Understanding My Data, Myself: Supporting Self-Reflection with Ubicomp Technologies

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ABSTRACT
We live in a world where many kinds of data about us can be collected and more will be collected as Ubicomp technologies mature. People reflect on this data using different tools for personal informatics. However, current tools do not have sufficient understanding of users' self-reflection needs to appropriately leverage Ubicomp technologies. To design tools that effectively assist self-reflection, we need to comprehensively understand what kinds of questions people have about their data, why they ask these questions, how they answer them with current tools, and what kinds of problems they encounter. To explore this, we conducted interviews with people who use various kinds of tools for personal informatics. We found six *kinds of questions* that people asked about their data. We also found that certain kinds of questions are more important at certain times, which we call *phases*. We identified two phases of reflection: *Discovery* and *Maintenance*. We discuss the kinds of questions and the phases in detail and identify features that should be supported in personal informatics tools for which Ubicomp technologies can play an important role.

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Personal informatics, reflection, phases, discovery, design features, visualizations

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Design, Human Factors

INTRODUCTION
The abundance of computers, mobile devices, sensors, and access to information via the Internet enables the recording of a myriad of personal data (*e.g.*, physiological data, behaviors, habits, and thoughts). All of this data can be used for self-reflection to help people become more aware of their own behavior [5], make better decisions [8], and change behavior in domains ranging from health to energy conservation [7,28]. More tools are being developed that people use for *personal informatics*, which help people collect and reflect on personally relevant data for the purpose of self-knowledge [17]. Many Ubicomp tools have been created for personal informatics, such as Fish'n'Steps [18], Ubigreen [10], and mobile apps for diabetes [24].

However, we believe current tools for personal informatics were not designed with sufficient understanding of users' self-reflection needs. For example, a tool might show the user's current step counts, but the user might prefer a historical view of her average step counts to inform her how to increase her steps. To appropriately design these tools, we need a comprehensive understanding of what kinds of questions people want to answer about their data, why they ask these questions, how they answer them with current tools, and what kinds of problems they encounter. By doing so, developers and designers can better take advantage of Ubicomp technologies to help users self-reflect.

To explore these issues, we conducted a study in which we interviewed people who used tools for personal informatics. We identified six *kinds of questions* that people asked about their data: *Status*, *History*, *Goals*, *Discrepancies*, *Context*, and *Factors*. We discuss the tools that people used to answer these kinds of questions and the problems that they encountered. We also discovered that people's information needs change, which we called *phases of reflection*: *Discovery* and *Maintenance*. These phases differ by how frequently people asked the different kinds of questions. An important aspect of the phases is that people transitioned between them. People transitioned from *Maintenance* to *Discovery* when they were unable to reach their goals or when they had to redefine their goals because they experienced a new set of problems. On the other hand, people transitioned from *Discovery* to *Maintenance* when they had identified their goal and had learned the steps they needed to take to achieve their goal.

The importance of this work to Ubicomp is threefold. First, this work describes the kinds of questions that people ask about their data, which suggests how data should be presented to inform users of proper actions towards behavior change. Second, this work identifies features that Ubicomp tools should have, so that users can get the

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information they need to make better decisions towards behavior change. Lastly, this work describes how Ubicomp technologies can appropriately support people to answer the questions they ask within the phases and help them transition between the phases. This work shows that Ubicomp technologies can play an important role in helping people become more self-aware, which is valuable in making good decisions and changing behavior.

This paper is organized in the following manner. First, we discuss what we mean by personal informatics and discuss related work in personal informatics. Second, we describe our interviews, which explore what questions people ask about their data and how they answer these questions with current tools. We then discuss our findings: the six main questions people asked about their data and the two phases of reflection that they transitioned between. We present a list of features that Ubicomp tools should support to help users with reflection, and discuss their implications.

Defining Personal Informatics

We extend the definition of personal informatics [17] from a class of tools to an *activity* where people collect and reflect on personal data to gain a better understanding of their own behavior. People can and will use almost any tool for personal informatics. Tools can vary by form factor (paper, web sites, devices, *etc.*) and level of support (manual *vs.* automated). However, the limitations of tools that people use can make the activity of personal informatics cumbersome and time-consuming [17]. Therefore, Ubicomp technologies have an opportunity to assist the people in their personal informatics activity.

Data for personal informatics include data about behavior (*e.g.*, frequency of exercise) and physiology (*e.g.*, heart rate). They may include current and historical data and may be quantitative or qualitative (*e.g.*, step counts *vs.* moods). In addition to personal information, external data can be used when it is personally relevant, *e.g.*, weather data might be personally relevant if the user is interested in knowing how the weather affects her physical activity.

As we will discuss later, our exploration found that people collected personal data for other reasons other than personal informatics, such as reminiscing about the past [21], aiding memory [14], and personal information management [16]. In this paper, we focus on collection of personal data for the purpose of gaining insights and understanding oneself. There is much research that shows that reflection plays an important role in changing behaviors [see 7 for a review].

