. Just change the eye one. It associates with being watched."(P7)*

Six participants noted that availability of additional information would be ideal to get a general understanding of the system. This additional information could be details of how the data is used, what is the general lighting schedule, or a global explanation of how the system works in general. Some users specifically mentioned the need for a global explanation at the beginning of adapting the system. Some remarks are: *"It could be nice to know more if you click on it. I maybe not always want to know more but I want to have the option. Especially in the beginning when you gain trust. "(P4); "When you start using the system, you gain an instruction of how it works, you can go through all the different types of interaction. "(P6)*

Interestingly, five participants addressed the fear of being bothered by the explanations. Some suggested that the message should not be a pop-up message, and several mentioned that the message should disappear automatically after some time. Some remarks are: *"I'm worried that more activities would make things piled up, a lot of buttons to swap. ideally, it only has one notification there, don't bother me"(P2); "I would like to have information accessible somewhere, but not pop-up. That's annoying. "(P9)*

There were several topics mentioned by a few participants. Two users mentioned the concerns of multiple users. They suggested that the explanation should be targeted to the specific user, or tailored to different members who are under the same roof. As Participant #7 explained, *" I have a technical background, I like these kinds of things. For my wife and kids,* *they need to understand it. I would like to make it different for somebody else".* Another topic being specifically mentioned is the communication style by two participants. As Participant #4 stated, *"I like to feel more humane. It gives me some personal thought."* Using the second pronoun as a personal approach is also mentioned by some participants. Participant #8 said, "*I would like to be 'the light scene is customized to you'. The saying, to you, makes me feel nicer.*"

2.2.3 Theme 3: Explanation types

In most of the stories, participants preferred the user-centered explanation or the system-centered explanation more than the plan-based description or no explanation. Participants considered the former two similar, and more informative and clear to show the reasoning behind the decision.

Some participants preferred the user-centered explanation to the system-centered explanation due to the hedonic aspect of the message. Some remarks are: "*It's nice, I like it's telling me it's for my comfort. It feels that it care about my experience."(P6); "It's more humane. There is a personal attitude, which I like. I like it to be less formal, less official."(P4)* In some stories, some participants disliked the user-centered explanation due to the text length, or the tone of the information. Some remarks are: *"It's too long, and it's creepy. It feels like some of my data is harvested, I wouldn't like having a smart agent at home, I would like to have more control of my own life."(P5)* The use of pronoun also being considered improper, as participant #3 suggested, *"I don't like the 'we', either there is a fictional person, like Siri, then it makes sense. Now it's like, who is it connected to? it's weird"(P3)*

In general, several participants who preferred the system-centered explanation over the user-centered explanation stated that it's shorter in text and it's more precise. Some remarks are: *"It's explicit, precise and short. I prefer the sterile way of information. Also it's the right amount of information. I don't not need more."(P5); "I like the other one [user-centered explanation] telling me the story... but this one [system-centered explanation] has enough information, it's shorter. The shorter, the more efficient."(P6).* However, few participants argued that the tone of the information was not preferred in the explanation, as participant #4 considered the explanation *" too objective and robotic."(P4)*

In some stories, few participants preferred the plan-based description, or a combination of the plan-based description and explanations. They claimed that information about what the system will do next would put their mind at ease. As participant #6 suggested, "*I'll be concerned that the burglar will think that I'm not at home. And I will be relieved if I know my lights will be on in 35 mins. So this is the solution to my concern.*". However, in some stories, the plan-based information confused the participants. Some participants also expressed that the plan-based one is unnecessary, or may make them feel like they are losing control. Some remarks are: *"It doesn't make sense, I don't need this kind of information. I think if you have experience more often, you'll know it will dim up"(P10); " it's forcing or pushing me, it decided things for me. It's like 'we decided this will stay the same until we decide to change'."(P4)*

Three participants preferred the "no explanation" option during all interviews only when the explanation is still accessible. They mentioned the fear of having too many texts constantly within the app and chose to click notification if more explanation was needed. Participant #10 explains, *"If you every time see a very long message, it's not necessary. I think it's clear that it's active. If I click on it, it explains me more, like a two-step explanation"(P2).* Most participants ignored the no explanation option during the study. Some of them showed negative responses to the due to the lack of information. Participant #5 mentioned, *" It doesn't really provide me with input, what I can do to resolve it."*

2.2.4 Theme 4: Explanation in different lighting scenarios

In the first scenario presence mimic, all participants showed a positive attitude towards adopting the system. Although most participants were confused or annoyed, they suspected that there was a system fault rather than a system decision. Their expectation is to re-run the application, or consult the customer services, rather than seeking an explanation. When talking about explanation, half of the participants preferred the combination of the plan-based description and other explanation.

In the second scenario activity-based mode, all participants expressed the willingness to have activity-based lighting mode at home. Their concern mainly lies in the performance of the system, especially for multiple users who may express different interests and needs in the lighting. They talked about the possible benefit the system can bring, and the curiosity to see the implementation. In terms of explanation, almost all participants didn't mention two options: plan-based description and no explanation. The number of people who preferred the system-centered explanations is similar to those who preferred user-centered explanations.

In the last scenario lighting assistant, although most participants showed a willingness to adopt the system, they expressed more doubts and uncertainty about the performance of the system. In this scenario, they are more aware of the data usage of the system. Several participants showed a strong concern about the accuracy of the recommended lighting. Some mentioned that the recommendation may not be the preference, even for the good of the user. Several users mentioned they preferred a combination of explanation with the plan-based description.

2.3 Discussion

The most important insight from the online semi-structured interviews is that most participants have a positive attitude towards having an explanation of a smart home lighting system decision. They consider the information helpful to understand the system. The results showed that providing explanations can help them to understand and learn about the system, which is consistent with previous studies (Wilson et al., 2014; Miller, 2019). It is also noticeable that without the explanation, participants were likely to assume the system is misbehaving or there was a performance problem, thus leading to mistrust of the system. However, the timing of the explanation should be decided carefully since a few participants suggested only showing the information when it is necessary. This is consistent with the study of Sørmo et al. (2005), which suggested that explanations should be in response to relevant situations such as a violation of expectations or system anomalies.

Another point worth mentioning is the different expected aspects of a good explanation for the end users. Participants expected an explanation to be short and simple with proper visualization such as icons. This is consistent with several studies in delivering explanations to end users in human-AI systems (Szymanski et al., 2021; Ribera & Lapedriza, 2019). Participants mentioned the explanation should be seamless and less intrusive, which matches the finding of Alam (2020) that explanation should only help at critical times. Participants request to have detailed information accessible in the system, especially the global information on how the system works. This finding is in line with the study of Kulesza et al.(2013) that end users also need global explanations as well as local explanations. As mentioned in section 1.4, the mixed-modality with texts and visualization was also preferred by the participants, which was suggested by Szymanski et al.(2021). In general, the explanation design were appreciated by the participants.

Based on the result of Study 1, the design of Study 2 can be adjusted to reflect the findings. First, although the plan-based description of the system was appreciated in story 1, it was not appreciated in other stories. The reason for the plan-based description being preferred in story 1 might be that users can not see the status of lights when they are away. Therefore, knowing the light changing plan can increase the perceived control of the system when they cannot see the light status themselves. In other stories, some participants found the plan-based description superfluous or patronizing. Moreover, there is little information about how the system works. Hence, the plan-based description was not chosen in Study 2. Second, three stories (story1, story2, story 4, see Appendix A) with matching scenarios were chosen based on the feedback of the participants. Compared to other stories, the three chosen stories were considered more likely to confuse participants, therefore the explanations were more needed.

The qualitative results of Study 1 showed a positive attitude of participants towards explanation in smart home lighting systems, but it was still yet unknown how the explanation can have an impact on adoption intention. The preference between user-centered explanation and system-centered remained unclear. Therefore, Study 2 aimed to assess the explainability of scenarios and explanation on adoption intention, as well as perceived control, perceived ease of use, perceived usefulness. The relationship between the aforementioned constructs were investigated. Moreover, the explanation satisfaction between user-centered explanation and system-centered explanation was tested.

3. Study 2

3.1 Method

3.1.1 Design

The second study was an online experiment with three proposed scenarios and three explanations of the smart lighting system. The independent variable of the study was the different formats of explanation of the smart home lighting system and three scenarios corresponding to three scenarios of the smart home lighting system. The main dependent variable was the user's adoption intention. Perceived control, perceived ease of use, and perceived usefulness were measured to examine how they possibly mediate the effect of explanation on users' adoption intention. The study used a between-subjects design of three scenarios (presence mimic, activity-based mode, lighting assistant) * three explanations (user-centered, system-centered, no explanation). The manipulation in the different explanation conditions and different scenarios was based on the results of Study 1, see section 2.3. This study was approved by the Ethical Review Board of both the Concept Creation Lab of Signify Netherlands B.V. and the Human-Technology Interaction group at the Eindhoven University of Technology.

