Supporting Reflection Through Play: Field Testing the Home Trivia System

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ABSTRACT
In this work, we designed and field-tested a system called Home Trivia to explore how we can use activity traces captured in the home to allow household members to reflect on how they use technology, which has become an issue of increasing concern among families that have seen their home lives intertwined with Internet-enabled devices. Home Trivia captures traces of using technology at home and then shows those traces to family members as content of a puzzle game they can play together. The results of testing Home Trivia in the field show that the design of the game allows engagement and reflection to reinforce each other. Moreover, our work enriches and further develops the idea of using ambiguity as a resource for design with the insight that allowing users to reduce ambiguity through recollecting past events and communicating with others can help trigger reflection.

Author Keywords
Reflection; Home; Family; Games; Domestic Sensing; Activity Traces

INTRODUCTION
In the summer of 2013, a video entitled "I Forgot My Phone" went viral on social media. It was viewed over 15 million times within 10 days after its release [1]. Many viewers were discomforted by the video which highlighted societies' smartphone use—and overuse. People expressed anxiety that it exemplified our increasing tendency to be *alone together*, a phenomenon sociologist Sherry Turkle brought to the public's attention [27]. Turkle argued that many people's increasing dependence on technology and their tendency to seek sanctuary in cyberspace has led them to be mentally absent when they are physically together.

In the era of mobile computing, the problem of being alone together is even harder to tackle, because staying aware of mobile device usage can be particularly challenging due to the unplanned and fragmented nature of use [22]. This concern is especially critical in a home environment. Researchers have found that using mobile devices in family spaces can create an "invisible shield" around the user [17], and such a shield discourages family interactions which are important for promoting positive social relationships.

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Therefore, this work was aimed to help families become more aware of and start reflecting on technology use at home, which can often be stressful or contentious to talk about. Prior work shows that parents employ a number of strategies to regulate their children's technology use, such as monitoring usage, cutting off access, and stigmatizing overuse, yet these approaches tend to be both ineffective and counterproductive [3]. Furthermore, some reports suggest that parents often fail to be mindful of their own technology use and may feel guilty about their own behaviors [2,16,26].

In particular, we introduce a novel system called Home Trivia which harnesses the emerging ability of augmented homes to capture activity traces to inform occupants of how and when they use technology. Home Trivia consists of a router-based device activity tracker capturing usage of devices connected to the home Wi-Fi, several space usage trackers providing additional contexts of home activities, and an interactive puzzle game which uses the captured activity traces as its main content.

To understand potential user behaviors, we deployed Home Trivia in five households in the US. Each field trial consisted of an initial interview, a weeklong deployment of activity trackers, and a gameplay session where the participating family played the game together in their home. The main findings of our field study include the following:

- The Home Trivia game engaged both child and adult participants by serving personalized puzzles, encouraging teamwork, and putting children and parents on an equal footing.

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- The Home Trivia game created opportunities for family members to revisit and rediscover their past experience by turning aggregated activity traces into puzzles.
- The Home Trivia game provoked participants' reflections on technology use by highlighting discrepancies between their beliefs and the activity data captured by the system.

This paper offers three contributions. First, we demonstrate a new approach to helping families manage technology use by creatively presenting behavioral traces to raise awareness, enhance communication, and support reflection. Second, our work enriches and further develops Gaver's [12] idea of using ambiguity as a resource for design with the insight that allowing users to reduce ambiguity through recollecting past events and communicating with others can help trigger reflection. Last, our research expands the nascent design space of using sensor data for non-task oriented computing (e.g., [8,10,11,24]), which is one of the emerging issues under the third paradigm of HCI [15].

In the rest of the paper, we first provide an overview of related work from which we derive a set of design requirements, and then we describe the Home Trivia system. Following that, we detail our field study and its results. We then offer a discussion of our design approach, the study's limitations, and future work.

RELATED WORK AND DESIGN REQUIREMENTS

Home Trivia is an exploration of using technology to support reflection. According to Moon [21], reflection is "a form of mental processing with a purpose and/or an anticipated outcome that is applied to relatively complicated or unstructured ideas for which there is not an obvious solution" (p. 4). Dewey [7] suggested that it is the experience of uncertainty that often triggers reflection because moments of uncertainty can defamiliarize one's everyday environments, suspend beliefs used to be taken for granted, and reveal discrepancies that calls for explanations.

Fleck and Fitzpatrick [9] suggested a number of ways technology could be used to create favorable conditions for reflection. Two of them are particularly relevant to the design of Home Trivia. First, technology can enhance users' awareness of certain events that are otherwise not available to their perception. Not only does reviewing recording of past events provide the "material" on which later reflection is based, it also provides an alternative perspective with which one can re-examine and make sense of those events. Second, technology can connect people who are interested in exchanging different ideas about a common topic. Being exposed to a perspective different from one's own can potentially trigger reflection as one's beliefs are challenged and justifications become necessary. In the rest of this section, we describe work related to these two approaches and then define a set of requirements for the design of Home Trivia.

Triggering Reflection by Enhancing Awareness

Staying aware of one's mobile device usage can be challenging because use can be habitual, unplanned, and fragmented [22]. Research has shown that some people lose sense of time when they are engaged in habit-driven usage of their mobile phones [19]. In response to the difficulty of keeping track of one's device usage, a few commercial tools (e.g., RescueTime [†] on personal computers and Moments [‡] on the iPhone) have emerged to provide individual users with information about when, how long, and for what they used their devices. However, tools for a household instead of an individual to stay aware of their technology use are relatively rare. One example is Home Watcher, a research system that monitors and displays each device's bandwidth usage in the home [5].