RELATED WORK

This work builds on top of other research that has looked into investigating appropriate feedback for users. This paper focuses on supporting users' reflection needs, which is one of the stages of the model of personal informatics systems [17]: *Preparation*, *Collection*, *Integration*, *Reflection*, and *Action*. The model describes the different types of support that tools must provide to assist users through their personal informatics activity. The model also highlights that the stages are inter-related, *i.e.*, problems from the earlier stages affect the later stages. This implies that the person's ability to reflect on her data and the value of the reflection are affected by how and what data she collects. Thus, the support that Ubicomp technologies can provide in improving how data is collected and in increasing the types of data that can be collected can help with self-reflection.

Related to the PI model is the Transtheoretical Model of Behavior Change (TTM) [25], which also consists of five stages: *Precontemplation*, *Contemplation*, *Preparation*, *Action*, and *Maintenance*. Unlike the PI model, which describes the different types of support needed to assist personal informatics activities, the TTM describes people's different levels of motivation and ability to change behavior. The TTM is used to classify people's readiness to change behavior, which is useful for tailoring interventions, such as, designing feedback to encourage environmentally friendly behavior [13]. Others have also explored other behavioral theories. Consolvo and colleagues used various psychological theories to describe eight design strategies to support behavior change [6]. Froehlich and colleagues described different ways of designing eco-feedback technologies [10]. While these models suggest the need for Ubicomp technologies, they do not define how tools should be designed based on people's changing information needs when engaging in personal informatics activities.

There is plenty of research on effective information visualization techniques to explore data for insights [see 4 for an extensive review], but they are not all focused on personal data. Some projects have applied exploration techniques on personal data. For example, Frost and Smith used visualizations to help diabetic patients explore the relationship between their blood glucose level and the types of food they consumed [11]. Commercial products, such as Mint (expenditures), Nike+ (physical activity), and Wattson (electricity), use information visualizations to assist users in exploring their data for patterns and trends. Some information visualizations, such as ambient displays [22], glanceable displays [19], and information art [20], are less focused on exploration of historical information. Instead, they increase awareness of one's current status (*e.g.*, you've got mail, your stock portfolio is currently up, your bus is arriving) while minimizing cognitive load. This work explores how people use these existing tools to answer their questions about themselves and what problems they encounter. We use this exploration to define users' specific information needs and to describe how Ubicomp technologies can provide support.

In the next section, we describe our interviews of people who used tools for personal informatics. We analyzed the responses for the kinds of questions they asked and how they used existing tools to answer them.

INTERVIEWS

The goal of the interviews was to study how people explore and reflect on the data they collect for personal informatics.

We conducted interviews with people who were already self-tracking and reflecting on collected data. This helped us see behavior in a natural setting where people's routines around tracking and reflecting were focused on their own needs, rather than forcing people to use a system we designed. In the following sections, we describe how we recruited participants and conducted the interviews.

Recruitment

We advertised the study on Craigslist, the Quantified Self blog, and a campus recruiting web site. The recruitment letter stated that we were looking for users of self-tracking/personal informatics tools, such as Mint, Nike+, MoodJam, *etc*. People interested in the study completed a pre-questionnaire that asked what type of data they collect, for how long, and contact information. They had to be currently using a tool for personal informatics and must have used it for a month or more. We recruited a diverse group of people from around the nation and our city. Given that we were only going to be able to talk to a limited number of people, the pre-questionnaire helped us ensure that we recruited a set of participants using a range of tools for a range of types of data.

91 people responded to the pre-questionnaire (local: 76, remote: 15). We selected 15 people (P1-P15) from all the respondents to participate in the study. Ten lived locally within the city limits and five lived remotely. A third were male (5 vs. 10 females). The age ranges and their respective counts were 20-25 (6), 25-30 (4), 30-35 (1), and over 50 (4). Additionally, half were professionals (8) and the rest were students (graduate: 4, undergraduate: 3).

Procedure

We invited participants for a one-hour interview in either our lab or over Skype, depending on whether they lived locally or remotely. Local participants were required to bring the tools they used for personal informatics (e.g., laptop, devices, notebooks) to the interview. Remote participants used Skype's Screen Sharing and Video features to show us the tools they used.

At the beginning of the interview, we introduced participants to the study. Participants signed the study consent form and completed an online survey that asked about their general personal informatics usage. The questionnaire is a condensed version of the survey described in [17]. We sat with the participants in front of their laptop or mobile phone and asked them to describe their general usage. We observed participants as they used their tools. We asked them how they reflected on their data and to show us how they reviewed their data: What were they looking for? What questions did they have? Why did they ask these questions? How did they answer their questions using their tools? What problems did they experience while trying to answer their questions?

Participants were compensated $10 (in cash or as Amazon gift certificates) for the one hour they spent with us. The interviews were videotaped.

