# Fostering Engagement with Personal Informatics Systems

**Rebecca Gulotta, Jodi Forlizzi**
Human-Computer Interaction Institute
Carnegie Mellon University
{rgulotta, forlizzi}@cs.cmu.edu

**Rayoung Yang, Mark W. Newman**
School of Information
University of Michigan
{rayang, mwnewman}@umich.edu

## ABSTRACT

Personal informatics systems are becoming increasingly prevalent as their price, form, and ease of use improves. Though these systems offer great potential value to users, many systems are hampered by issues that limit their ability to foster engagement, and people often abandon use of these systems without garnering meaningful outcomes. While continued use of these systems is not necessary for all people, there is an opportunity to better support people working towards achievement-based goals.

In this paper, we draw from the literature and our own prior work to identify a number of problems that hinder engagement with achievement-based personal informatics systems — problems related to inadequate support for goal-setting, misalignment of user and system goals, and the burden of system maintenance. We then propose seven strategies for the design community to explore for mitigating these problems and discuss how these strategies could be used to foster engagement with PI systems.

## Author Keywords

Personal informatics; activity trackers; self-tracking; fitness; health; personalization; reflection.

## ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

## INTRODUCTION

There has been a surge of interest in the use of personal informatics (PI) systems, such as fitness trackers and banking applications, which track and provide feedback about people's behaviors. This emerging category of systems includes physical devices, such as the FitBit and the Nest Thermostat, but also systems with no specific tangible form, such as MyFitnessPal, a food logging service that can be accessed on a computer, tablet, or smartphone. For individuals, these systems offer a variety of potential benefits, such as increased physical fitness, a better sense of

one's finances, and, in some cases, a better understanding of one's own goals, values, and desires. Taking into consideration higher-level societal needs, these systems can also offer a way for technology to help address or raise awareness of complex, large-scale problems like climate change and widespread health issues.

While certain types of PI systems, such as heart rate monitors, have been used for years, the accessible price and form of new systems have significantly expanded their use. Their popularity is clear. FitBit, one of the most popular makers of activity trackers, sold over 8 million devices in 2015 alone [24]. PI systems are increasingly being bundled with new devices, such as the Google Fit app for Android smartphones and the Activity app for the Apple Watch. Organizations are also beginning to provide tracking tools to customers by partnering with third parties. One example is Walgreen's Balance Reward Points program, which was designed to help customers stay healthy and become more active [86].

Despite technological and aesthetic improvements to these systems, and their broadening availability, a number of challenges remain that limit the usefulness of these systems. People frequently stop using PI systems without having achieved their goals; those who do reach their goals may lack motivation to continue using the system to maintain their progress or to refine their goals over time. For some people, continued use of the system may no longer be necessary or desired [11]. However, we believe that systems can better support people who are interested in continuing to use PI systems to pursue their goals. Supporting users in this way also benefits product developers, who stand to gain from the potential to collect more complete and more accurate data from users.

In this paper, we draw from our collective experience conducting research on the design and development of PI systems and from related literature to produce a collection of strategies we have developed to help foster engagement between achievement-based PI systems and the people who use them. To do so, we first conduct a literature review identifying problems that hinder or disrupt engagement with PI systems. We then draw from our own research to identify examples of these issues and specific areas to address in the future design of PI systems. Using that information, we propose a set of seven design strategies, grounded in research from related fields including behavioral economics, cognitive psychology, and game design, which we hope will provide direction for the HCI

community as they experiment with these strategies in their own work. With that goal in mind, we describe these strategies and consider how they might address challenges encountered by people who use existing systems. In the final section of the paper, we discuss broader implications for implementing these strategies.