3.1.2 Participants

All participants were Philips Hue users who used the Philips Hue app. All participants were recruited from the Hue beta community, which is a platform for Hue users to give feedback or participate in studies. Participants had to be at least 18-year-old. All of them were required to have good English skills and be able to understand the questionnaire in English. Additionally, participants required to have experience with Philips Hue systems.

In total, 452 participants participated in the study. The sample consisted of 34 females, 413 males, and two non-binary. Three participants preferred not to state their gender. The reason for this asymmetric distribution was because the Hue Beta community is predominantly male in composition. The average age of the participants was 42 (M = 41.97, SD =10.60, Min = 19, Max = 74) with 16 missing values. The sample consisted of 20 nationalities, mostly affluent countries from the global North, including the United States (N=122), the United Kingdom (N=85), the Netherlands (N=82), Germany (N=58), France (N=27), and Canada(N=22). The sample size of other nationalities did not exceed ten. The sample descriptive information is listed in Table 1.

Table 1

Descriptive information of the sample

	Option	Count (*N*)	Percentage (%)
Gender	male	413	91.37
	female	37	7.52
	non-binary	2	0.44
Age	18-24	17	3.76
	25-34	98	21.68
	35-44	142	31.42
	45-54	125	27.65

	55-64	43	9.07
	>64	29	6.42
Nationalities	United States	122	26.99
	United Kingdom	85	18.81
	Netherlands	82	18.14
	Germany	58	12.83
	France	27	5.97
	Canada	22	4.87
	Others	56	12.39
Frequency of using Philips Hue app	Almost everyday	317	70.13
	2-3 times a week	90	19.91
	Several times a month	40	8.85
	Several times a year / never	5	1.10
Philips Hue lights number	0-10	83	18.36
	10-20	127	28.10
	20-30	98	21.68
	30-40	63	13.94
	>40	81	17.92
Years of experience with Philips Hue system	Less than 1 year	7	1.11
	1-2 years	75	16.59
	3-5 years	148	32.74
	More than 5 years	224	49.56

Participants were randomly assigned to one of nine conditions using a randomization feature in Qualtrics, in a 3x3 matrix (scenario x explanation type); see Table 2 for the distribution of participants across cells.

Table 2

Sample size for all conditions

	User-centered explanation (*N*)	System-centered explanation (*N*)	No explanation (*N*)	Total (*N*)
Presence mimic (*N*)	54	55	54	142
Activity-based mode (*N*)	45	57	40	172
Lighting assistant (*N*)	43	60	44	138
Total (*N*)	163	142	147	452

3.1.3 Settings and stimulus materials

Three lighting scenarios with stories were presented to participants, see Appendix C. Additionally, Qualtrics is used to conduct the online survey in the study. The scenarios followed the principles of scenario-based design and experimental vignette (Carroll, 2000; Aguinis & Bradley, 2014). In each scenario, four illustrations with descriptions were shown to the participants (see Appendix C). The first illustration introduced how the service is adopted by a fictional character. The second illustration introduced what is the service and how the service works. Then the third and fourth illustrations depicted a fictional story when the lighting service made a decision that confused or annoyed the fictional character in the home context.

In each scenario, there are three corresponding explanations, see Appendix D. The interfaces used in the study were based on the home page of the Philips Hue app. Participants were shown one notification interface of the corresponding explanation. The notification consisted of one icon in the left, one sentence with system status, and one explanation that differed from scenarios. The detailed descriptions for each scenario and corresponding explanations are as follows:

Scenario presence mimic.

1) Recently Tony's neighbor got burgled. He was about to go on a vacation and wanted to have a quick way to improve his safety. Tony noticed the automation "presence mimic" in the hue app. 2) This service is tailored to Tony's lighting habit, turning on and off his lights as if he is at home. It creates an impression of "you're at home" when you're away. Before he went on vacation, he turned on the "presence mimic". 3) As Tony's waiting for food on his vacation, he started wondering what the lights are doing. It's 9:00 pm, and usually, he's watching TV at home with the lights dimmed. 4) He turns on the app. It shows the "presence mimic" is on, but somehow, all the lights are off. He is wondering, "Why are my lights off? "

User-centered explanation. The notification part indicates: "Presence mimic is active"; "We found you're usually out of home at this time in the past month".

System-centered explanation. The notification part indicates: "Presence mimic is active"; "In the past month, the lights are usually off at this time".

No explanation. The notification part indicates: "Presence mimic is active".

Scenario activity-based mode.

1) Tom visited Kylie recently. In her home, he saw the lighting change automatically based on what he was doing. "This is cool, I also want to try it" He decided to try the system at his home. 2) Based on Tom's activity, this lighting system can provide the most suitable scenes by using multiple sensors at his home. Tom tried it in his bedroom and bathroom, hoping to automate his lighting. 3) One day in the morning, Tom got up and walked to the bathroom. As he walked in, the light starts brightening up slowly, as always. He started to check his teeth in the mirror. 4) At the same time, his partner walks into the bathroom. The lights dim down. "I can't see my teeth now," Tom thinks, "Why are my lights dimmer?"

User-centered explanation. The notification part indicates: "Activity-based mode is active"; "We would like to avoid blinding the new person by dimming the lights for comfort".

System-centered explanation. The notification part indicates: "Activity-based mode is active"; "Lights dim down to avoid blinding the new presence in the room".

No explanation. The notification part indicates: “Activity-based mode is active”.

Scenario lighting assistant.

1) John is a tech fan. He hates to walk a long way to reach the switch for lights or open the app for a small change in lights. He has been trying the “lighting assistant” recently. 2) The system can keep learning about his habits and routines. The system collected not only the sensing data including levels of activity, but also the surrounding data including the weather, humidity, etc. In this way, the system can predict the most suitable lighting. 3) It was a gloomy day. John got home late from a long drive. He opened the door, with a feeling of relief. Then he started to notice that the lights were different from other days. 4) They are much brighter than usual. In addition, some lights that he used to turn off, are now turned on with a bright scene. John is confused, “Why are the lights different?”

User-centered explanation. The notification part indicates: “The light scene is customized for you”; “With insufficient light exposure, we increase the brightness for your health”.

System-centered explanation. The notification part indicates: “The light scene is customized for you”; “The brightness is increased based on the insufficient light exposure”.

No explanation. The notification part indicates: “The light scene is customized for you”.

3.1.4 Measurements

Manipulation check.

One survey after each scenario was used for the manipulation check. The goal of the manipulation check was to ensure that the participants were likely to read the explanation after the situation described in three scenarios. In the scenario activity-based mode and lighting assistant, participants were asked to indicate their agreement to the three statements in 5-point Likert scale ranging from “strongly disagree” (1) to “strongly agree” (5): “In my case, I would be annoyed by the situation; I would be confused by the situation; I would check the Hue app after the scenario happened”. Due to the difference in the scenarios, the last item with the scenario presence mimic was slightly altered: “If I use the service, I would check the Hue app for my lighting status when I'm on vacation”. The three questions were developed specifically for this study by the researcher.

Dependent variables and demographics.

Another questionnaire was used in the study to measure control variables and demographics, see Appendix E. The questionnaire included three parts: 1) explanation satisfaction; 2)evaluation of the smart lighting service; 3)demographic questions. In the first part, several items were derived from the full explanation satisfaction scale in the explainable AI domain to evaluate the explanation. In the second part, the evaluation of the smart home system was sent to all participants with corresponding service names to assess the perceived control, perceived ease of use, perceived usefulness, and adoption intention for the specific service. In the last part, participants were asked to fill in their demographic information, their usage of the original Philips Hue system, and the construct of self-efficacy. Each item linked to the constructs was assessed using a 5-point Likert scale, ranging from strongly disagree (1) to strongly agree (5). Due to the modifications to the original scale (see each original scale reference below), the reliability coefficients for all scales were checked. The scales were composed of the following items:

- Scale *Explanation Satisfaction,* adapted from Hoffman et al.(2018): “From the explanation, I understand how the presence mimic/activity-based mode/lighting assistant works; This explanation of how the presence mimic/activity-based mode/lighting assistant works is satisfying; This explanation of how the presence mimic/activity-based mode/lighting assistant works is useful to my goals; This explanation lets me judge when I should trust and not trust the presence mimic/activity-based mode/lighting assistant”(Cronbach’s $\alpha = .98$). For groups with no explanation, this scale was not tested.