RESULTS

We transcribed the interview recordings. We analyzed the interviews by coding the responses line by line. We did not have a pre-determined coding scheme before the analysis. Instead, we identified themes from the data as we processed the responses. The themes emerged after we organized the codes using affinity diagrams. During the analysis, we focused on the reasons people reflected on their data, what questions people were trying to answer when reflecting on their data, how the tools they used supported or prevented finding answers to their questions), and what design features in the tools they used supported their personal informatics activity.

Participant Information

To help focus our interviews, we asked participants to describe the *primary data* about themselves that they collected [Table 1]. The participants varied in the types of information they collected. The primary data that participants collected were: financial expenditures (3), sleep (3), weight (2), blood glucose level (2), exercise (1), productivity (1), web history (1), books read (1), and life events (1). Half of the participants collected one or more types of data. For example, P7, who collected the widest variety of data, used Daytum and your.flowingdata to track television shows and movies that she watched, restaurants she dined at, and places she visited. She recorded her eating habits with DailyBurn. Because of periods of insomnia, she used Fitbit to record her sleep patterns and physical activity levels. She also complemented her sleep tracking by taking notes about the quality of her sleep in YawnLog. There was also a diversity of experiences in self-tracking. Four participants had been self-tracking for a month or two; seven participants, for a year or two; and three participants, for more than three years. P3, who has diabetes, had been tracking her blood glucose level for 15 years. For several years, she used a fingerstick blood glucose meter that required piercing the skin to draw blood 3 to 10 times a day. In the past year, she started using a Dexcom device, which has a sensor that adheres to the body and continuously takes blood glucose readings very 5 minutes.

ID	Primary Data	Multiple Types?	Reason
P1	expenses	No	Behavior Change
P2	weight	Yes	Behavior Change
P3	blood glucose	Was	Behavior Change
P4	exercise	Was	Behavior Change
P5	expenses	Yes	Behavior Change
P6	blood glucose	Was	Behavior Change
P7	sleep	Was	Behavior Change
P8	sleep	Yes	Behavior Change
P9	sleep	Yes	Behavior Change
P10	life events	No	Reminiscence
P11	weight	Was	Behavior Change
P12	expenses	No	Coordination
P13	productivity	No	Behavior Change
P14	web history	No	Retrieval
P15	books	No	Sharing

Table 1. The participants, their primary data, whether they collected multiple types of data, and their reasons for collection.

Reasons

Participants cited different reasons for collecting personal data. Many participants (11 out of 15) self-tracked to reflect on the data, because they wanted to change or maintain a behavior. For example, P1 used Mint to maintain a budget after moving to a new city. P8 tracked her sleep patterns and various factors that might affect the quality of her sleep using the Sleeptracker watch and laptop application. Four participants collected data for other uses. P14 collected his web history with Google Web History for *later retrieval*. P15 collected book information in GoodReads to *share* with other people. P12 recorded his grocery and utility expenditures in Buxfer to easily *coordinate* expenses with his roommates. P10 wrote about life events in online journals to better *remember* her past. These four participants' usage of personal informatics tools is more closely in line with other types of applications (in order): personal information management, social networking, coordination, and reminiscence. In the following section, we focus our discussion on the 11 participants who wanted to change or maintain their behavior, because personal informatics tools are useful when they help people gain self-knowledge that improves decision-making and assists in behavior change.

QUESTIONS

In this section, we discuss the 6 kinds of questions that people asked about their personal information: *Status*, *History*, *Goals*, *Discrepancies*, *Context*, and *Factors*. We describe in detail what participants were looking for and how they answered their questions.

Status

People were interested in data that revealed their current status. For example, P7 checked her Fitbit device several times a day to determine her current physical activity level. Checking one's status doesn't have to happen several times a day; P5 checked her finances using Mint and her bank web site at the end of each day.

People also checked their current status to determine whether they were meeting their goal and whether they should act to correct their behavior. For example, P7 checked her step count to determine whether she took enough steps for the day. If not, she would go out for a walk. P5 checked her finances to make sure that she is staying within her daily budget. If not, she tried to spend less the subsequent days.

How often people checked their status is dependent on what kind of data they were tracking and how they were tracking it. For example, P3 and P6 have diabetes, and used blood glucose meters to measure their current blood sugar level. P3 wore a Dexcom continuous blood glucose meter, which measured her blood glucose level every 5 minutes. However, P6 used a fingerstick device, so he could only check 3 to 6 times a day.

For some kinds of data, participants did not use a device to measure their current status; instead, they used their own senses. For example, P9 who was interested in her sleep quality recorded the quality of her sleep and whether leg cramps occurred. P8 used the SleepTracker watch to measure her sleep, but she used her senses to record information related to sleep, such as mood and stress.