In a field study of Home Watcher, Chetty et al. found that making bandwidth usage visible in the home had interesting social consequences [5]. First, not only did Home Watcher enhance participants' awareness of Internet uses at home but also their awareness of activities linked to those uses (e.g., waking up, doing homework, staying up late, etc.). Second, the information about bandwidth usage shown by Home Watcher allowed participants to better negotiate the distribution of this shared resource with other household members. Third, some participants were concerned about personal representation in the home as others could "read" their activities from their usage of bandwidth. While the field evaluation of Home Watcher was not focused on reflection, the enhanced awareness of bandwidth usage can potentially support reflection. For example, some participants envisioned that they could use Home Watcher to validate or invalidate their suspicions about who had been hogging the bandwidth.

Though our primary concern over technology use in the home was about its impact on family togetherness rather than resource management, and we wanted Home Trivia to support not only awareness but also reflection, we, like Chetty et al., wanted to explore the social consequences of revealing household members' traces of technology use by having them interact with Home Trivia. Thus, we made the first design requirement of Home Trivia as follows:

Requirement #1: Enhance family awareness instead of only personal awareness of domestic activities related to technology use.

Unlike Home Watcher which represents bandwidth usage in clear and familiar visualizations, we embraced ambiguity in the design of the Home Trivia game. We believe that when it comes to supporting reflection, which is often triggered by perplexity [7], ambiguity could be more effective than clarity if designed properly. Some researchers have

[†] RescueTime. https://www.rescuetime.com/

[‡] Moment. http://inthemoment.io/

experimented with designs that intentionally introduce ambiguity in the representation of recorded events, following Gaver et al.'s call for employing ambiguity as a design resource [12]. In the particular domain of supporting reflection in the home, the Home Health Horoscope [11] seeks to give feedback to household members on the state of affairs in the home by generating daily horoscopes based on activity traces captured by sensors installed in specific areas in the home. The Home Health Horoscope exploits the obscure writing style of horoscopes to allow users to make their own interpretations. Another example, Tableau Machine [23], is an ambient display that characterizes home activities based on analyzing and aggregating overhead video feeds in the home. Tableau Machine presents "the character" of the activities it captured in the form of continually updating abstract animations. Field tests of the Home Health Horoscope in one household and Tableau Machine in three households found that the output of these two systems made users wonder about the meanings of the systems' output and sometimes the systems' true intentions. However, as Pousman et al. acknowledged, actual reflections on home life rarely occurred.

In the design of Home Trivia, we wanted to address an important lesson we learned from the successes and limitations these two systems had in their respective field tests. Specifically, it appeared that the participants' goal of reflection in both systems' field tests was primarily about the meanings of the system output but not the home life the output represented. This limitation might be attributed to the fact that both systems neither confirmed nor refuted users' interpretations of the meaning of the representations. As a result, users' existing understandings (or lack thereof) of their home lives remained unchallenged. While it might be reasonable for a system prioritizing playfulness to stay enigmatic, we believe for systems that intend to serve more specific goals such as facilitating reflection on technology use, the ambiguity in the representations needs to be resolvable or at least reducible to allow users to check if there is any difference between their existing beliefs and the reality. Along the same lines, Consolvo et al. argued that cognitive dissonance can provoke reflection [6]. Thus, our second design requirement for Home Trivia was:

Requirement #2: Trigger reflection by revealing discrepancies between existing beliefs and reality, as indicated by captured traces.

Triggering Reflection by Facilitating Communication

An additional issue that has potentially impeded reflection in the field deployments of the Home Health Horoscope and Tableau Machine is that both systems lack the affordance of gathering family members and allowing them to interact with the system at the same time. This is important because recounting past events with peers [13] and seeing the past from a different perspective [14], which a different person may provide, can help trigger reflection. In our case, talking about technology use in the home with one's family members might help provoke reflection among families, about family technology use. This has led to the third design requirement of Home Trivia:

Requirement #3: Motivate family members to collectively reflect on technology use in the same place at the same time so they can share their thoughts and experience.

In order to support such communication among family members, especially between parents and children about technology use, we must address barriers related to two notions in Schön's theoretical framework about reflection-in-action [25].

The first notion is called *role frame*, and refers to the way an individual perceives his/her role in a situation. According to Schön, a person's role frame exerts a strong yet often unnoticed influence on how she determines what facts are relevant, what problems belong to her, what knowledge is useful, what actions are appropriate, and what kinds of reflections should be undertaken [25]. Though parenting styles vary from family to family, an asymmetry of power between parents and children exists. Children are often in a passive role of adhering to rules but not enacting them and they are often asked to listen but are not always heard [3]. In contrast, parents might believe that as adults, they do not need to, or should not have to, regulate their own technology use. These role frames could hold both children and parents back from talking about, let alone reflecting on, how they use technology as part of their home life. Therefore, we wanted Home Trivia to place children and parents on an equal footing, though temporarily, that would enable them to discuss family technology use in an open and supportive setting. This was the fourth design requirement of Home Trivia.

Requirement #4: Change family members' role frames when they reflect on their technology use by putting children and parents on an equal footing.

The second notion of Schön's theoretical framework is called *Interpersonal Theory of Action*, and refers to a set of guiding principles for how to behave in a multi-party conversation [25]. It affects reflection by changing the willingness of different parties to openly communicate their thoughts and calculations. According to Schön, when an individual conforms to a competitive interpersonal theory of action, he will be more likely to reserve his information about and understanding of the situation to himself. As a result, it would be difficult for parties in the conversation to detect potential misunderstandings and reexamine their assumptions and behaviors. In contrast, a cooperative interpersonal theory of action leads to a more open and transparent conversation that facilitates reflection. Therefore, it is important to encourage users to share instead of withhold their knowledge and assumptions with others. This constitutes our fifth design requirement for Home Trivia:

Requirement #5: Encourage family members to share their thoughts and experience by fostering a cooperative interpersonal theory of action.