## SCOPE OF OUR WORK

Our work explores *long-term engagement with achievement-based personal informatics systems*. We chose to focus on the achievement of goals rather than reflective or documentary use of PI systems for three reasons. The first is that the majority of people who use PI systems are motivated principally by the desire to reach some goal [21]. The second is that while some of our strategies encourage reflection, it is not yet clear if people with purely reflective goals would benefit from engaging with PI systems in a way that differs from current practices. The third is that failing to engage with a PI system may not actually negatively impact a person's ability to engage in self-reflection. Refection and documentation are, of course, necessary parts of achieving a goal, and these practices are discussed as a part of our larger consideration of how systems can help people achieve their goals.  For more information about reflective and documentary use of personal informatics systems, see [21, 61, 69].

Drawing from prior work in personal informatics, we define engagement as the active use of a system that aligns with practices that support a person's ability to achieve a goal using that system. Engagement is not itself an activity or state, but describes a collection of actions that a person may undertake over time, such as regularly contributing data to a system, accessing and reflecting on the data, or making an effort to understand the information it provides. Engagement is not a universal set of behaviors; engagement with a FitBit activity tracker may be different than engagement with the financial management tool Mint, for example.

The goal of supporting long-term engagement with achievement-based PI systems is different from that of supporting only the achievement of a specific or singular goal. Though achieving a goal is an important motivator for many people, focusing exclusively on a single milestone does not reflect the idea that people's goals often change over time, and that the process of reflecting on and refining one's goals is a valuable part of a person's development. As a result, we chose to focus on *fostering engagement* as a way of supporting people as they work to achieve meaningful outcomes, while still being sensitive to the notion that people's goals and activities often change over time, as do the larger contexts in which PI systems operate [12]. This framing also provides an opportunity to explore why people stop using personal informatics systems. For example, a person may feel that PI systems do not align with their understanding of their identity; they may have difficulty of interpreting data captured by PI systems; or

they may feel that PI systems require too much maintenance and effort relative to the value they get from using the system [39].

Fostering engagement with PI systems can be beneficial in other ways beyond achieving a personal goal. People sometimes benefit from information provided by other users, so increased engagement can improve the quality of the service that is provided. For example, many food-logging applications rely on users to contribute nutritional information about foods that are not yet in their databases. This information is then available to all users. People also benefit from being actively engaged with a system when that system is able to use the information they provide to give them tailored feedback. That is, if a system can adapt in response to the information it has collected, that may help encourage reflection and further use. Finally, systems that have access to more complete or more accurate information about their users have an opportunity to provide a better service and meet business needs, such as by providing targeted advertising.

## RELATED WORK

A number of different strands of research inform this work, illustrating the motivation for, and impact of, human behavior tracking over time. In this section, we discuss research from personal informatics and from broader technological disciplines that describes how and why people use — and subsequently stop using — these systems and devices. Additionally, we focus on cases from our prior research in this area to enrich these findings.

### Contextualizing and Motivating Self-Tracking

People have long recorded different aspects of their life such as food intake, exercise, health symptoms, and mood. Though there are limits to what aspects of one's life can be captured through these means, tracking is commonly used in many communities, including medicine, fitness, and mental health [1, 39, 66]. This technique serves a way to track certain metrics over time, to produce data that can be analyzed, and to reflect on one's behavior and experiences [53, 58]. Research has demonstrated that even simple self-tracking efforts, such as writing out one's thoughts, can have a powerful influence on one's understanding of their own life [35]. Self-tracking also supports a number of other outcomes, such as defining one's identity as an individual and developing a sense of control over one's life [63]. Although these activities do not always support healthy behaviors, they do have the potential to deeply impact a person's life, their understanding of that life, and their interactions with other people [87].

Tracking information about oneself is also a way to leverage resources. In some cases, the data generated enables other people to participate in the analysis and use of this data — caregivers, for example, might use this information to better understand a patient's experience outside of treatment sessions. Generating data about one's life also offers opportunities to garner support from other

people [20]. People with chronic illness and rare conditions have used online communities as a way to compare symptom experiences and to learn more about treatment options [47]. Finally, generating data provides people with a way to leverage the computational abilities of algorithms that can expose trends in their own data and that learn from information collected from other people [1, 83].