- Scale *Perceived control,* adapted from Venkatesh (2000) and Lu et al.(2009): "I would feel I am in control of the presence mimic/activity-based mode/lighting assistant; I would find it easy to get the presence mimic/activity-based mode/ lighting assistant to do what I want it; I would be able to operate the presence mimic/activity-based mode/lighting assistant in my own way"(Cronbach's α = .85).
- Scale *Perceived ease of use,* adapted from Davis (1989):" I would find the presence mimic/activity-based mode/lighting assistant easy to use; my interaction with the presence mimic/activity-based mode/lighting assistant would be clear and understandable" (Cronbach's α = .89).
- Scale *Perceived usefulness,* adapted from Davis (1989):" Using the presence mimic/activity-based mode/lighting assistant would improve my experience with lights at home; I would find the presence mimic/activity-based mode/lighting assistant useful in my home" (Cronbach's α = .89).
- Scale *Adoption intention,* ada*pted from Moon and Kim (2001):" I* would use the presence mimic/activity-based mode/lighting assistant on a regular basis in the future; I would frequently use the presence mimic/activity-based mode/lighting assistant in the future; I would strongly recommend others to use the presence mimic/activity-based mode/lighting assistant" (Cronbach's α = .90).
- Scale *Self-efficacy*: " I feel confident using the Hue system; I feel confident setting up Hue automation and routines; I feel confident configuring the lights myself" (Cronbach's α = .81).

3.1.5 Procedure

All participants were invited via email. Participants were asked to read the informed consent of the study and voluntarily decided to participate before starting the survey. They gave their consent for using their anonymized data in an academic research publication. Then they were randomly allocated to one scenario by Qualtrics. Next, they were asked to read attentively to the story, and fill out three manipulation check items. After the scenario was finished, they were randomly allocated again to one explanation (or no explanation) corresponding to the scenario. They were asked to read through the notification page. After this phase, they were asked to fill in the 4-item explanation satisfaction scale. Participants who received no explanation did not receive the same scale. Then, participants were asked to fill in a questionnaire to measure all dependent variables and demographics (see section 3.1.3).

3.1.6 Statistical analysis

To test the relationship between the explainability, perceived control, perceived ease of use, perceived usefulness, and adoption intention, two-way between-subject ANOVAs were performed to examine the difference in three explanations types and three scenarios. Based on the results, Tukey post-hoc tests were performed if deemed necessary. Pearson correlation coefficients were tested in order to gain an understanding with the correlation among all constructs. In addition, differences in explanation satisfaction were examined using two-way between-subject ANOVA. However, the Shapiro-Wilk test indicated that some of the constructs (explanation satisfaction, perceived control, perceived ease of use, perceived usefulness, and adoption intention) were not normally distributed, thus indicating the normality was violated. All other assumptions, such as homogeneity, met the requirements. After inspecting the data distribution with histograms, due to the small deviations to normality, two-way ANOVAs were considered for the current analysis. The results of ANOVA should be interpreted with caution.

3.2 Results

3.2.1 Data preparation

Manipulation check.

After the scenario was presented, the participants were asked to answer three questions about their level of general confusion (level of annoyance, confusion, and possibility for app checking, see section 3.1.3) as a manipulation check. Four observations that resulted in the lowest score (strongly disagree) in all manipulation items were dropped because the manipulation did not create confusion. For each scenario, an independent sample t-test was performed. In all three scenarios, the confusion score in presence mimic (M = 3.90, SD = .07), in activity-based mode (M = 3.83, SD = .07), and in lighting assistant (M = 3.27, SD = .08) were all significantly larger than the medium score (M = 3.00) with p<.001. All three scenarios showed a decent manipulation to create confusion. The result indicated that participants were more likely to be confused or annoyed, and would see the explanation after the scenarios happened.

Missing data and outlier detection.

The collected data were inspected regarding missing data and outliers. There were sixteen missing values in the age and numbers of Philips Hue light bulbs. The reason for the missing value is that the data were collected directly from the user profile of Beta community with users' permission. However, age or numbers of Philips Hue light bulbs were not independent variables or mediation factors in the study. Z-score was used for outlier detection. A z-score bigger than 3 or smaller than -3 is considered as an outliner. The z-score was calculated for all dependent variables. Six observations in the self-efficacy scale were dropped with a z-score smaller than -3. All other z-score values from the constructs were within the range of [-3, 3].

Reliability check.

For all the multiple items adapted from original scales, internal-consistency reliability was checked. Most constructs, including explanation satisfaction, perceived control, perceived ease of use, perceived usefulness, adoption intention and self-efficacy, are acceptable with a Cronbach's alpha larger than 0.80. However, the reliability of the confusion items (manipulation) didn't exceed the expectation score 0.7 (Cronbach's α = 60). Dropping any items of the scale did not result in a reliability score higher than 0.7.

3.2.2 Data analysis

Descriptive statistics.

Descriptive statistics were the general value of the constructs with manipulations. All means in descriptive statistics were larger than 3.0, indicating that the participants' responses to the scenario and smart home lighting system were relatively positive. Means and standard deviations of the constructs are illustrated in Table 3.

Table 3

Means and standard deviations of the constructs = mean (standard deviation), with UCE = user-centered explanation; SCE = system-centered explanation; NE = no explanation. N =442.

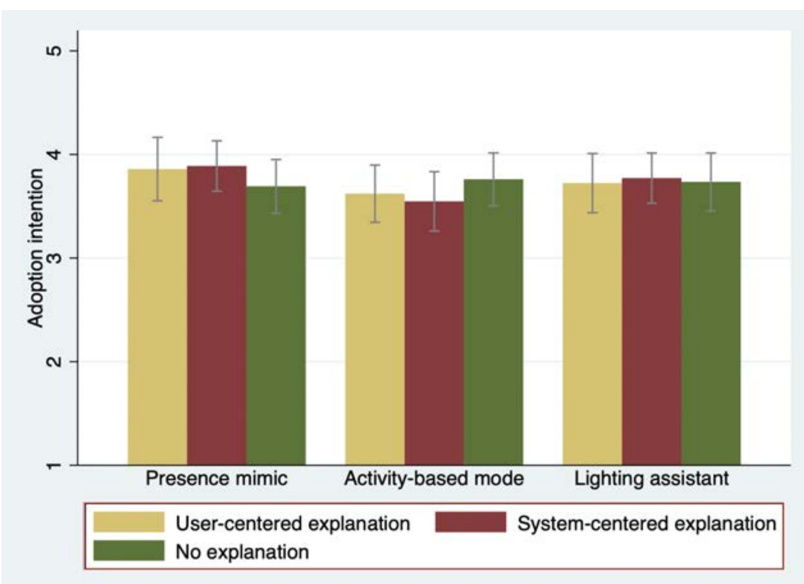
		Perceived control	Perceived ease of use	Perceived usefulness	Adoption intention	Explanation satisfaction
Presence mimic	UCE (*N* = 52)	3.05 (1.07)	3.75 (0.98)	3.99 (1.09)	3.85 (1.12)	3.87 (1.07)
	SCE (*N*= 54)	3.43 (1.15)	4.06 (0.95)	4.21 (0.87)	3.88 (0.90)	4.47 (0.66)
	NE (*N* = 52)	3.45 (1.06)	3.64 (1.05)	3.95 (0.88)	3.69 (0.95)	N/A
Activity-based mode	UCE (*N* = 44)	3.51 (1.05)	3.61 (0.92)	3.78 (0.92)	3.62 (0.93)	3.62 (0.95)
	SCE (*N*= 56)	3.29 (1.04)	3.66 (1.03)	3.79 (1.03)	3.54 (1.09)	3.98 (0.70)
	NE (*N* = 39)	3.70 (1.00)	3.60 (1.04)	4.15 (0.78)	3.76 (0.80)	N/A
Lighting assistant	UCE (*N* = 41)	3.42 (1.11)	3.71 (1.01)	4.06 (1.06)	3.72 (0.93)	3.87 (0.81)
	SCE (*N*= 60)	3.28 (0.94)	3.70 (0.90)	3.90 (1.04)	3.77 (0.95)	4.00 (0.84)
	NE (*N* = 44)	3.53 (0.99)	3.67 (1.01)	3.96 (0.91)	3.73 (0.94)	N/A

Adoption intention.

First, to answer SQ2.1, it was tested whether format of explanations and scenarios has an impact on users' adoption intention. The adoption intention in three scenarios and three explanation types can be seen in Figure 4. A two-way between-subject ANOVA was conducted to compare the effect of scenarios and explanations on adoption intention. The analysis revealed that there was no statistically significant interaction between the scenarios and explanation with $F(4, 433) = 0.60$, $p = .66$. Simple main effects analysis showed that both explanation ($p = .99$) and scenario ($p = .33$) did not have a statistically significant effect on adoption intention.

Figure 4

A bar graph with confidence intervals on adoption intention for all explanations and scenarios, error bars represent 95% confidence interval.