In addition to providing an additional perspective through communicating ideas and opinions about technology use with others, increased communication complements more conventional methods used by parents today (e.g., technical restrictions and monitoring). Byrne and Lee's survey of parent-child pairs shows that mutual respect resulting from open communication could make children less likely to perceive that regulating their Internet usage was intended to take away their freedoms [3]. Given this, we arrived at the sixth design requirement of Home Trivia:

Requirement #6: Create opportunities in the home to talk about technology use casually and regularly among family members.

Aligning Engagement with Communication, Awareness and Reflection

To enhance awareness, facilitate communication, and ultimately support reflection, Home Trivia must engage both adult and child members of a family. To this end, we drew on the Problem-based Gaming (PBG) approach [18] originally developed in education to align engagement with these goals. PBG motivates learners to reflect on their knowledge by supporting experimentation, providing feedback, and facilitating collaboration.

In the model proposed by Kiili [18], problem-based gaming is characterized as a cyclic process. The problem-solving cycle usually starts from formation of a playing strategy based on the player's prior knowledge. Next, the player can test her knowledge by engaging in active experimentation in the game world. The cycle will be completed when the player receives feedback from the game and reflects on her understanding. Based on what she has learned from reflecting on the outcome of the previous cycle, the player will adjust her strategy and a new cycle will start.

This model fits our goals nicely. In Home Trivia, we wanted users to test their knowledge about their family's technology use in the home through experimentation, and we also anticipated that the difficulty and surprise they might experience during such experimentation would likely to provoke reflection. Thus, our last design requirement for Home Trivia is stated as follows:

Requirement #7: Encourage thinking about as well as talking about technology use in the recent past by making it a requirement to win the game.

SYSTEM DESIGN AND IMPLEMENTATION

In this section, we describe how we designed and implemented Home Trivia to meet the requirements we have outlined in the previous section. Home Trivia consists of a device activity tracker capturing usage of devices connected to the home router, several space usage trackers capturing acoustic and motion signals in selected rooms, and a Web-based computer/tablet game which displays the captured activity traces as its main content. Below, we describe these components and how they work together.

Sensing Activity

The device usage tracker in Home Trivia consists of an instrumented wireless router and a log-parsing program running on a remote server. It uses the Internet access records kept by the router to approximate when a device was used in the home. Though the device usage tracker is not capable of tracking usage of devices with no network connectivity or usage instances that do not use the Internet, such untraceable usage is generally uncommon today.

Device usage traces are captured in three steps. First, the Web Monitor in the Tomato firmware [28], which we installed on our router, generates a log file that contains Internet access records of all the devices connected to the router. Each record includes a timestamp, the device's LAN IP address, and the domain the device accessed. Second, the router periodically transmits the latest version of the log file and the updated device list (i.e., DHCP records) to our server. Last, upon receiving the log file, the server runs a program that looks up each device's hostname in the latest device list based on its IP address and then creates a device usage record in the database containing three fields: home id, device name, and access time. To mitigate potential privacy concerns, the program discards information about the domains devices accessed and any records generated by devices that do not belong to a participant.

To provide additional context of home activities, Home Trivia also includes several space usage trackers (see Figure 1). Each of them includes a PIR motion sensor, a microphone, and a Raspberry Pi. The space usage tracker combines acoustic and motion signals near an indoor location to characterize its activeness. Our assumption is that when a space in the home is active, there are usually people talking or moving around. Every minute, the space usage tracker saves the number of motions detected and the average amplitude of each second of this minute to a

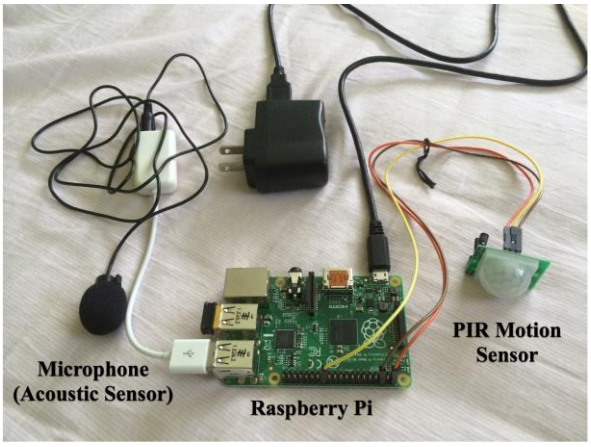

Figure 1: A space usage tracker consists of a microphone, a PIR motion sensor, and a Raspberry Pi.

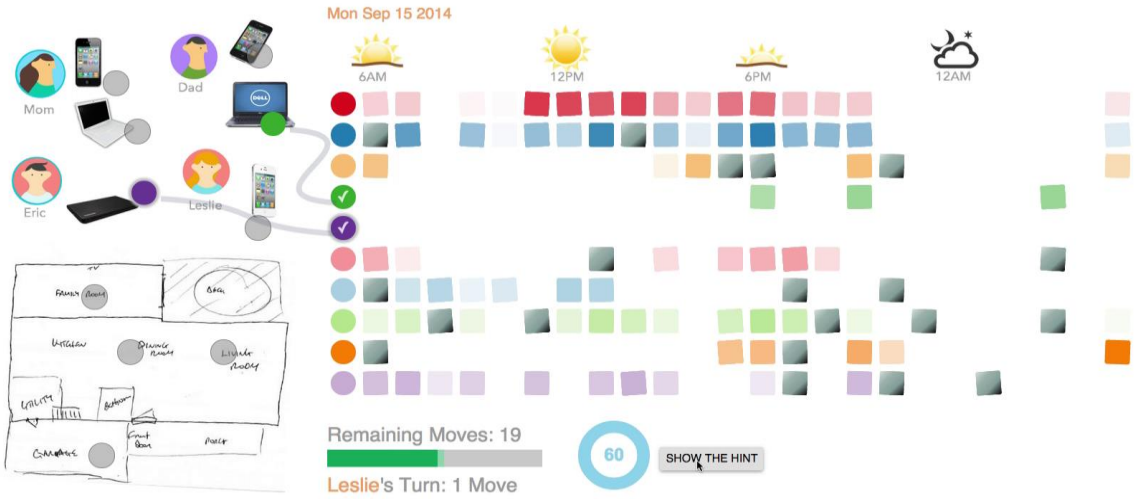

Figure 2: A screenshot of a puzzle in the Home Trivia game. On the upper left side, the icons represent the players and their devices. On the lower left side, the gray dots on the floor plan indicate the instrumented rooms where sensors were deployed. The usage traces captured from those devices and rooms are then represented by the grid on the right-hand side. Each row in the grid depicts the changing Activeness of a device or a room throughout a day in a unique color. The more the device or space was used, the darker the color of the square would become. To solve the puzzle, players need to match the activity streams on the right-hand side to the activity sources on the left-hand side.