History

Beyond looking at one's current status, participants were also interested in seeing their data over the long term. Instead of looking at one piece of data or a short time's worth of data (an hour to a day), people wanted to see their data over a long range to find trends and patterns. Trends (whether the data is going up, going down, or remaining steady) are especially important to figure out whether they are making progress towards a particular goal. For example, P4 looked for trends in her physical activity data to make sure that she was maintaining her goal of regular physical activity over a long period of time. P5 also looked at trends to make sure that she was reducing her monthly expenditures to save for a trip abroad.

People experienced different kinds of problems in understanding their history. One problem is that the ability to see trends and patterns largely depends on having collected data over a long period of time. Thus, the person has to first put in the effort of collecting data before the value of the data becomes evident. For example, P5 started using Mint when her mom introduced her to the site. She could not make any significant conclusions regarding her spending trends because she had only been collecting data for a month prior to the interview. Another problem is that tools do not provide adequate support to allow reflection over the long term. P8 experienced this problem with the SleepTracker watch, which she had been using for several months. The watch had a desktop interface to review her past history. However, the software just listed her sleep quantity on a spreadsheet-like interface, which made it difficult to see trends. She said a simple bar graph would have been helpful.

A related question is: *how does data from one time range compare with another?* Viewing one's data over a long period of time allows the person to answer this question. For example, P1 compared her spending between two different months. She was particularly interested in seeing how her recent move affected her spending.

Goal

In addition to wanting to know their status and their history, people also wanted to figure out what goals would be appropriate to pursue. Sometimes, people started self-tracking without knowing their goal and they used self-tracking as way to 1) determine what actions they should take to fix a problem or 2) establish a "baseline" of their activities to determine whether they have a problem.

Before we go into detail about this question, we need to define what kind of goals we are talking about, because the distinction between the different kinds of goals is important. Powers [23] described goals as a hierarchical

structure ranging from abstract to more specific. The four levels are *system concept*, *principle*, *program*, and *sequence*. The *system-concept goal* refers to the sense of an idealized self, an idealized relationship, or an idealized society, and, as such, is very abstract. The next level of goals is the *principle level*, which refers to the set of goals (or guiding principles) that one tries to achieve to reach an ideal. Some examples of principle-level goals are: be physically fit, be thrifty, and be productive. This level is still quite abstract; a person does not just become physically fit or thrifty or productive, one has to exhibit such qualities by doing specific activities or *programs* [26]. Some example of *program-level goals* are: 1) running three times a week to become physically fit; 2) spending money within a budget to become thrifty; and 3) minimizing the amount of time spent browsing social media websites to become productive. To perform a program-level goal, a person does *sequences* of specific actions. For example, the *sequence-level goals* to complete the goal of running three times a week may consist of putting on shoes, going outside, running a specified route, *etc.*

In the rest of this paper, we are talking about "program-level goals" when we refer to "goals". Program-level goals are more specific than principle- or system-concept level goals, so they are more actionable or more ready to be acted upon. We found that people use personal informatics tools to help them set and complete program-level goals. For example, P4 used SparkPeople because she wanted to become physically fit (principle-level goal), but the value of the tool was in helping her track her progress in accomplishing her program-level goals: running three times per week and eating within a specified amount of calories.

Knowing one's goals had an effect on the number of kinds of data the participants collected. For example, P9 had problems sleeping because of her leg cramps. She wanted to address the problem to improve her sleep (principle-level goal), but she did not know what caused her leg cramps. She tracked what she ate and her physical activity to see if these were causing the leg cramps, so she could make program-level goals, such as "avoid X kind of food" or "don't do physical activity X hours before sleeping."

Once participants identified their program-level goals, they changed their data collection habits. For example, when P3 was diagnosed with diabetes, she did not know the appropriate program-level goals to manage her diabetes, such as what specific foods to avoid, how active she could be, *etc*. To figure out her goals, she collected multiple kinds of data: what she ate, what physical activity she did, as well as her blood sugar level. She is a "brittle diabetic" (her blood sugar fluctuates to dangerous levels quickly), so figuring out the effects of food and physical activity was critical, but difficult to do. She did this for two years until she understood her blood sugar fluctuations better and she was able to set appropriate food and physical activity goals. When this happened, she stopped collecting the other pieces of data because she already knew their effects. She still tracks her blood sugar level, but she just takes mental notes of the meal, physical activity, and sleep quality prior to her blood sugar level measurement.

Discrepancies

Once people know their goal, they compare their current status with their goal [5]. We also observed this in our interviews. Participants checked their current status then compared it with their goal: Is there a difference between my current status and my goal? How big is the difference? And what should I do to reduce the difference? For example, P4 wanted to become more physically active, so she set a goal of exercising every other day or about three times a week. She looked at her weekly physical activity using SparkPeople. She checked how much her current status differed from the goal. When she found a difference, she modified her schedule to compensate for her missed physical activity. Also, how participants addressed discrepancies changed over time. At the beginning, P4 was very strict at meeting her goals, so she immediately addressed missing her goal by exercising the same day. A year after her physical activity tracking she became less strict about meeting her goal. She allowed herself to miss days, and instead of exercising immediately, she postponed physical activity until the end of the week when she had more time. Another example is P11 who compared her daily food consumption with a range of calories, a goal that she had set in the DailyPlate tool. Every day she checked whether she was within the range of her allotted daily consumption. When her consumption was below her goal, she increased her consumption for that day. If she was within range, she made sure that she did not go over. Both P4 and P11 found that comparing their current status with their goal helped them make immediate decisions to address any differences. If they were meeting their goal, they could focus on maintaining it.