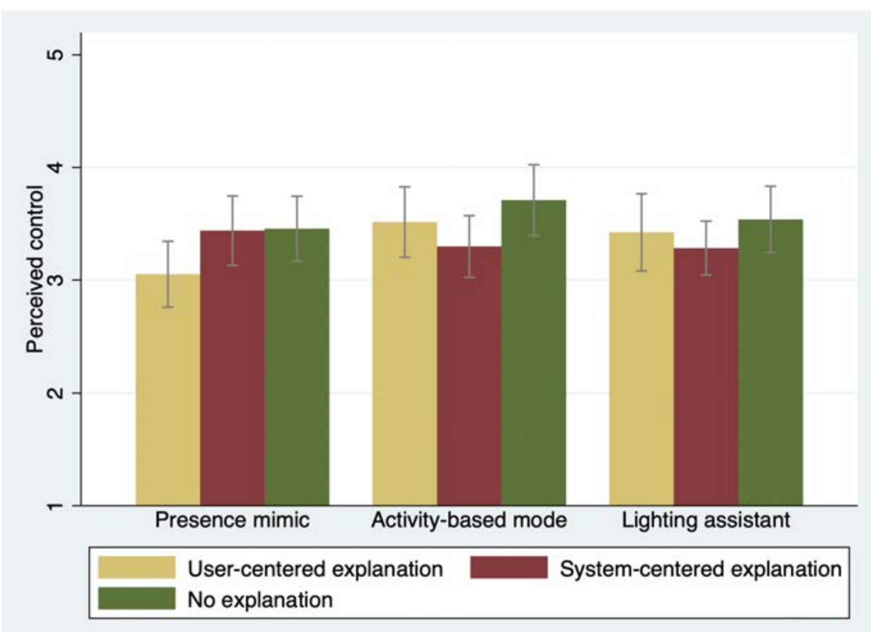


Perceived control, perceived ease of use, perceived usefulness.

To answer SQ2.2, *a* bar graph was created to inspect the effect of explanations and scenarios on the perceived control, see Figure 5. First, a two-way between subjects ANOVA was performed to analyze the effect of scenarios and explanations on perceived control. The result showed that there is no statistical significant difference in interaction between the scenarios and explanation (F(4, 433) = 1.36, p = .26), nor the main effect on perceived control by scenarios (p = .29) or explanation (p = .10). By observing the bar graph on perceived control, it was noticeable that perceived control in no explanation group was slightly different than other groups in Figure 5. For further investigation, considering the difference in sample sizes and variances, a Welch's t-test was performed to compare the perceived control between group with explanation and group without explanation (Delacre, Lakens, & Leys, 2017). The result showed that the group without explanation (N = 135, M = 3.55, SD = 1.01) scored higher on perceived control than the groups receiving an explanation (N = 307, M = 3.32, SD = 1.06). There is a small negative effect of explanation on perceived control with a difference of 0.23, t(268) = 2.15, p = .03.

Figure 5

A bar graph with confidence intervals on perceived control for all explanations and scenarios, error bars represent 95% confidence intervals.



A two-way between-subject ANOVA was performed to analyze the effect of scenarios and explanations on perceived ease of use, see Figure 6. The result showed that there is no interaction effect between the effects of scenarios and explanations with $F(4, 433) = 0.69$, $p = .59$. Simple main effects analysis showed that scenarios did not have a statistically significant effect on perceived ease of use ($p = .22$). Simple main effects analysis showed that explanations did not have a statistically significant effect on perceived ease of use ($p = .30$). In addition, a two-way between subjects ANOVA was performed to compare the effect of scenarios and explanations on perceived usefulness, see Figure 7. No statistically significant interaction was found between the effects of scenarios and explanation with $F(4, 433) = 1.64$, $p = .16$. Simple main effects analysis showed that there is no main effect on perceived usefulness by explanation ($p = .79$) or scenario ($p = .46$). To conclude, there is no statistically significant difference of scenarios and explanations on perceived control, perceived ease of use, and perceived usefulness.

Figure 6

A bar graph with confidence intervals on perceived ease of use for all explanations and scenarios, error bars represent 95% confidence intervals.

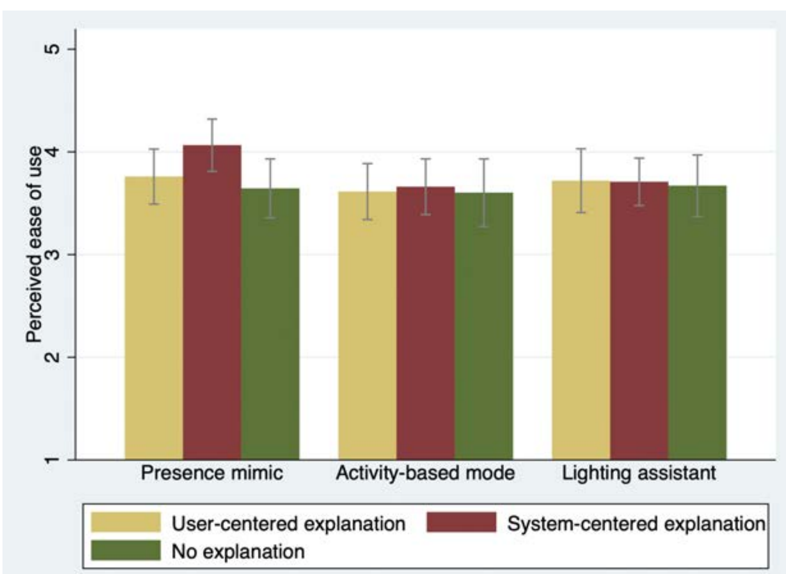
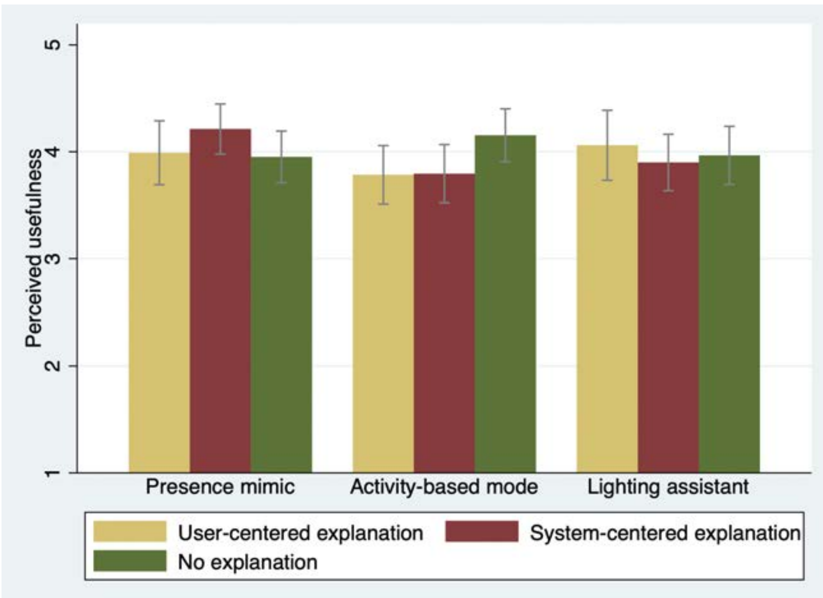


Figure 7

A bar graph with confidence intervals on perceived usefulness for all explanations and scenarios, error bars represent 95% confidence intervals.



Correlation between the constructs.

To answer the SQ 2.3, a Pearson correlation coefficient was computed to assess the linear relationship among all the constructs, including explanation satisfaction(ES), self-efficacy (SE), perceived control (PC), perceived ease of use (PEU), perceived usefulness (PU), and adoption intention (AdI), see Table 4. According to the guideline about Pearson correlation (Cohen, 1988), the coefficient determines the strength of the correlation. There were several pairs with a strong correlation ($|r|>.5$), such as explanation satisfaction and perceived ease of use (r =.55, p <.001), perceived control and perceived ease of use (r =.70, p <.001), and perceived usefulness and adoption intention (r =.79, p <.001). There were more constructs with moderate correlation ($.3 <| r| <.5$), including explanation satisfaction and perceived control (r =.48, p <0.001), explanation satisfaction and perceived usefulness (r =.37, p <.001), perceived control and perceived usefulness (r =.48, p <.001), perceived ease of use and perceived usefulness (r =.47, p <.001). Moreover, adoption intention illustrated a moderate correlation with explanation satisfaction (r =.33, p <.001), perceived control (r =.45, p <.001), and perceived ease of use (r =.44, p <.001).

Table 4.

Pearson correlation coefficient for constructs, ES = explanation satisfaction, SE = self-efficacy, PC = perceived control, PEU = perceived ease of use, PU = perceived usefulness, AdI = adoption intention, N = 307.

	ES	SE	PC	PEU	PU
ES	1.000				
SE	0.14*	1.000			
PC	0.48**	0.17*	1.000		
PEU	0.55**	0.22**	0.70**	1.000	
PU	0.37**	0.21**	0.48**	0.47**	1.000
AdI	0.33**	0.20**	0.45**	0.44**	0.79**

Note. *, $p < .05$; **, $p < .001$.

Explanation satisfaction.