database. To maintain participant privacy, space usage trackers were deployed in shared spaces in the home only, such as the living room, the kitchen, and the garage.

Characterizing Activeness

To generate puzzles in Home Trivia, raw activity traces need to be aggregated and transformed to characterize how active a device was during the hours when it was tracked. We defined a normalized measure called *Activeness* for this purpose. In a nutshell, Activeness is the percentile rank of the amount of activity a device or a space had during a particular hour based on its entire activity history. In other words, a device or a space's Activeness is always relative to its own activity history, and the value of Activeness ranges from 0% to 100%.

Defining Activeness this way has pros and cons. One of the main advantages of making Activeness relative to the activity source's own activity history is that it can make usage spikes of generally lightly-used devices or spaces stand out, which could indicate unusual events or behavior. It also helps reduce the noise introduced by frequent background networking processes (e.g., checking updates and sending status) on some devices, especially PCs. The downside is that Activeness cannot be easily compared between two devices or two spaces on absolute terms.

Gamifying Activity Traces

The activity data captured by the system is then used to generate puzzles in the Home Trivia game, which family members can play together to learn how they spent time at home. Designed as an online board game, Home Trivia allows conversations about technology use to happen in a relaxed atmosphere (Requirement #6). In addition, like a board game, Home Trivia requires family members to play in the same place at the same time (Requirement #3) in order to promote sharing of thoughts and experience.

The game is implemented with Web technologies (i.e., JavaScript and HTML), so it can be played on either a laptop computer or a tablet. When a family plays the game together, the game UI can be mirrored to a television via a device called Chromecast[§] so that everyone in the room can see the progression of the game (Requirement #1).

Visual Representation of Activity Data

Each puzzle in the game includes a 24 by N grid, which visually represents the device and space usage traces captured in the participants' home on a particular day (see Figure 2). N equals the total number of *activity sources*—the devices and spaces tracked by the system in the home. Each row in the grid depicts the changing Activeness (defined previously) of a device or a space throughout a day in a unique color. Each square in the grid corresponds to a particular activity source's Activeness during a particular hour. The more the device or space was used, the darker the color of the square would become. On the left-hand side of the puzzle, the devices and spaces where the activity traces originated are represented with icons or dots on a floor plan. The floor plan was hand-drawn by one of the family members during the initial interview.

Objective: Identifying Activity Sources

The objective of the game is to match each color in the grid to an activity source, a device or a space that was

[§] Chromecast. http://www.chromecast.com

responsible for generating activities represented in that color. To identify an activity source for a particular color, the player is expected to examine all the squares in various shades of the color, think about and probably discuss with others what device or space's activity might be responsible for generating those activities represented in those squares, and then make an informed guess. This process reflects Requirement #7, which ties recalling home activities in the recent past to the progress the player can make in the game.

To link up an activity stream and an activity source, the player will "grab" the dot in front of a row and then "drop" it onto the gray slot near the target activity source on the left-hand side. The player will receive immediate feedback on whether or not she has made a successful move. This feedback is crucial to provoke reflection because it allows the player to compare her existing beliefs and the reality captured by the system (Requirement #2).

Collaborative Play

Family members play this game collaboratively instead of competitively in order to encourage exchanges of thoughts and perspectives (Requirement #5). Moreover, in order to put children and parents on an equal footing, family members take turns in the game, thus each of them can have equal opportunities to help understand how they use technology and spend time at home (Requirement #4). Each player makes the same number of moves when it is her turn. Every matching attempt costs a move in the game.

Challenges: Limiting the Number of Moves

In order to stimulate thinking, the game requires family members to identify all the activity sources within a limited number of moves. This constraint is expected to discourage mindless trial and error and motivate players to think about their activities in the home before they make a match.

Hints: Identifying the Type of Activity

It is important to maintain players' confidence that they can eventually solve the puzzle. Therefore, each puzzle provides hints that identify the type of activity source (i.e., device or space) represented by a randomly selected color. A new hint will become available every minute until the type of every color has been revealed.

Reward: Playing Back the Rhythm of the Day

When a puzzle is solved, meaning all the colors have been matched to correct activity sources, the game will reward the players with a "victory" animation called *The Rhythm of The Day*. In the animation, the dots next to the sources will dynamically change their sizes based on the source's activeness in each hour. The players will see a fast-forwarded recap of their household's activities throughout the day and have another chance to think and talk about it.

FIELD STUDY

Study Sites and Participants

To understand how Home Trivia might help families understand, talk about, and change perspectives on technology use in the home, we conducted a field study of Home Trivia with five local families, after a pilot deployment in the first author's home.

We recruited participants by posting ads to parenting mailing lists, public libraries, and other family oriented public spaces. We also used snowball sampling in our recruiting process. Potential participants signed up for the study via a web form, where we asked a few questions to confirm their eligibility. We specifically targeted families with at least one child aged from 7 to 13 because children in this age range start to have their own mobile devices and laptop computers [20]. We believe it is beneficial for parents and children to engage in conversations about technology use at this formative stage when children start to develop habits of using technology.