A problem with this question is that it is largely dependent on knowing what the program-level goal is. If the goal is undefined, the person cannot act on fixing their problem. This is what happened with P9. She knew her principle-level goal: fix her leg cramps when she goes to sleep. Unfortunately, she did not understand the causes of her leg cramps well enough to set appropriate program-level goals, such as avoiding certain foods or certain physical activity.

Context

Participants also wondered what other things were happening at or near the same time as their current information-seeking context. They were curious about how other events may explain what was happening to them *in the present*. For example, P3 kept in mind other events at or near the time she checked her blood sugar level (*e.g.*, what she ate, what physical activity she did), so she could act on problems appropriately. P6 noted his current mood and stress level along with his blood sugar level. He thought that his blood sugar level might explain how he was feeling.

How participants answered this question was dependent on their access to additional data. Some people depended on

other devices. For example, P6 used Fitbit and Zeo to automatically record his physical activity and sleep quality. He used the data from these devices to figure out the relationship of his physical activity and sleep with his blood sugar level. Some people used written notes (on paper or a web site) to remind themselves of other events that happened at a particular time. P8 used the annotation feature in the SleepTracker software to record her mood, stress level, and caffeine intake, which may be related to her sleep quality. P5 kept a journal of her activities to remind her of what she did when she spent her money. Sometimes, people just depended on their memory to remind them of what happened. For example, P4 diligently recorded her data at the start of her self-tracking, but after a while she just used her memory. She explained, "I just depend on my memory…I didn't want to become, like, OCD (obsessive-compulsive) about it." However, one problem with dependence on memory is that one's memory of events can be unreliable and degrades over time.

Factors

Unlike the previous question, which asks what influences a person's current status, this question asks what influences behavior *over a long period of time*. Factors collected over time help to identify and monitor trends. For example, P4 was curious how her physical activity and nutrition affected her overall health over a long period of time.

Participants were interested in how other factors may be affecting their behavior. For example, it is not sufficient to say that one wants to lose weight; it is important to know how one's physical activity level and food consumption affect one's weight. By knowing the factors, people can act on those factors to change their behavior. This is especially important when other things could cause the behavior. For example, P2 was interested in losing weight. To help her accomplish this goal, she tracked several types of information in addition to her weight: exercises she did, what she ate, total calories, and water drank. She used the CalorieTracker Android app to help her compute the calories of her food and DailyPlate to store all the data online. She used the DailyPlate graphs and charts to see the trends in her weight and how they were affected by other factors. When her weight went up, she reduced her food intake and increased her physical activity. She also made sure that her weight went down at a "healthy rate of decline", so that she lost weight in a healthy way. P2 also wrote in a journal to record her goals and how she felt about her progress. She said, "I look for things that I have done well. Places where I might have made a misstep, either I've done too much exercise in one day or I've done too little. Or maybe I didn't meet all of my exchanges or maybe I met all of my exchanges, calorie-wise."

One problem with this kind of question is that a tool did not exist that could help users explore their data holistically. Instead, they had to look at their data one at a time. Even when data was stored in the same tool, they had to look at different graphs separately (*e.g.*, Daytum). Using different tools for different types of data exacerbated this problem. For example, P6 used Fitbit for physical activity and Zeo for sleep and there was not an easy way to look at these data together. P7 used Fitbit for both sleep and physical activity tracking, so she was able to explore both types of data together. However, she also collected other types of data using Daytum and your.flowingdata, which she could not easily review along with her Fitbit data. Some participants managed to explore their data together by using paper graphs (P9 and P6) or by painstakingly reviewing logs of their data (P2 and P8). However, participants experienced other setbacks: exploring multiple types of data was confusing and understanding the influences of the factors on their behavior was difficult.

PHASES OF REFLECTION

We noticed that participants asked some questions more often than others at different times. We analyzed our data further by looking at when participants asked certain questions. We identified two distinct phases when participants asked different sets of questions: Maintenance and Discovery. We also found that participants did not remain in one phase; instead they transitioned between the two. We discuss the properties of each phase and the transitions between the phases in the next sections.

Maintenance Phase

The Maintenance phase is marked with participants mostly asking *Status* and *Discrepancy* questions. In this phase, participants used their collected data to maintain awareness of their status relative to a goal and to maintain their behavior. When in the Maintenance phase, participants can be characterized in the following way: 1) they already knew the goal they were trying to meet and 2) they have identified how different factors affected their behavior. We describe each of these characteristics below.