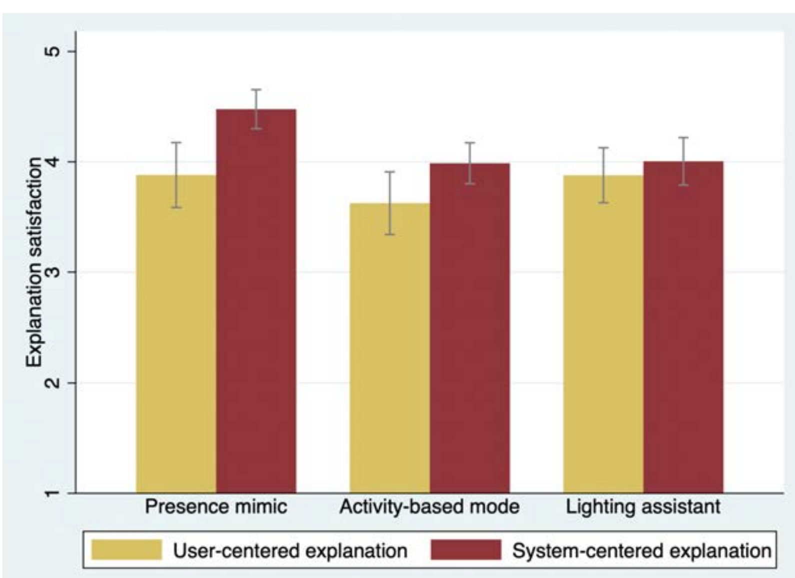
To answer the SQ2.4, explanation satisfaction scores were compared between two explanations given. The explanation satisfaction in three scenarios and two explanation types (without no explanation group) can be seen in Figure 8. A two-way between-subjects ANOVA was conducted to compare the effect of scenarios and explanations on satisfaction. The result revealed that there was no statistically significant interaction effect between explanation types and scenarios with $F(2, 301) = 1.94$, $p = .15$. Main effects analysis showed that participants were significantly more satisfied with the system-centered explanation than user-centered explanation ($F(1, 301) = 13.58$, $p < .001$). Main effect analysis also illustrated that there was a statistically significant difference of scenarios on explanation satisfaction ($F(2, 301) = 5.03$, p =

0.007). The results showed that the explanation satisfaction in explanation types does not dependent on the scenarios. In other words, scenarios and explanations independently impact the explanation satisfaction.

A Tukey post-hoc test revealed significant pairwise differences between scenario presence mimic and scenario activity-based mode (p=0.01). The result showed explanation satisfaction in scenario presence mimic is significantly higher than in scenario activity-based mode. To further investigate the difference in explanations, three two-sample t-tests were performed to compare explanation satisfaction for each scenario. Explanation satisfaction scores of user-centered explanation group are significantly higher than system centered explanation group in both scenario presence mimic ($t(104) = -3.44$, $p < .001$) and activity-based mode ($t(98) = -2.17$, $p = .03$). In scenario lighting assistant, there is no statistical significant difference on explanation satisfaction between the user-centered explanation group and the system-centered explanation group with $t(99) = -0.74$, $p = .45$.

Figure 8

A bar graph with confidence intervals on explanation satisfaction for user-centered and system-centered explanations grouped with scenarios, error bars represent 95% confidence intervals.



3.2.3 Qualitative analysis of open questions

In the current study, there were two open questions. One was placed after an explanation was provided ("Would you mention something else or do it differently in the notification? "), and another question was at the end of the online experiment ("In the end, we are wondering if you have any other comments or suggestions about the study?"). After inspecting the initial codes, most answers in the second question were not relevant for the current study including attitudes towards the brand, current products or services, or general suggestions for Philips Hue systems. Hence, only answers from question 1 were analyzed. In total, 185 comments were collected and analyzed using thematic analysis. Four themes were generated. Interestingly, all themes were consistent and similar to the results of Study 1. Another point worth mentioning is that 28% of participants (N = 16) in No Explanation group (N = 56) from three scenarios were confused, and requested an explanation or more information to the system. They stated that they would require more information about how and why the specific decision is made.

To summarize, 25% of participants mentioned the possibility to control the system in the comments, and some participants also noted other aspects of explanations, such as wording and simplicity, proper visualization and accessibility to additional information. The other user comments were not relevant comments to the current study, such as the system implementation, concerns of performance of the system, etc. Some user remarks were introduced in the following section.

25% of participants (N = 47) commented on the possible actions linked to the explanation. They specifically expressed their willingness to change the system decision by altering the setting, giving feedback, turning off the feature, toggling back to the previous lighting, etc. Some remarks are: *"It could be good to interact with notifications to agree or not agree." (From scenario presence mimic, user-centered explanation); "I would like to see an "Edit settings" option, or it would be helpful to have an onscreen button to activate/deactivate the lighting assistant" (From scenario lighting assistant, system-centered explanation)*

10% of participants (*N* = 19) stated that there should be more information accessible, especially global information in the system. They sought to learn more if they tapped the notification. Some remarks are: *"Provide a "More info" link to the science behind it on how to get the right light for your health." (From scenario lighting assistant, system-centered explanation); "Easing the process should not mean trusting invisible magics without knowing or controlling what happens behind the scene"(From scenario activity-based mode, user-centered explanation).*

5% of participants (*N* = 10) mentioned the wording and text of the given explanations. This indicates that the explanation design for end users should be carefully picking proper wording. Some remarks are: *"Simplify the language, maybe use easier to understand terms, not lifting exposure" (From scenario activity-based mode, user-centered explanation); "The wording above makes it seem it's preprogrammed and unchangeable." (From scenario presence mimic, system-centered explanation).*

4% of participants (*N* = 7) indicated that they would make the explanation more noticeable and easier to understand with proper visualization, such as corresponding icons. Some comments are: *"Some icons that can explain what certain aspects of the app does or can do would help people with less technically mind, someone like me" (From scenario lighting assistant, user-centered explanation);"It is not very noticeable. I would expect it with a different color and a toggle switch for activation"(From scenario activity-based mode, system-centered explanation).*

3.3 Discussion

All conditions had no impact on the perceived ease of use, perceived usefulness, and adoption intention. The result showed that receiving an explanation of a smart home lighting system decision may lead to a minor negative effect on perceived control (p=.03). Explanation satisfaction was found positively correlated with perceived ease of use (r =.55, p <.001) and perceived control (r =.48, p <.001). Moreover, the result has identified that system-based explanation leads to higher satisfaction in smart home lighting systems in scenario presence mimic ($p < .001$) and activity-based mode ($p = .03$). The qualitative results identified four main themes that need to be addressed in the explanation design for the smart home context.

3.3.1 Influence of providing explanation on perceived control

Surprisingly, this study found that having an explanation implied a minor negative impact on the perceived control of users compared to the group without explanation. One possible reason might be that the current lighting system does not match users' mental model of a traditional lighting system. As suggested in Study 1, when there is no explanation provided, users may consider the mismatch between the lighting provided and their expectations as a system error. Users who received explanations may consider the system to be unexpectedly "intelligent" or "smart", which created an inconsistency in their mental models. Updating the mental model requires cognitive effort, which may not be achieved during the study. The mismatch between mental model and the experience may lead to negative consequences (Lee & See, 2004). Therefore, it may bring on a minor decrease in the perceived control. Another alternative explanation may be that receiving an explanation may activate the notion of control, thus leading to a higher perceived risk of the system. There is a potential parallel with regards to cognitive processes involved in users' privacy calculus in terms of system-related perceptions (Dinev & Hart, 2006). Previous study has shown that when informing users explicitly of the ways in which their data may be used by an app, paradoxically increases their distrust or concerns of the system (Kehr et al., 2015; Phelan, et al., 2016). Giving an explanation to participants may trigger their awareness of privacy concerns, thus activating notions of potential risk, rather than put their minds at ease about taking a well-informed decision. Therefore, the increased perceived risk may lead to lower perceived control. The result on perceived control between explanation presence group and explanation absence group matches the findings of the qualitative result, which shows that although most participants are satisfied with the current explanation, they still proactively required an action to revert settings, changing lights, or alter the lighting configuration. However, considering the duration of the study is relatively short, the perceived control may change in the long run. As suggested in the study of Beggiato and Krems (2013), experience with the system can update and correct the mental model over time. As users continue to learn and understand the system more by receiving relevant information, their perceived control may grow steadily in the future.

3.3.2 Influence of providing explanation on adoption intention

There is no significant effect observed of explanations or scenarios on perceived ease of use, perceived usefulness, and adoption intention. The main reason might be that adoption intention is likely to be influenced by many other factors. For instance, the strong correlation between perceived usefulness and adoption intention (r =.79, p <.001) may imply that participants adopt the system mainly based on the potential practical aspects of the system. The explanation manipulation is unlikely to change perceived usefulness. A number of users in open questions of Study 2 suggested that their adoption intention is dependent on the safety and energy saving aspects of the lighting system, the connectivity of other smart home devices, or the health benefits the system can bring. Another interpretation is that perceived control might mediate the effect of explanation on perceived ease of use. Several studies have found that lower perceived control contributes to a lower score in the perceived ease of use (Lu et al, 2009; Park et al., 2017; Elwalda et al, 2016; van Dolen et al., 2007). At the same time, the result showed a strong positive correlation between the explanation satisfaction and the perceived ease of use (r =.55, p <.001). The result indicates that when receiving an explanation that meets their expectation, the perceived ease of use of the system would increase. A possible rationale is that while receiving explanations contributes to higher perceived ease of use, the effect was moderated by a slightly lower perceived control, thus resulting in no difference of explanation absent group and present group on perceived use and adoption intention.