All five households in our study consisted of two parents at home, a father and a mother, and H03 also included a grandmother. Nine children in total participated, and their average age was 10. They all had regular access to at least one Internet-enabled device at home, and seven of them had their own devices. We paid the parents of each family $100 to compensate them for their participation in the study.

In the rest of the paper, we will use abbreviations in the following forms to refer to households and individuals: F (Father), M (Mother), S (Son), D (Daughter), G (Grandmother) and H01-F (the father in Household 01). All names appearing in quotes and figures are pseudonyms. All participants (adults and minors) in the study completed consent/assent forms; it is possible that other household members or household visitors could be captured in the system, but their networking data was deleted to the extent possible and they are not quoted in the paper.

Study Procedure

Each field trial involved three steps. The first step was a semi-structured interview conducted in the participating family's home. At the second step, activity trackers were deployed to the participants' home. The final step was a gameplay session with the family.

The initial interview was conducted with two parents in all households, as well as the grandparent in H03. The primary purpose of this interview was to learn about the family's routines and technology-related practices to provide a context for the rest of the study. Furthermore, the researcher examined the networking infrastructure in the participants' home and the family spaces they wanted to monitor to prepare for the deployment of the activity trackers.

During the interview, the researcher employed techniques including floor plan drawing, calendar annotation, and artifact walkthrough to elicit grounded responses from participants. In particular, the researcher asked the participants to draw a floor plan of their home and circle main family spaces, annotate a week-view calendar with family times, and describe usage of devices in the home. Each interview lasted about an hour and was audiotaped.

Following the initial interview, the researcher deployed the activity trackers on a subsequent visit. During the deployment, the researcher swapped the participants' WiFi router with an instrumented router. In addition, the researcher installed the space usage trackers in three or four family spaces identified by participants in the interview. Those activity trackers stayed in the participants' home for at least one week to capture activity traces.

After activity traces were collected, the researcher came back to the participants' home to host a gameplay session in which participants played several puzzles made of the device and space usage data captured in their home. The researcher started this session with a short introduction to the game including its controls, rules, and objectives. Then participants had an opportunity to practice with some guidance provided by the researcher. As soon as participants appeared to be familiar with the game, the researcher asked the family to take over and run the session as if it was one of their family's game nights.

The researcher then retreated into the background and observed how participants went about solving the puzzles and reacted to the activity data revealed to them. When participants had completed two or three puzzles, the researcher asked whether they wanted to play one more puzzle or stop there. This question was intentionally directed to the children in order to understand whether the game was engaging to them.

When participants finished playing, the researcher conducted a quick debriefing with all the players, including children. The researcher then asked the adult participants to fill out a short questionnaire and explain their responses. The gameplay session usually lasted about 70 minutes. All five gameplay sessions, including the game screens, were recorded and partially transcribed.

Data Analysis

We analyzed the data collected from initial interviews and gameplay sessions to understand how participants interacted with the game and with one another. We started with an initial analytical framework derived from the goals we set for Home Trivia, including facilitating communication, enhancing awareness, supporting reflection, and engaging family, as well as relevant theoretical work reviewed earlier. The initial framework included high-level themes such as Engagement, Remembering, Reflection, Learning, and Family Communication. This framework evolved as we analyzed each new case.

For each case, we conducted a three-step analysis guided by this evolving framework. First, we reviewed and annotated the screen recording of the gameplay session. Each move in the gameplay session was tagged with one or more attributes and critical incidents (e.g., recounting events, taking suggestions from others, or making a reflective statement). Second, we coded transcriptions of the initial interview and the debriefing with the themes in our framework. Third, we wrote an analytical memo for the case to organize evidence and develop arguments. The memoing process also helped us update and refine our framework, which was then used to analyze the next case. After we finished analyzing all the cases, we applied the framework developed from this process to all the cases again to ensure our analyses were consistent and thorough.

FINDINGS

Our analysis shows that Home Trivia successfully engaged participants, and its game mechanics were able to translate engagement to enhanced awareness of and communication about technology use at home, which then resulted in participants' reflection on their behaviors and beliefs.

Engaging Families

Without engaging family members, it would be impossible for Home Trivia to achieve its goals of enhancing awareness, increase communication, and provoking reflection. The field tests show that the vast majority of our participants, both children and adults, enjoyed playing the game.

On the one hand, children were engaged with the game. The most direct evidence was that when asked whether they wanted to play one more puzzle or stop, all but one of the nine children wanted to continue playing. Some child participants expressed disappointment when they realized that it was the last puzzle they could play.

On the other hand, adults also had fun playing the game. Ten out of the eleven adult participants strongly agreed with the statement "I found the game engaging" in the post-test questionnaire, and they cited two main reasons.

First, many of them were pleased to find that each puzzle in the game was uniquely created based on their activity data. As the grandmother in H03 said, "I think it was entertaining in the fact that it told us about us." The mother in H04 further explained why using her family's data made the game engaging:

It made it more personal and we were more interested in getting it right, because it showed how much you know the people in the family.

Second, some participants praised the game's collaborative play mode. The father in H04 appreciated that the game mobilized everyone in the family:

It was neat to use everybody's experiences and thoughts. Even [H04-S] became quite perceptive. That was good.

Furthermore, the father in H03 thought collaborative play helped sustain the engagement. He compared Home Trivia with the board games they had played before, in which they usually competed with one another:

Board games usually are [played together], but then someone gets upset 'cause they're losing... Then people quit and walk away, and so we sometimes have a hard time with

games. But there's no winners and losers in this, so that kept everyone going.

As we shall see, the design of the Home Trivia game translated participants' engagement with the game to enhanced awareness and communication by making revisiting past events and exchanging ideas necessary to win the game.