## Personal Informatics Systems

The increasing ubiquity of computing has enabled the creation of a wide variety of personal informatics systems designed to facilitate the capture of data about a person's life or the about the lives of a small group of people (such as a family). These systems vary tremendously, as do the goals of the people that use them, but across categories they offer some benefits that extend beyond those offered by non-digital tracking methods.

In addition to the ability to make use of the resources described in the previous section, one advantage is that PI systems assist people with some of the burdensome aspects of self-tracking. Counting one's steps as the FitBit does would be infeasible, for example. While not conventionally considered a "Personal Informatics" system, the Nest Thermostat provides a core PI feature by recording data about users' interactions with the system and then using that information to try and make decisions on their behalf [64]. Many food logging applications are prepopulated with nutritional information about thousands of foods, eliminating the need for people to gather this information on their own [17]. Another benefit of PI systems is the ability for a system to be available as a person changes locations and contexts. Many systems, even those that require the use of a physical device, are available through both websites and mobile apps. Furthermore, the relative ease of tracking with digital systems has enabled people to track more information and to switch between systems, which is a common practice for users [21]. PI systems also allow people to connect with other people that can support them as they work towards their goal [20, 62]. Looking forward, the data captured by PI systems may also offer opportunities to generate historical records about one's life that allow for reflection many years in the future [19].

## Understanding Abandonment

As use of personal informatics systems has spread, there has been a growing interest in understanding what leads people to stop using them. Prior work has highlighted a number of factors, ranging from misalignment of goals, to expectations of system use, to aligning with needs and values, to issues with system functionality.

These are not issues that are unique to PI systems, but they do greatly hamper a person's ability to use them effectively [54]. One significant factor that influences the use of PI systems is people's perceptions about the usefulness of those systems. It can be difficult for people to understand how to interpret the information presented to them by a system [48], or to assess the information accuracy [89].

Additionally, people have reported a mismatch between their goals and the goals that were supported by the system [12, 48]. There are also people who have stopped using PI systems because they have reached their goals. This is not an undesirable form of abandonment, but exposes an opportunity to think about how we can support people even after their initial goal has been achieved. Abandonment is also influenced by the sense that a system does not align with a person's needs and values — prior work describes situations in which people have abandoned a system because it seemed to support a type of person that they did not identify with [48, 76]. Other people who have stopped using, or who intermittently use, PI systems note that a high level of maintenance and interaction was required to use the system relative to the expected benefits [17, 21, 48].

Prior work has also investigated what motivates people to leave or stop using a related category of services: social networks. Although there are important differences between these two categories of systems, people who stop using social networks describe many of the same motivations as people who stop using PI systems (some of which share many features with social networks). These include wanting to limit the time one spent using the service [75], concerns about the burdens of maintaining social relationships [5], and concerns about privacy [2]. Prior work also highlights the value of non-use in particular situations. For example, a study of people leaving the social network Grindr describes how some people who left the site did so to illustrate their investment in other social groups and relationships [8].

## Our research on long-term engagement

Our own research has explored problems with abandonment and misuse of PI systems in more detail, in particular misalignment with goals, expectations for frequency of use, perception of usefulness, and issues with system maintenance. Our work helps us move from problem to strategy by beginning to populate the vast design space of PI systems with designs that are less and more successful. Below, we describe this work and highlight design implications for personal informatics systems. It is important to note that the research we describe below took place across different time periods, domains, and research institutions, with each of the authors contributing their expertise to an understanding of the higher-level issues addressed in this paper.

Some of this work has focused on the goal-setting process. In [52], we investigated how prompting users to reflect on their goals could shape their ability to achieve those goals. To do so, we deployed a website called Fitbit Plan that prompted people to set daily step goals by either allowing the system to generate suggestions based on their past performance or by prompting users to reflect on their overall goals. This work articulates design strategies that leverage reflective personalization to help people achieve their goals and that might foster engagement with a system over time.