Participants in the Maintenance phase have already identified their program-level goals. In this phase, they self-track to determine whether their current actions are in line with their goals. P13 wanted to be more productive (principle-level goal), and had already determined his program-level goal: limit his visits to social media websites to 20 minutes a day. While his StayFocusd Chrome browser extension stored his total web site visit times over a week and a month, he did not look at those numbers; he just needed the tool to alert him when he went above his goal. P1 used Mint to keep track of her expenditures to make sure that she is meeting several budgets that she had already set for various categories of expenditures (program-level goals). When she showed us her Mint account, she had set budgets for 14 categories!

Also, participants in the Maintenance phase already knew the relationships between their behavior and factors that affect their behavior. They collected information about their behavior; they did not collect other types of data that might affect their behavior because they were not useful anymore. For example, P13 just tracked the minutes that he spent on Facebook, Twitter, and other social media sites, because he

already knew how browsing such web sites affected his productivity. He did not track other factors that might affect his productivity (*e.g.*, sleep quality, interruptions). P1 did not use the exploratory tools within Mint to see how much she had spent on different categories and what she purchased. Instead, she primarily used the main screen where her budget was prominently displayed to check whether she was within her monthly budget.

During the Maintenance phase, participants only tracked one or a few types of data. They have already defined their goal and were collecting just enough information that would allow them to tell whether they were meeting their goal. For example, P1 and P5 only reflected on their expenses and P13, on his productivity.

Discovery Phase

The Discovery phase is marked with participants mostly asking *History*, *Goals*, *Context*, and *Factors* questions. When in the Discovery phase, participants can be characterized in the following way: 1) they did not know the goal they were trying to meet and/or 2) they have not identified the factors that influenced their behavior. We describe each of these characteristics below.

Participants in the Discovery phase were still trying to figure out what their program-level goals were. When P3 was newly diagnosed with diabetes, she knew that she had to manage her blood sugar level (principle-level goal), but she did not know specifically what kinds of foods to avoid or how much physical activity she could perform (program-level goals). P8 tracked the quality of her sleep so that she feels better rested (principle-level goal). She explored her sleep data to "spot trends for which I can take corrective action." She wanted to figure out the specific program-level goals that would improve her sleep quality, such as eating dinner earlier or refraining from coffee or alcohol. She also added that she was "trying to take a long-term view", so that the solution is "not a quick-fix approach."

Also, participants in the Discovery phase did not know how different factors affected their behavior. Because of this lack of knowledge, participants collected different types of data, so they could figure out the correlations between them. P3 tracked food consumption and physical activity along with her blood glucose levels because she wanted to figure out how her eating and exercise habits affected the fluctuations in her blood glucose level. P9 had leg cramps while sleeping. She had several hypotheses about what caused her leg cramps. She talked to her doctor who said the leg cramps might be due to an electrolyte imbalance, so she tracked the types of food she ate. She also used FitBit to see if her amount of physical activity had an effect on the occurrence of her leg cramps.

Transitions Between Phases

We found in our interviews that people did not stay in one phase; instead, they transitioned between the two phases. Several participants who were in the Maintenance phase at the time of the interviews were in the Discovery phase earlier in their self-tracking regimen. P6 initially tracked his blood sugar level, his food consumption, and mood until he found that "it turns out one of the things I do to manage stress is eat something, because blood sugar feels good. So if things are unsettled or high pressure, eating something feels good." P6 described his transition to gaining control of his diabetes, "In the initial phase, three and a half years ago, over about six months, I learned to control my blood sugar down to a level from 300 to about 180. Then I escaped there and measurement became less interesting because there was no progress to be made; it was steady state stuff." P3 had a similar experience in dealing with her diabetes. She said, "When I first became diabetic, I needed to keep track of everything. At this point in my life, I've had diabetes for about 15 years, and I no longer write anything down." Now, she just wears a continuous blood glucose monitoring device to alert her whether her blood glucose is too high or too low. Her reason for transitioning was two-fold: 1) tracking all the information "would be onerous" and 2) "it wasn't helping me anymore. I was remembering. Not the exact numbers, but I was remembering trends."

P4 tracked her physical activity and food consumption diligently at the beginning, but became more lax later and did not track her food consumption. She said, "I feel like I have a handle on it. I have accomplished the goals of creating a healthy lifestyle for myself. As long as I stay like this I'm good. It's more maintenance." She still kept track of her physical activity, but for her food tracking, she just "keeps a mental note of it and just overall have become more self aware of what I eat and stuff."

Sometimes people have difficulty transitioning to the Maintenance phase because they could not find an actionable goal. P9 described that she still did not know what caused the leg cramps when she sleeps. She said, "They're not completely gone, but they're not as bad as they were. But I still don't know exactly what's caused them." She added that she still recorded the recurrence of the leg cramps, "It may always be sort of a mystery, and so I still have data for every night I've had leg cramps."