Revisiting the Past and Enhancing Awareness

Soon after they started playing, participants realized that they needed to think about what they did on the particular day represented by the puzzle in order to win the game. This is important because participants' enhanced awareness of their recent behaviors and the state of affairs in their homes was a necessary condition for them to reflect on how they spent time at home [9]. Our analysis of interview data, logs, and real-time observations has revealed three main ways in which Home Trivia enhanced participants' awareness of how they spent time at home in the recent past.

Reinforcing Knowledge of Routines and Patterns

First of all, playing the Home Trivia game helped participants reinforce their existing knowledge of routines of their families, habits of individual family members, and other general patterns related to device and space usage in the home. Invoking such knowledge was usually a good starting point to determine an activity stream's source, as the father in H04 said, "We are such creatures of habit."

A popular strategy employed by many participants was first thinking about their activities by identifying the type of day (e.g., weekend vs. workday/school day, or a mom-stays-at-home day vs. a mom-goes-to-work day), and then considering their usual schedules and usage of their devices on days of that type. When participants were talking about their schedules, they paid special attention to the events that could carry the most information about their activeness or presence in the home, such as leaving for work, coming back home, going to bed, etc. Thinking about those "landmark" events on a particular day was often quite helpful in recognizing a device or a room. Consider the following dialog:

H01-D: It's after 2 [pm]…

H01-M: Hang on. Let's see what it goes to.

H01-D: It's probably an iPad…

H01-M: 6, 7, 8… till 8. I'm guess that's probably [H01-S]'s iPad.

Nonetheless, when the existing knowledge of routines was not sufficient to narrowing down choices or it led to surprising outcome, participants would often try to recollect and recount specific events and experiences.

Reminding Past Events

We observed that activity traces displayed in the game occasionally served as reminders of past events that were not noticed in the first place or were being forgotten. For example, a seemingly odd movement in the living room captured by the sensors in the early morning reminded the parents in H04 that their eldest daughter had left home at dawn for a hockey game.

H04-F: So who was up [at] 5 [AM] to 6 [AM], doing stuff?
H04-D: Cookie [one of the family dogs].
H04-M: 5 to 6. Hmm...
H04-F: [An elder daughter] was up!
H04-M: Yeah, you're right!

(Note the elder daughter mentioned above was not a participant in the game because she was older than our target age range.)

Sharing Personal Experience

Finally, family members recounted past events together, with one correcting or complementing another's story. According to Casey, "remembering with others" (p. 105) is the essence of reminiscing [4]. Recounting mundane bits of everyday life appeared to be surprisingly delightful to some participants. For example, the father in H04 was amused when he found that the activity trackers captured his foray into the dining room at 2 AM to finish some overdue paperwork on his laptop. He was eager to tell his family about it:

H04-F: Boom! Daddy wakes up.

Everyone: (laughter)

In sum, seeing activity traces as the content of puzzles allowed participants to engage with their existing knowledge and memory in a wide range of mnemonic modes [4], including recognizing, reminding, and reminiscing. Playing Home Trivia together also provided an opportunity for some participants to learn more about how other family members spent time at home by examining the activity data revealed by the game and listening to the stories told by others. This enhanced awareness was often a precursor for reflection.

Talking about Technology Use

Another major goal of designing Home Trivia was to improve how families talk about technology use, not only for the purpose of democratizing adoption of mediation strategies but also for the purpose of exposing users to different viewpoints and narratives of events that can potentially trigger reflection. In particular, Home Trivia was specifically designed to encourage children to share their observations and allow conversations about technology use to occur in a relaxed atmosphere.

Based on our initial interviews, regular and open communication about family technology use was lacking in our participants' homes. Most parents said they intervened when they found their children were on their devices too long. It was especially revealing when the mother and grandmother in H03 answered the researcher's question

about whether they talked about technology use with the two girls in their family:

H03-M: Other than saying, "Would you get off the tablet? Would you get off the tablet now?" (chuckle)

H03-M: No, [we did] not really [talk about it].

H03-G: Literally take it out of their hands and pull it out of their ears.

In contrast, family members talked about technology use during playing Home Trivia in ways very different from this kind of knee-jerk reaction.

First, Home Trivia allowed participants to notice and talk about positive behaviors of technology use, instead of focusing on correcting problems. For example, the mother in H02 was pleased to learn that she did not watch TV (via a streaming box called Roku) as much as she thought:

Wow, I was pretty good with the Roku that day!

Second, the conversations around technology use tended to be evaluative rather than reactive, since the event in question was in the past rather than ongoing. The abstract nature of the usage traces presented by Home Trivia also made room for explanation and prevented tension from escalating. Consider this dialog:

H04-M: What time was that? Was it midnight? 11 o'clock. You need to stop that.

H04-D: That's because I didn't set the alarm. I forgot to. Then I woke up at 11, and then [I set the alarm].

Third, the game mechanics of Home Trivia encouraged children, especially younger children, to talk about how and when technology was used and how they spent time in the home from their perspectives, which was not often solicited and valued from other members of their families. For example, when asked what the most interesting part of the game was, the son in H04 told us:

It makes them [his parents and sister] understand that I know best, so they should always listen to me. But still they don't.

Triggering Reflections

Did enhanced awareness and communication lead to reflective thought? Our data indicate that participants adopted new perspectives, at least during the game playing sessions, because Home Trivia allowed them to check their presumptions against reality, receive feedback from others, and relate space usage to device usage.

Reflection through Checking the Reality

Reflection often occurred when participants learned something contrary to what they believed to be from the activity traces presented in the game.

In the initial interview with the parents in H04, the mother said she was worried that they used electronic devices too much. She specifically mentioned that her son liked playing games on his laptop. However, that perception turned out to be inaccurate, at least on warm days. During the debriefing, she told us:

When you asked me last week, I would say he was on the computer all the time (Laugh). But actually that [the Home Trivia game] showed his computer had the least usage.