We found similar phenomena in a different domain, identifying challenges that a person might face as they try to understand the relative trade offs associated with setting a particular goal. This study, which investigated the use of the Nest Thermostat, found that when the control of a smart, predictive thermostat was left to users, they often tended to prioritize their personal comfort goals rather than taking advantage of the potential energy savings. As such, this work explored the topic of prioritizing one aspect of a goal over another to better align with one's broader needs and values [89].

Misalignment of goals has also been a salient thread in our prior work, where participants frequently described how changes to their goals have led them to stop using a particular system or to switch to another system [53]. In some cases, this change was a result of increased familiarity with the functionality provided by a particular system, which led people to look for a system that might better suit their needs [53, 88]. Other work has demonstrated how systems can successfully foster engagement, and overcome challenges that limit people's desire to use a system, such as by providing information to users that successfully conveys how particular goals are supported by the functionality of the system [89].

Another piece of our prior work explores a pivotal issue — the ability for a PI system to align with a user's motivations and desires. This work surveyed 133 people who use or have used personal informatics systems and explored how these systems supported particular psychological needs, such as the feeling that is a person is competent and that they are continuing to grow and develop [40]. This work highlights the ways in which systems can foster engagement with users.

Our research has also investigated the factors that influence how users perceive the effort needed to use a particular system. [54] published the results of interviews with fifteen people who use personal informatics systems such as activity trackers and financial tracking websites. This work illustrated that people often found it difficult to interpret the information provided by those systems, a difficultly that reduced people's perceptions of the value they were getting from each of these systems.

Finally, our research has also noted issues that arise when system functionality does not meet people's expectations. The study of the Nest Thermostat described how users were disappointed in the thermostat's inability to correctly interpret individual behaviors [88]. This misinterpretation sometimes required users to make corrections to the thermostat and frustrated users who reported feeling as though the thermostat was not working properly.

In the next section, we build on these findings to identify specific problems that arise from how personal informatics systems are designed and used.

## DESIGN PROBLEMS THAT HINDER LONG-TERM ENGAGEMENT WITH PI SYSTEMS

A survey of related work and a growing design space populated by results from research done in our labs and beyond yields a set of problems that affect long-term engagement with achievement-based PI systems. We summarize them here:

*People's goals do not match system goals* — PI systems typically support a combination of different types of goals, most often reflective and achievement-based goals. Reflective goals or documentary goals are those motivated by the desire to learn about one's habits, but do not necessarily involve making any behavior changes [74]. Achievement-based goals focus on a particular thing that a person wants to achieve, such as walking a certain number of steps per day. Not all systems support both, but some do to varying degrees.

*A person's goal changes over time* — People's goals will sometimes change as they use a PI system [76]. For example, a person who decides to increase their physical activity may find that their initial goal was too ambitious or that it does not account for their changing fitness level. PI systems often do not provide opportunities for users to reconsider their goals in a way that reflects their experience using the system over time.

*A person achieves their goal* — When a goal is achieved, a person may stop using a particular system. In some cases, it may be advantageous for a person to continue using a system but to shift their goals, however systems do not adequately support this process [12].

*Information may be hard to access or interpret* — People may find it difficult to interpret the information that is provided to them by the system. For example, a system might display a graph of a person's performance over time without providing them with the tools to draw out any conclusions or direction from that information [54]. Additionally, people may find it difficult to assess the accuracy and reliability of the information provided by the system, which in turn may lead to mistrust [90].

*Maintenance and routine use requirements may be burdensome* — All systems require some degree of maintenance. For example, some need to be charged, some require the user to correct errors in the data they record, and some require a user to provide feedback in order to make decisions about how to operate. Others may require users to input information about their behaviors. For example, MyFitnessPal — a food and activity logging service — encourages users to return at least once a day. Users may come to believe that these requirements outweigh the benefits they receive from the system [78].

*System does not align with aspects of the user's identity* — The use of a personal informatics system may intersect with identity presentation concerns, particularly when the systems involve wearing devices or engaging in behaviors

that may elicit reactions from other people [48]. In addition, a system may not support the needs that drive a person's use of that system, nor a person's understanding of their own values.