All the participants who were in the Maintenance phase at the time of the study described anecdotes when they might go back to the Discovery phase. For example, while looking at her budget, P1 saw that she made a purchase of $24 for a gift and she asked herself, "What was that?" She said since she did not remember, she explored her data to find an explanation. Since Mint provided enough detail about her purchases, she easily found that the gifts were bought at a local mall, which reminded her that she recently purchased a gift for a friend there. Sometimes the explanatory data was not immediately available, so the participant had to restart data collection of influencing factors. For example, P7 who had recurrent insomnia tracked her sleep using FitBit. Patterns of insomnia or weird dreams would appear intermittently and she would again note factors that may have caused the problem.

FEATURES

We have identified the questions that people asked and the phases in which people asked these different questions. Now, we discuss the features that should be supported in building personal informatics tools and how Ubicomp technologies can help. We also describe opportunities for Ubicomp to explore.

Supporting the Maintenance Phase

Supporting the Maintenance Phase is not as difficult as the Discovery phase because many personal informatics tools already support collecting the user's current status. Additionally, if a Ubicomp technology can sense simple things about a user's behavior, it is not difficult to display the information back to the user. However, there are some opportunities to better support the Maintenance phase.

Alert the user when they are not meeting their goal

During the Maintenance phase, it is possible for a user to know how to fix their problem, but still not fix the problem. For example, a pedometer user may know that they can get plenty of steps while walking their dog at the park, but the user may still not consistently walk their dog. In cases like this, feedback about progress towards goals can have a positive effect on self-efficacy and achievement [27]. Additionally, Ubicomp technologies can help by identifying whether the user is meeting their goal. Because alerts can sometimes be unwelcome, Ubicomp technologies, such as just-in-time feedback [15], can help determine the opportune time to alert the user of discrepancies.

Participants were more interested in their current status during the Maintenance phase compared to during the Discovery phase. Most tools for personal informatics have daily reminders of the user's current status, but this may become bothersome if the status is the same as the past several days. Instead, tools should reserve alerts for when special circumstances arise (*e.g.*, the user's step counts changed significantly). Tools can better support this by giving users control of when they are alerted.

Assist the user when they don't meet their goal

The phases of reflection do not address the question of how users could act on their newfound insights to change their behavior. Thus, it is possible for a user in the Maintenance phase to still not meet their goal. When the user does not meet her goal, the tool can be proactive in assisting her in resolving the problem. One idea is to analyze the user's history to create suggestions for resolution. For example, an automated analysis can reveal the causes of the problem. The tool can say "when you drink coffee at 6pm, you have a hard time sleeping, so avoid drinking coffee at 6pm". Automated analysis can also remind users of what they did before to resolve the problem. For example, "last time when you weren't being active you were sitting on the couch watching TV. During the other times you were active, you decided to walk your dog around the neighborhood."

Supporting the Discovery Phase

There are many opportunities for support in the Discovery phase because 1) there are many questions that are asked during this phase; 2) some questions require data collected over a long time; and 3) some questions can be answered using multiple types of data.

Collect data anytime, anywhere, and often

People in the Discovery phase try to better understand their behavior by collecting sufficient data to yield insights during reflection. Getting sufficient data may require tracking over a long period of time, over different contexts, and with great frequency. For example, understanding how one's environment affects physical activity may require tracking over a couple of weeks, at multiple locations, throughout the day. Many barriers to personal informatics are associated the burden of collecting data [17]. Automated data capture as exemplified by many Ubicomp technologies (*e.g.*, [1,12]) can reduce this burden by automating the data collection and storing large amounts of data about the user. By reducing the burden of data collection, users can focus on exploring their data.

There is a caveat about user involvement in reflection that is important. In the Discovery phase, user involvement is critical. People want to discover the relationships between data. Automation can diminish users' engagement with their data. This does not mean that automation should not be supported. It just means that automation should be balanced with ways to keep users engaged with their data. One way to do this is to force users to interact with their data daily, either by sending reports or alerts. On the other hand, user involvement in the Maintenance phase is not as critical. Users are just trying to maintain their behavior. Telling people that they are doing well can become annoying. Instead, the Ubicomp tool should be there to notify the user if anything unusual happens.

Support different kinds of collection tools

Corollary to the previously discussed need, understanding behavior may require exploring the relationships between multiple types of data. For example, understanding how one's environment affects physical activity may require collection of multiple types of data, such as location, type of activity, and weather. However, most tools for personal informatics only support collection of one or a few types of data. One thing to do is to wait for an "ultimate" data collection tool that can collect any kind of the data that a user wants to collect. However, this might just be a pipe dream or could be too far off into the future. More realistically, users should be allowed to use different kinds of collection tools, and then a system or a service can help users integrate data from the different collection tools. There is a proliferation of APIs available, and we can take advantage of this. Recently, Fitbit and Zeo partnered with RunKeeper to share data with each other. This is a good development because people can now use different tools to collect data. However, this is still incomplete because there is a plethora of tools that are not interoperable. Device

interoperability has been part of Ubicomp since Weiser started the field [29], so the expertise exists in Ubicomp to help develop and establish standards for interoperation between self-tracking devices and systems.