This discrepancy between her impression and the reality triggered reflection. Seeing that her son was not on his computer as much as she believed, the mother reported that it made sense after thinking about it:

Because when I thought about it he was outside awful a lot. He would come home from school doing his homework and he was gone until it was dark. And then he would get on it a little bit, but [not very long].

She further reflected that she probably has "nagged" her son too much about computer usage.

Reflection through Communicating with Family Members

Another situation where participants reflected on their behavior was when they switched from a first-person view of their experience to an observer view when they learned about the perception of other family members. For example, the mother in H01 realized that she probably should get off her phone more after her daughter showed surprisingly accurate knowledge of her technology-use habits by correctly attributing device usage late in the night to her. The mother then said the following during debriefing:

You can tell my patterns because I'm the night owl… So if it's between the hours, like she [her daughter] even said, if it's between the hours of 10 and midnight, it's me.

Reflection through Relating Space Usage to Device Usage

While Home Trivia is primarily designed to facilitate users' reflection on their technology use, including space usage data not only helped participants better reconstruct their memory but also supported reflection by allowing participants to examine their space usage and device usage in tandem. For example, the mother in H04 observed an interesting pattern in her home:

I thought it's interesting because lighter colors seem to always be in periods of time that we are having dinners and stuff, when there is no [device] usage, so that's time we are all together talking… There's a lot of usage when people are scattered, but when there's a lot of motion in the room it seem to be a lot less usage.

In addition to these clear instances of reflection, there was considerable amount of gray space between reflective and descriptive statements. For example, the mother in H02 said the information displayed in the puzzles made what she already knew official. It was somewhat reflective, because it implied an evaluative process that resulted in a confirmation of belief. There were many instances of this kind of reflection in our field tests. They were brief, non-dramatic, and sometimes not fully articulated.

DISCUSSION

Reducing Ambiguity through Play

Our analysis has shown that the Home Trivia game was engaging to both the adults and children who participated in our field study. Moreover, our data indicate that their engagement with the game led to increased awareness of past experience, new opportunities to talk about technology use, and reflections on how participants used technology as well as how they spent time at home. We were especially pleased to find that the reflective aspect and the playful aspect of the system seemed to support one another in the field trial. We believe this was enabled by giving users the ability to reduce ambiguity through play.

We intentionally chose to provide activity tracking results with "missing information" (i.e., the links between activity streams and their sources), in order to leverage participants' curiosity about their own behaviors in the past. Home Trivia then allowed those participants to take actions in the game to satisfy their curiosity.

This aspect of Home Trivia bears some similarity to Gaver's idea of using ambiguity as a resource for design [12], but we introduced an important change to the approach. The design of the game makes it very clear that players can reduce the ambiguity in the relationship between activity sources and activity traces by using their memories, exchanging ideas with one another, and experimenting in the game. The behaviors we observed in our field tests suggest that it is engaging to work on a meaningful problem that is solvable. Moreover, as the user tries to resolve the ambiguity in the relationship between an activity stream and its source, the user has many opportunities to check whether her existing beliefs match the reality revealed in the data captured by the activity trackers based on the feedback she receives from the game. We have shown that this allowed some participants to notice discrepancies between beliefs and reality, which often triggered reflection.

Limitations

While this study has generated useful insights about using traces to support reflection, it has several limitations. First, the number of homes in which we tested Home Trivia was small, though it was on par with prior work in this space [5,11,23]. Furthermore, the families who signed up for the study were not particularly diverse in terms of socio-economic status, education, and ethnicity. Second, each field trial lasted less than two weeks and the game was tested once for about an hour in each trial. While we believe getting quick feedback from participants is valuable, a longer-term study is needed to understand the novelty effect, the learning effect, and potential ways to incorporate the game into the routines of busy families. Last, each puzzle only showed activity data for a particular day, as opposed to, say, a week or a month in aggregate. We do not know if representations at other levels of granularity might have been more or less engaging and thought provoking when used as game content.

Future Work

The promising results of our field study as well as its limitations warrant both additional technical work and further investigations in user behaviors. First, the sensing infrastructure of Home Trivia can be improved to capture more types of data. For example, Bluetooth-based beacons can be deployed in the home to enable localization of devices. This data can provide additional context to device usage. However, introducing new types of data to the game would require creative redesign of the game interfaces and game mechanics in order to take advantage of the additional information. Second, a longitudinal study is needed to understand how families might integrate Home Trivia to their home lives and how the opportunity of seeing their activity traces in the game might impact their technology use behavior in the long run. It would be especially interesting to see how children might change the way they think about the game as they get older. Privacy considerations would also become more critical as children become teenagers and may not want their behaviors revealed to their families.

CONCLUSION

In this paper, we have presented the design and a field study of the Home Trivia system. Home Trivia captures device usage and space usage in the home through an instrumented router, acoustic sensors, and motion sensors. Home Trivia then uses the captured activity traces as the content of a puzzle game family members can play together for the purpose of raising their awareness of how they spend time at home and triggering their reflections on technology use.

The results of testing Home Trivia in the field show that the game mechanics of Home Trivia allow engagement and reflection to reinforce each other. Moreover, our work enriches and further develops the idea of using ambiguity as a resource for design with the insight that allowing users to reduce ambiguity through recollecting past events and communicating with others can help trigger reflection. Finally, Home Trivia expands the emerging design space of using domestic sensing for non-task oriented computing.