3.3.3 Difference of explanation types on explanation satisfaction

The result of the explanation satisfaction score illustrated that system-centered explanation gained a statistically significant higher score than user-centered explanation in presence mimic and activity-based scenarios. This effect on explanation satisfaction could be attributed to several reasons. First, compared with the user-centered explanation, the system-centered explanation emphasized on utilization of the same amount of information. It may indicate that utilitarian aspects in the explanation enhance a higher level of perceived informativeness of users (Li & Mao, 2015). Users may see the hedonic aspects of the information as noise or barriers to gain information. This may indicate that compared to other systems, users do not expect a smart home lighting system to provide a feeling of social presence (Li & Mao, 2015). Second, the use of pronoun can possibly have a negative impact on the explanation satisfaction. The user-centered explanation used “we” as the subject, whereas the system-centered explanation used “the system” as the main subject. Few users mentioned the confusion of the pronoun in Study 1. Although using first-person plural pronouns indicates intimacy and closeness to the users, there are other studies indicating that using “we” can be harmful to communication when the language is inconsistent with the expectation (Sela et al., 2012). Therefore, the lower satisfaction in user-centered explanation may be attributed to the misuse of pronouns.

Second, the system-centered explanation includes fewer texts than the user-centered explanation. The structure of the sentence is simpler with less texts, thus enhancing the ease of understanding. This is in line with the study of Narayanan et al.(2018), which suggested that reducing the complexity of explanation, such as decreasing the number of text lines, can result in higher user satisfaction.

An interesting finding is that the explanation satisfaction in scenario presence mimic is significantly higher than the scenario activity-based mode. The reason might be that in the scenario activity-based mode, the word “blinding” implied a negative expression that was mentioned by multiple participants. There is a universal bias in positive words among people (Dodds et al., 2015). Therefore, negative expression may reduce the satisfaction in activity-based mode compared to other scenarios without negative expression.

4. General discussion

4.1 Summary

The main goal of the current study was to explore the effect of explainability of system behavior on users' adoption intention of smart home lighting systems. Study 1 focused on users' attitudes and understanding of smart home lighting systems in different lighting scenarios, and explored the optimal explanation design of smart home lighting systems to the users. The results showed a generally positive attitude towards receiving an explanation, and several expectations users expressed for an optimal explanation. Based on the results, three stories with corresponding scenarios and three types of explanation were chosen for Study 2. Study 2 mainly aimed at assessing the effect of the explanations and scenarios on adoption intention. The result showed that receiving an explanation of a smart home lighting system decision may lead to a minor negative effect on perceived control, but has no impact on the perceived ease of use, perceived usefulness, and adoption intention. The study has developed two explanation types (user-centered explanation and system-based explanation), and has identified that system-based explanation leads to higher satisfaction in smart home lighting systems. Moreover, explanation satisfaction was found to be positively correlated with perceived ease of use and perceived control. Lastly, the qualitative results identified several main themes that were consistent with the result of Study 1, which needed to be addressed in the explanation design for the smart home context.

4.2 Theoretical implications

First, both studies addressed the importance of the availability of providing controls of smart home lighting systems. It is essential in smart home systems to consider the optimal controllability and availability to override the system along with providing explanation (Yang et al.; 2018). Giving explanation to the user may activate the notion of control and create an inconsistency in their mental models, especially in unfamiliar intelligent systems (Lee & See, 2004; Kehr et al., 2015). Users may see the explanation as a reminder of the system being harvesting their data, or being more "intelligent" than they think, rather than safely assume there is a system error occurs when there is a mismatch between system decision and their expectations and neglect the possible risk of the system. Hence, the study addressed the complexity of providing explanations in a highly automated system, and raised the question for the future explanation design. An important direction for future work is to consider what aspects of explanation design can impact positively on the perceived control, while assisting users in making a well-informed decision.

Second, the current study explored the effect of explainability for end users in smart home lighting systems. Although there is no significant effect of explanations on adoption intention, it is not sufficient to draw the conclusion that providing explanations of a smart lighting system decision is not necessary. Previous studies showed that explanations could assist users to learn and correct their mental models for the system (Miller, 2019; Mueller et al., 2021). Both studies showed that most participants considered having explanations helpful to understand how the system works. Participants from Study 1 considered the system broken when not receiving any feedback of the system, while participants in no explanation group of Study 2 mentioned the need for an explanation. This means that the harmful aspects of not having an explanation may exceed the negative impact of perceived control of having an explanation. The indication is that explanation can assist users to clarify the decision-making process, whereas the possible harmful effect need to be taken into consideration.

Last, the current study introduced explainability to the original Technology Acceptance Model (TAM) as a possible extended factor (Davis et al., 1989; Venkatesh, 2000). The result of Study 2 showed a relatively strong correlation between perceived ease of use, perceived usefulness and adoption intention (p <.001), which indicates the validation of the original TAM in explaining the adoption of smart home lighting systems. The correlation between perceived control and preceding constructs is consistent with several previous studies in the framework based on the Technology acceptance model (Lu et al, 2009; Park et al. 2017; Elwalda et al, 2016; van Dolen et al., 2007). In addition, the results illustrated a relatively strong correlation between explanation satisfaction and perceived control (r =.48, p <.001), as well as explanation satisfaction and perceived ease of use (r =.55, p <.001). There were few studies exploring the possible relationship between explainability, perceived control, and perceived ease of use. A further study could assess the extended framework of TAM combining explainability.

4.3 Practical implications

Practical implications are primarily related to the future explanation design in a smart home lighting system. The result of the current study may indicate different explanation design principles or guidelines focusing on combining user controls with automation in a smart home context for future research. Some recommendations might be helpful for future designs of user interaction with similar systems in a pragmatic perspective:

- **Short, simple with human-readable language**: Considering some user comments in both Study 1 and Study 2, explanations for end users should carefully use wording and plain language, and shorten the length of information. This is in line with several previous studies, showing that the explanation should be simple and short for end users (Szymanski et al., 2021; Ribera & Lapedriza, 2019).
- **Accessibility to global information**: In both qualitative studies, participants mentioned the importance of understanding the system on a general level. It should be noted that the results contradict the claims of Ribera and Lapedriza (2019) that it is not necessary to provide global information to end users. However, this is in line with the study of Kulesza et al.(2013), which suggested that completeness of the explanations is helpful to end users' mental models. The implication is that having global explanations accessible can help users to increase their understanding of the system.

- **Combined with control option**: As discussed in section 3.8.1, perceived control and explanation can both have a positive effect on perceived ease of use, thus affecting adoption intention. The implication in perceived control is that in future lighting system design, it is essential to retain the availability of user control along with explanation to increase the perceived control of users.
- **Proper visualization combined with text**: For both studies, participants mentioned visualization, e.g. icons, could help them understand the explanation better. This finding verified the importance of the mixed modality design with visualization and texts (Szymanski et al., 2021).

4.4 Limitations and future research

The major limitation of this study is the study design of the online experiment. First, the hypothetical scenario might not have been enough to elicit actual intention or other judgment. Although the use of vignettes can help participants to imagine experiencing a particular situation, several participants mentioned that they tend to make decisions based on actual usage of the smart home lighting system. The unfamiliarity of the experience and lower intensity of emotions induced by the scenario can lead to less reliability and validity of the results(Collett & Childs, 2011). It needs to be considered that unrealistic scenarios can be insufficient to capture the real-life dynamics of decision-making processes (Erfanian et al., 2020). Second, even if it is possible to have realistic smart home lighting systems, there is still a gap between behavioral intention and actual behavior (Ajzen & Madden, 1986). This gap implies that even with realistic materials, the actual adoption behavior of the users and their subjective statements might differ to a large extent. Third, the current study was conducted in a short amount of time. A couple of minutes may not be sufficient for the cognitive process of adopting a new concept and making judgements. As mentioned in section 3.8.1, it takes time for users to learn and upgrade their mental models with increasing experience with the system (Lee & See, 2004). Although an actual adoption decision of consumers may not be long, it takes time to grow trust and habituation to the system, leading to long-term adoption. This is not tested in the current study. To conclude, with limited time in hypothetical scenarios, the adoption intention and perceived control could be imperfect to elicit participants' actual behaviors. A longitudinal study, especially lighting systems in a real-life environment, is therefore recommended to address these limitations in the future.