Data should be presented together

One of the consequences of needing multiple types of data during the Discovery phase is that people have to use different kinds of tools. Unfortunately, the current state of personal informatics systems is that they tend to be *silos of data*, that is, they do not share data with other systems. When they do share data, they do so in a limited fashion, only supporting a few tools. One of the many complaints that people had was that they had to go to different applications/web sites to answer their questions. They wished that they could explore their data in a single interface. Again, Ubicomp technologies can help here. There has been plenty of research in Ubicomp on how to integrate data together [9,12]. The technology is already available to help people collect and see their data from multiple sources at once.

Reduce the upfront cost of data collection

People in the Discovery phase are interested in relationships between different kinds of personal data. This presents two kinds of problems. First, users have to spend a significant amount of time collecting data. One solution is to support lifelong automated data collection of personal data, which many Ubicomp research projects are exploring [12,14]. The second problem is that users cannot predict whether they are collecting all of the data they need. This problem is called the *relevance paradox* [2]. For example, people often do not decide to self-track because the data is not important to them. However, when the data becomes important (*e.g.*, they get sick or they want to develop new habits), they do not have the necessary data to start reflecting immediately. Thus, they have to invest plenty of upfront cost to bootstrap their data collection. With lifelong data collection, once the user needs the data, Ubicomp tools can provide the necessary data for the user to figure out what their goal should be or what factors are influencing their behavior.

Supporting Transitions between Phases

Since people transition between the two phases, personal informatics tools should not be designed for just one phase, but should be flexible to support both. This is important because it prevents a potential problem with any personal informatics tool: people may stop using the tool because their information needs are not appropriately supported.

Identify which phase the user is in

Personal informatics tools should identify what phase the user is in and change its reflection features appropriately. Without this support, people might find the tool useless because of too little information during the Discovery phase, or people may be burdened with too much information during the Maintenance phase. It is an interesting Ubicomp research challenge to automatically determine what phase the user is in, based on sensed data.

Help users transition from Discovery to Maintenance quickly

The Discovery phase is data intensive and can be burdensome to users. Personal informatics tools should help users who are in the Discovery phase to identify program-level goals and how different factors affect their behavior, so users can transition quickly to the Maintenance phase. This would be interesting future work to explore how Ubicomp technologies help users understand their data.

Continuous data collection throughout the phases

The amount of data that users need decreases when users transition from the Discovery phase to the Maintenance phase. However, this does not mean that tools should collect less data during the Maintenance phase. Instead, only the amount of data presented to the user should decrease. We suggest tools should continue collecting as much data in the Maintenance phase as during the Discovery phase. This ensures that if a user who is in the Maintenance has to transition to the Discovery phase because of a new problem, the user can immediately reflect on her data.

CONCLUSIONS

This paper explores the different questions that people ask about their data and why they ask these questions. We identified six types of questions: *Status*, *History*, *Goals*, *Discrepancies*, *Context*, and *Factors*. We discuss how people answered these questions using existing tools and the problems that they encountered. Identifying these questions is important because they require different answers and different kinds of data, which have implications on how tools should support them. Ubicomp technologies play a big role in addressing these needs because what data is collected and how data is collected affect how people reflect on their data.

We also discovered that these questions are not asked at the same time. We identified two distinct phases in which people ask certain questions more often than others: Discovery and Maintenance. The distinction between the phases is important because it highlights the need for personal informatics tools to support different information needs, and to be better tailored to users' current needs, instead of providing them all the tools to answer all six questions at once (when they do not need all of them). Additionally, the phases are not static; people's information needs change. They transition from Discovery to Maintenance, and vice versa. Again, Ubicomp can play a big role here supporting the different information demands of the two phases and the transitions between them.

Though we did not conduct a controlled study to observe how the questions differ between the phases because it is out of the scope of this research, the identification of the questions and the phases is an important first step towards the development of future controlled studies. For example, we could create visualizations for each of the questions then observe whether people use certain visualizations more often than others based on what phase they are in. We expect that people in the Discovery phase will heavily use

visualizations that answer *History*, *Goals*, *Context*, and *Factors* questions, while people who are in the Maintenance phase will use visualizations that answer *Status* and *Discrepancy* questions.

As evidenced by articles on personal informatics [3,30] and the growing Quantified Self community around the world (http://quantifiedself.com/), more and more people are using personal informatics tools. However, current personal informatics tools are not designed with a sufficient understanding of users' self-reflection needs. This study takes one step towards an understanding of these needs. We identified six main questions, which people ask in varying frequency between two phases. We presented features that should be supported in personal informatics tools and discussed ways that Ubicomp can provide the necessary support. We believe that this work will help developers and designers more appropriately build personal informatics tools and take better advantage of Ubicomp technologies to help users self-reflect.

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