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REFERENCES

1. Nick Bilton. 2013. Disruptions: More Connected, Yet More Alone. *Bits Blog*. Retrieved November 11, 2014 from

http://bits.blogs.nytimes.com/2013/09/01/disruptions-more-connected-yet-more-alone/
2. Dave Boehi. 2012. Are You Married to Your Cell Phone. *FamilyLife*. Retrieved July 1, 2014 from http://www.familylife.com/articles/topics/marriage/staying-married/communication/are-you-married-to-your-cellphone
3. Sahara Byrne and Theodore Lee. 2011. Toward Predicting Youth Resistance to Internet Risk Prevention Strategies. *Journal of Broadcasting & Electronic Media* 55, 1, 90–113. http://doi.org/10.1080/08838151.2011.546255
4. Edward S. Casey. 2000. *Remembering: a phenomenological study*. Indiana University Press, Bloomington.
5. Marshini Chetty, Richard Banks, Richard Harper, et al. 2010. Who's Hogging the Bandwidth: The Consequences of Revealing the Invisible in the Home. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 659–668. http://doi.org/10.1145/1753326.1753423
6. Sunny Consolvo, David W. McDonald, and James A. Landay. 2009. Theory-driven design strategies for technologies that support behavior change in everyday life. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 405–414. Retrieved March 11, 2014 from http://dl.acm.org/citation.cfm?id=1518766
7. John Dewey. 1910. *How We Think [Kindle Edition]*. D.C. Heath & Co.
8. Tao Dong, Mark S. Ackerman, and Mark W. Newman. 2014. "If These Walls Could Talk:" Designing with Memories of Places. *Proceedings of the ACM Conference on Designing Interactive Systems*, ACM.
9. Rowanne Fleck and Geraldine Fitzpatrick. 2010. Reflecting on Reflection: Framing a Design Landscape. *Proceedings of the 22Nd Conference of the Computer-Human Interaction Special Interest Group of Australia on Computer-Human Interaction*, ACM, 216–223. http://doi.org/10.1145/1952222.1952269
10. William Gaver, John Bowers, Andy Boucher, Andy Law, Sarah Pennington, and Nicholas Villar. 2006. The History Tablecloth: Illuminating Domestic Activity. *Proceedings of the 6th Conference on Designing Interactive Systems*, ACM, 199–208. http://doi.org/10.1145/1142405.1142437
11. William Gaver, Phoebe Sengers, Tobie Kerridge, Joseph Kaye, and John Bowers. 2007. Enhancing ubiquitous computing with user interpretation: field testing the home health horoscope. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 537–546. http://doi.org/10.1145/1240624.1240711
12. William W. Gaver, Jacob Beaver, and Steve Benford. 2003. Ambiguity As a Resource for Design. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 233–240. http://doi.org/10.1145/642611.642653
13. Andrea Grimes, Martin Bednar, Jay David Bolter, and Rebecca E. Grinter. 2008. EatWell: sharing nutrition-related memories in a low-income community. *Proceedings of the ACM 2008 conference on Computer supported cooperative work*, ACM, 87–96.
14. R. Harper, D. Randall, N. Smyth, C. Evans, L. Heledd, and R. Moore. 2008. The Past is a Different Place: They Do Things Differently There. *Proceedings of the 7th ACM Conference on Designing Interactive Systems*, ACM, 271–280. http://doi.org/10.1145/1394445.1394474
15. S Harrison, D Tatar, and P Sengers. 2007. The Three Paradigms of HCI.
16. Alexis Hiniker, Kiley Sobel, Hyewon Suh, Yi-Chen Sung, Charlotte P. Lee, and Julie A. Kientz. 2015. Texting while Parenting: How Adults Use Mobile Phones while Caring for Children at the Playground. ACM Press, 727–736. http://doi.org/10.1145/2702123.2702199
17. Fahim Kawsar and A.J. Bernheim Brush. 2013. Home computing unplugged: why, where and when people use different connected devices at home. *Proceedings of the 2013 ACM international joint conference on Pervasive and ubiquitous computing*, ACM, 627–636. http://doi.org/10.1145/2493432.2493494
18. Kristian Kiili. 2007. Foundation for problem-based gaming. *British Journal of Educational Technology* 38, 3, 394–404. http://doi.org/10.1111/j.1467-8535.2007.00704.x
19. Uichin Lee, Joonwon Lee, Minsam Ko, et al. 2014. Hooked on Smartphones: An Exploratory Study on Smartphone Overuse Among College Students. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 2327–2336. http://doi.org/10.1145/2556288.2557366
20. Amanda Lenhart. Is the age at which kids get cell phones getting younger? *Pew Research Center's Internet & American Life Project*. Retrieved November 11, 2014 from http://www.pewinternet.org/2010/12/01/is-the-age-at-which-kids-get-cell-phones-getting-younger/
21. Jennifer A. Moon. 2013. *Reflection in Learning and Professional Development: Theory and Practice*. Routledge.
22. Antti Oulasvirta, Tye Rattenbury, Lingyi Ma, and Eeva Raita. 2012. Habits Make Smartphone Use More Pervasive. *Personal Ubiquitous Comput.* 16, 1, 105–114. http://doi.org/10.1007/s00779-011-0412-2
23. Zachary Pousman, Mario Romero, Adam Smith, and Michael Mateas. 2008. Living with tableau machine: a longitudinal investigation of a curious domestic intelligence. *Proceedings of the 10th international conference on Ubiquitous computing*, ACM, 370–379. http://doi.org/10.1145/1409635.1409685

24. Mario Romero, Zachary Pousman, and Michael Mateas. 2008. Alien presence in the home: the design of Tableau Machine. *Personal Ubiquitous Comput.* 12, 5, 373–382. http://doi.org/10.1007/s00779-007-0190-z
25. Donald A Schön. 1983. *The reflective practitioner: how professionals think in action*. Basic Books, New York.
26. Lois Tarter. If You Want a Stronger Marriage, Ditch the Cell Phone. *MORE Magazine*. Retrieved July 1, 2014 from http://www.more.com/if-you-want-stronger-marriage-ditch-cell-phone
27. Sherry Turkle. 2012. *Alone Together: Why We Expect More from Technology and Less from Each Other*. Basic Books, New York.
28. 2015. Tomato (firmware). *Wikipedia, the free encyclopedia*. Retrieved July 3, 2015 from https://en.wikipedia.org/w/index.php?title=Tomato_(firmware)&oldid=667724179