The second potential limitation is the bias in sampling. First, it should be noted that the current sample was predominantly male (413/452, 91%). Previous studies have shown that there is a gender difference in preferred communication style and the perception of intelligent systems (Furumo & Pearson, 2007; Eyssel et al., 2012). Second, while half of the participants have more than five years of experience with the Philips Hue system and 70% of participants use the Philips Hue system almost every day, they are more likely to be more tech-savvy than lay users. Hence, their attitude toward smart home lighting systems might differ from the population mean. As suggested in the Technology Acceptance Model 3 by Venkatesh and Bala (2008), experiences of one system would moderate the effect of perceived ease of use and perceived usefulness. Although participants did not have experience with decision-making by smart home lighting systems, the familiarity with the Philips Hue system may result in a higher score in the constructs than the population means. In general, this sample is not representative of the general population. Future study could explore the possible relationship of gender, system experience and explainability with a sample representing the general population.

5. Conclusion

The current explorative study aims to investigate what types of explanations could increase explanation satisfaction of users and which could affect a user's adoption of smart lighting systems in different scenarios. The results validated the original TAM model and introduced explainability as a possible extension to the TAM model. The practical implication of the study is to provide explanation design recommendations for future user interaction with smart home lighting systems. There are two major limitations of the study: 1) the hypothetical scenarios may not be sufficient to elicit actual intentions and judgments within a limited time frame; 2) the sampling of the study is limited to experienced Philips Hue users with predominantly tech-savvy males. These aspects will have an impact on the external validity of the study. Future studies can focus on longitudinal designs of smart home lighting systems in a real-life environment using a sample representing the general population. However, the study has been one of the early attempts to exploratively examine the explanation design for smart home automation systems. As the systems become more context-aware and intelligent, we hope that the findings of the study could shed light on understanding the complexity and subtleness in providing explanations Human-AI systems.

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Appendices

Appendix A Scenarios and stories in Study 1

Presence mimic

Recently Tony's neighbor got burgled. He was about to go on a vacation and wanted to have some quick way to improve the safety. Tony noticed the automation "*presence mimic*" in the hue app. This service is tailored to Tony's lighting habit, turning on and off his lights as if he is at home. It creates an impression of "you're at home" when you're away. Before he went on the vacation, he turned on the "presence mimic".

Story 1.

Now Tony's waiting for food, and starts wondering what the lights are doing. It's 9:00 pm, normally he's watching TV at home with the lights dimmed. He turned on the app, and it shows the "presence mimic" is on, but somehow, all the lights are off. He is wondering, *"Why are my lights off? "*

Activity-based mode

Tom visited Kylie recently. In her home, he saw the lighting change automatically based on what he was doing. "This is cool, I also want to try it" He decided to try the system at his home. Based on Tom's activity, this lighting system can provide the most suitable scenes. How? By using multiple sensors at his home. Tom tried it in his bedroom and bathroom, hoping to automate his lighting.

Story 2.

One day in the morning, Tom got up and walked to the bathroom. As he put the toothpaste in the toothbrush, he noticed that the light was dimming up slowly, as always, to wake him up. He lifted his head to check his teeth in the mirror. At the same time, his partner walked into the bathroom. The lights slowly started to dim. "I can't see my teeth now," Tom thinks, "Why my lights are dimmer?"

Story 3.

Tom loves to play games in the workday evening, so he set up a blue and purple game light scene. On a sunny Saturday afternoon, he decided to play fortnight with his friends. He turned on the game light scene. When he waited for the game to load, he started to stare at the light. And he started to notice, the light is much brighter and more saturated than in his setting. He was confused, “Why are my lights weird?”

Lighting assitant

John is a tech fan and a businessman. He hates to walk a long way to reach the switch for lights or open the app for a small change in lights. He has been trying the “customized lighting automation” recently. The system collected sensor data, health data, and more information about his family. In this way, the system can keep learning about their habits and routines. Using this information, the system can predict the most suitable lighting.

Story 4.

It was a gloomy day. John got home late from a long drive. He opened the door, with a feeling of relief. Before he sat on the sofa and relaxed, he started to notice that the lights are different from other days. They are much brighter than usual. In addition, some lights that he used to turn off, are now turned on with a bright scene. John is confused, “Why the lights are different?”

Story 5.

It’s an ordinary day. John likes to read books for an hour before going to bed. As always, he finished reading today, put the book on the nightstand, and lay down waiting for the lights to be dimmed. Unexpectedly, the lights brightened up and started to flicker. John is annoyed, “why my lights do not allow me to sleep?”

Story 6.

John came home from work a bit late today. He entered the living room, sitting with his kid on the sofa, who is watching the movie “Hulk”. Then he found out the whole atmosphere was quite different today. The lights were in a combination of red and green, with a dynamic effect. “I hate green so much,” John was thinking, “I have never set my lights like this… Why is that?”

Appendix B Interview protocol in Study 1

<table>
<tr><td colspan="2">Introduction + warm up</td></tr>
<tr><td rowspan="2">5 mins</td><td>Researcher notes:
Introduction researcher.
No wrong answers. Open interview: thinking aloud.
Opportunity to ask questions or quit at anytime
Paperwork: Informed Consent / Confidentiality / audio recordings / No phones.</td></tr>
<tr><td>Could you tell a bit about yourself?
Could you describe your current hue setup and products?
Could you tell us about your current smart home setting? (eg, devices, products, services…)</td></tr>
<tr><td colspan="2">Part 1: Automation interview</td></tr>
<tr><td>10 min</td><td>What kind of automation you are currently using in hue?
Have you been confused, or frustrated of your lights in the automations after everything sets up?
If so, (and if it’s not a performance problem), could you tell us a bit more what happened?
Could you tell more where are your hue lights located at your home?
Do you use any automation or sensors in other devices?
Do you consider the current automation is sufficient?
If no, is there any automation you would like to implement in the future?
(Possible questions)
In which room do you spend most time at home?</td></tr>
</table>

Scenario 1: Presence mimic	#Scenario 1 presence mimic scenario storyboard# ● What would you do in this scenario? How would you feel? ● What would you expect from the system? o If the person says explanation, then: what kind of explanation do you expect? What do you want to know? ● In your own case, during your trip, would you check your app to see what status are your lights? ● Would you like to take back control and make some changes yourself? ● Do you consider the scenario applicable in your case? #Show different explanation options we have# ● How do you feel? Are you satisfied with the explanation or not? ● Is there anything you would want to change? ● Do you expect the explanation in the notification or a page of information, or anywhere else? ● What would you be curious about? What information would you expect to get from the explanation? ● When do you think you need the explanations? There are another three explanations. Do you think they give you enough information? Which one would you prefer and why?
Scenario 2: Activity-based	#Show first two pictures, ask: ● Would you consider using the service at your home? ● Where and when you will use it?

	● Imagine you already set things up at your home, what problem will you expect in this case? #Show the story options, ask: ● Does the scenarios applicable in your case? ● Would you consider the scenario confusing in this case? ● Is there anything you would like to change? #Show different explanation options we have# ● How do you feel? Are you satisfied or not? ● Is there anything you would want to change? ● Do you expect the explanation in the notification or a page of information, or anything else? ● What would you be curious about? What information would you expect to get from the explanation? ● When do you think you need the explanations? ● There are other explanations. Do you think they give you enough information? Which one would you prefer and why? #After all stories being presented ● Which scenario would you think more applicable in your case and why?
Scenario 3: Prediction	Similar to scenario 2

Appendix C Scenarios in Study 2

Presence mimic

Activity-based mode

Tom visited Kylie recently. In her home, he saw the lighting change automatically based on what he was doing. "This is cool, I also want to try it" He decided to try the system at his home.

Based on Tom's activity, this lighting system **can provide the most suitable scenes**. How? By using multiple sensors at his home. Tom tried it in his bedroom and bathroom, hoping to automate his lighting.

One day in the morning, Tom got up and walked to the bathroom. As he walked in, he noticed that the light was dimming up slowly, as always, to wake him up. He started to check his teeth in the mirror.

At the same time, his partner walked into the bathroom. The lights slowly started to dim. "I can't see my teeth now," Tom thinks, **"Why my lights are dimmer?"**

Lighting assitant

John is a tech fan. He hates to walk a long way to reach the switch for lights or open the app for a small change in lights. He has been trying the "**lighting assistant**" recently.