*Connections to social support* — One common feature that PI systems offer is the ability to share information about one's progress through social media accounts. Another example is the ability to connect your account to that of another user so that you can see their activity and receive feedback from within the system. While these features can be motivating for some users [20], some work has shown that social sharing of information from PI systems can discourage use of the systems and cause apprehension for users [17, 72]. Other research has shown that public goal setting was effective at eliciting support from a social community and was helpful in setting goals [21].

*Dependencies on other systems* — Certain types of systems depend on databases of information to reduce the burden associated with self-tracking. For example, many food-tracking applications provide nutritional information for common or brand-name foods. This type of information can make using the system more convenient, but can also contain omissions and errors that make it difficult to assess one's progress [17].

## STRATEGIES TO FOSTER ENGAGEMENT
We have organized the problems identified in prior work into three overarching categories: inadequate support for goal-setting, misalignment of user and system goals, and burden of system maintenance. For each of the categories, we note the importance of addressing that category of problems and describe potential solutions informed by literature in this space. The remaining problem that does not fall into these categories — the inability for systems to re-engage users that have achieved their goals — is explored in the discussion section, due to the broader ethical questions involved in implementing strategies to address that issue.

### Problem: Inadequate Support for Goal-Setting
Goal-setting is a critical task for people who use PI systems; properly setting a goal can help support adherence to that goal over time [82]. The process of setting a goal involves considering one's current state, one's desired outcome, and a strategy for achieving that outcome. In addition, there are other key factors that can influence a person's ability and desire to achieve a goal. Two of these factors, efficacy and commitment, reflect a person's belief that they can achieve a goal and strength of their resolve to do so [15]. Goal-setting theory also suggests that one's ability to achieve a goal is influenced by that person's assessment of whether that goal is reasonable and in line with their personal understanding of what they'd like to achieve [56]. Consequently, setting goals that do not have the right level of specificity or difficulty can hamper a person's desire and ability to accomplish these goals.

*Proposed strategy: Reflective approach to goal-setting*
We believe that supporting a reflective approach to goal-setting will help address several of these issues, perhaps by helping people create system-specific goals that are better aligned with their broader goals, or by helping people consider the challenges that they might face when working to achieve a goal. Instead of simply asking a user to enter their goal, systems employing this strategy would help the user to choose a goal by asking them to reflect on what motivates their decision. Research from outside of PI also supports the idea of reflective goal-setting — literature from education and cognitive psychology describes how a high degree of metacognitive awareness, or understanding one's own thought processes, can help people achieve their goals [73].

Though there has been thoughtful work that has examined how to structure goal-setting in PI systems [15], few have examined using reflection as a part of this process. However, one example of recent work does examine how reflective goal-setting can be used to support people in increasing their physical activity. The study asked participants to describe why they had chosen a particular goal and then gave them time during which they were asked elaborate on that answer. This process was effective in increasing users' levels of physical activity [52].

While further research is necessary to understand the best ways of utilizing reflective approaches to encourage metacognition in the goal-setting phase, we believe that this strategy will likely help people set better goals and better understand their own motivations. There could also be benefits to users as they work toward their goal. The information provided during this initial process could be used by the system to tailor the feedback that a user receives over time. Finally, this strategy could also help manage user expectations. PI systems have made it easier to track and visualize information, but achieving one's goals is still a difficult process for many people [65]. Using reflection at the start of a person's effort is an opportunity to reinforce the idea that reflection can play an instrumental role in achieving long-term benefits.

In practice, this strategy could be implemented to draw from a number of different sources of information that enable reflection. One method would be to ask the user to think more deeply about their specific goal (such as losing ten pounds or biking 25 miles a week) and also their larger motivations (such as becoming more fit and preparing for a long distance bike trip) [52]. This information could then be used to provide more meaningful feedback to users, particularly when lapses occur or when a person is not making steady progress towards their goal. Another variation on this strategy would be to utilize the information provided by other users as a way of providing people with a better understanding of what might be a reasonable goal to set and to prepare them for the challenges they might face.