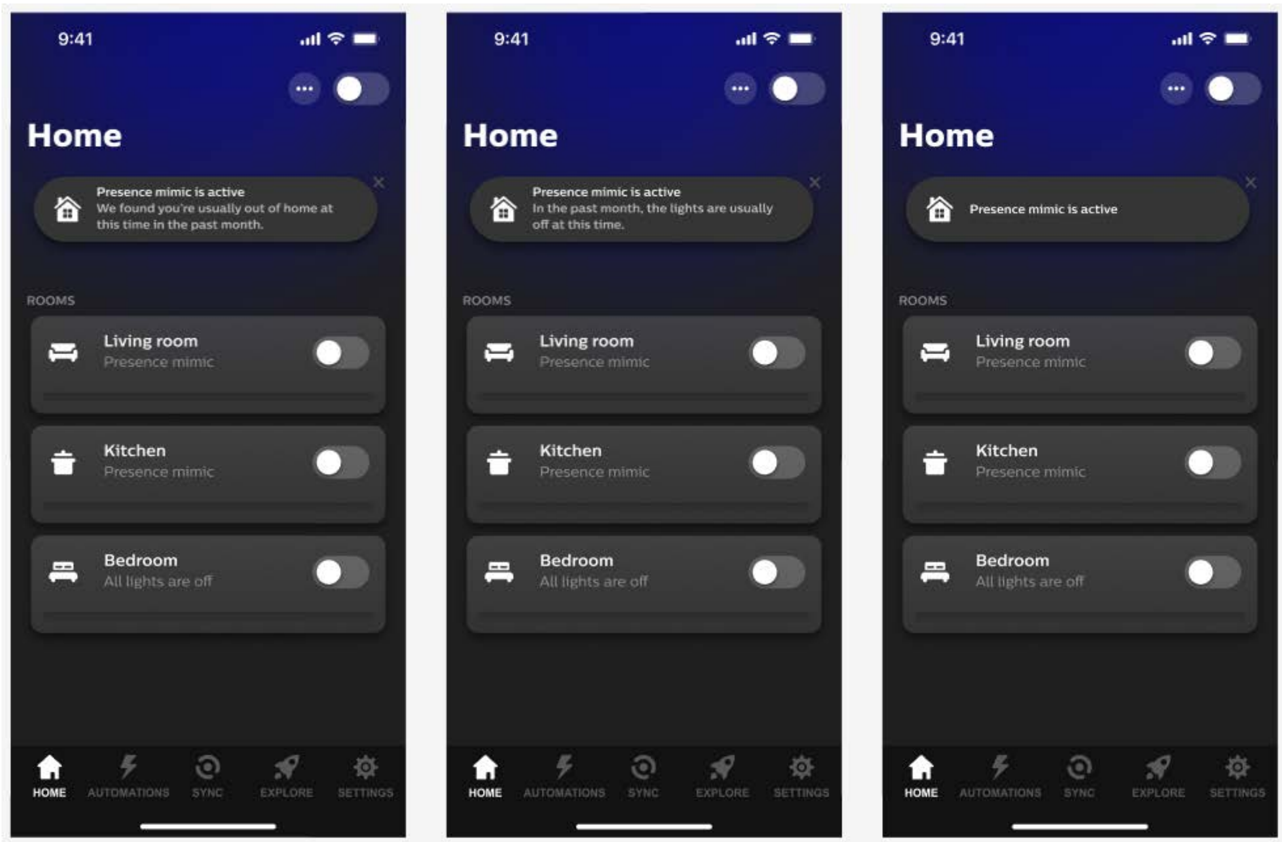
The system collected sensor data, health data, and more information about his family. In this way, the system can keep learning about their habits and routines. Using this information, the system can **predict** the most suitable lighting.

It was a gloomy day. John got home late from a long drive. He opened the door, with a feeling of relief. Then he started to notice that the lights are different from other days.

They are much brighter than usual. In addition, some lights that he used to turn off, are now turned on with a bright scene. John is confused, **"Why the lights are different?"**

Appendix D Explanations in Study 2

Presence mimic



(1)User-centered explanation (2) System-centered explanation (3) No explanation

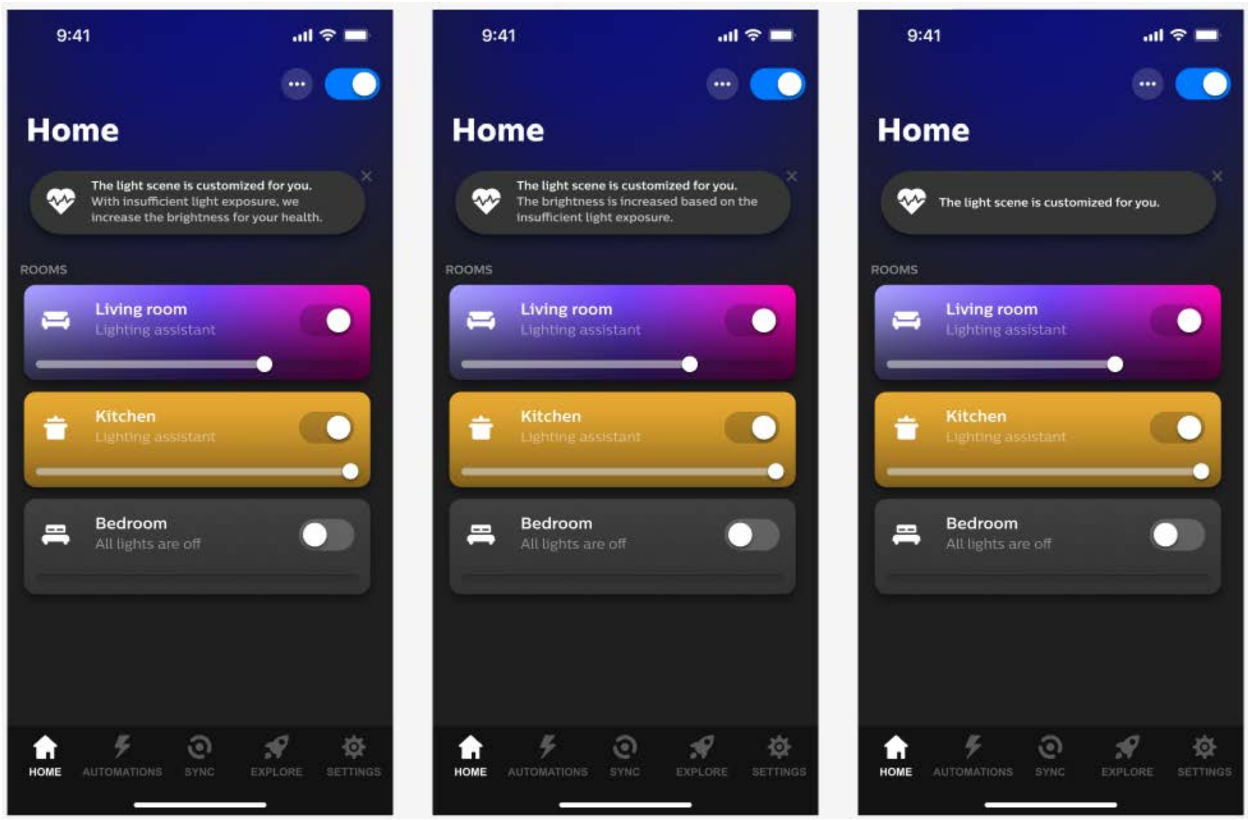
Activity-based mode

(1)User-centered explanation

(2) System-centered explanation

(3) No explanation

Lighting assitant



(1)User-centered explanation (2) System-centered explanation (3) No explanation

Appendix E Questionnaire in Study 2

- **(For participants received user-centered explanation or system-centered explanation only) Please select the option that best represents how you would feel about the statements below (From strongly disagree to strongly agree).**
    - From the explanation, I understand how the presence mimic/activity-based mode/lighting assistant works
    - This explanation of how the presence mimic/activity-based mode/lighting assistant works is satisfying
    - This explanation of how the presence mimic/activity-based mode/lighting assistant works is useful to my goals
- **(For all participants) Please select the option that best represents how you would feel about the statements below (From strongly disagree to strongly agree).**
    - This explanation lets me judge when I should trust and not trust the presence mimic/activity-based mode/lighting assistant
    - I would feel I am in control of the presence mimic/activity-based mode/lighting assistant
    - I would find it easy to get the presence mimic/activity-based mode/ lighting assistant to do what I want it
    - I would be able to operate the presence mimic/activity-based mode/lighting assistant in my own way
    - I would find the presence mimic/activity-based mode/lighting assistant easy to use
    - my interaction with the presence mimic/activity-based mode/lighting assistant would be clear and understandable

- I would find the presence mimic/activity-based mode/lighting assistant easy to use
- my interaction with the presence mimic/activity-based mode/lighting assistant would be clear and understandable
- Using the presence mimic/activity-based mode/lighting assistant would improve my experience with lights at home;
- I would find the presence mimic/activity-based mode/lighting assistant useful in my home"
- I would use the presence mimic/activity-based mode/lighting assistant on a regular basis in the future;
- I would frequently use the presence mimic/activity-based mode/lighting assistant in the future
- I would strongly recommend others to use the presence mimic/activity-based mode/lighting assistant
- I feel confident using the Hue system
- I feel confident setting up Hue automation and routines
- I feel confident configuring the lights myself

- **Would you mention something else or do it differently in the notification?**