**Problem: Misalignment of User and System Goals**

It is sometimes necessary for a person to refine or change a goal they originally set [53]. Though this process is often programmatically simple to do, it can be personally challenging because it requires to that a person engage in higher-level thinking about their goals and their progress towards those goals. It can also be personally challenging because of the negative feelings that may be associated with changing a goal. Though it is not an uncommon practice, users may be disinclined to change their goal when it feels like they have failed or when the system makes it seem as though this action is unusual or discouraged. There is also an opportunity to help people refine their long-term goals after they've accomplished an initial goal. Over time, a person may realize that their original goal does not ultimately suit their higher-level motivations and may return to the system to make revisions and begin working towards their new goal.

*Proposed strategy: Periodic reflection on goals*

Despite the widespread understanding that reflection is a critical process for people who use PI systems [54], systems have been slow to integrate formal opportunities for reflection into their programs. We suggest that systems should provide opportunities for periodic reflection on user goals to help people evaluate their progress and to help people engage with other resources that could support their efforts. While there is a need to balance the usefulness of user engagement with the costs to users, we believe that systems could use periodic reflection to help shift people's perceptions about the value that they receive from the system relative to the effort required to use it.

This strategy is informed by research that suggests that asking people what their reasons are for doing an activity triggers them to consider their underlying motivation and leads them to focus on their higher-level goals [85]. In addition, work on periodic prompting indicates that these interventions exert a positive influence on people's behaviors [28]. Thus, these requests for periodic reflection can be designed such that they provide value to the user, increasing perceived utility as well as engagement. Though prompts differ in meaningful ways from opportunities for reflection, this research does provide support for the use of periodic interaction with users and also describes some key considerations to consider when designing the reflections, namely the period, medium, composition, and personalization of the messages [28]. This work also highlights the importance of taking people's broader practices into account when designing these interactions [29].

There are several factors to consider when implementing periodic reflection on both user and system goals. The first is deciding when reflection will occur. We believe that personalized timing would reduce the potential negative impacts of engaging the user in a way that they don't perceive to be meaningful. For example, systems could time

reflection in response to a person's history of interaction with the system, to the length of time the system estimates that a person needs to achieve their goal, or to patterns of use derived from other people's data.

*Proposed strategy: Personalization in system configuration and use*

Personalization in technology services can be defined as using the decisions people make about their interactions with systems to influence the content they see and engage with. It also refers to allowing people to directly select features they want to use as a way to customize their interactions with a system [6]. Prior research has shown that personalization in system design offers many benefits, including reduced cognitive load, assistance with workflow, and more persuasive and satisfying interactions overall [4, 6, 41, 46, 50, 55, 84].

Personalization in systems can be classified into two types: system-driven personalization and user-driven personalization. In system-driven personalization, systems infer what people want based on their model of a user, occasionally with poor outcomes [49]. Though most personal informatics systems allow users to set particular preferences, the use of system-driven personalization is less widely used, perhaps due to the difficulties of implementing these features and the potential for negative consequences. That being said, some research has suggested that individuals (and different personality types) may vary in regards to what types of feedback help motivate their use of personal informatics systems [33]. In addition, personalization may allow a system to adapt to the needs of different types of users, such as people who are new to self-tracking, people who have broad goals, or people who are serious athletes.

User-driven personalization lets people choose from a number of alternatives, tailoring their experience with a system. This type of personalization can have positive outcomes as it minimizes cognitive overload and may support people in reaching their goals. However, choices provided to users may seem like formulaic customization, or may cause people to feel overwhelmed when they are faced with the task of making choices [38, 79].

Some research has shown that personalization in HCI can be beneficial for fostering interaction with a system. For example, [7] explored what personal and contextual factors come into play when personalizing TV viewing schedules and found that relying on knowledge of family members and prior viewing resulted in better recommendations. Similarly, personalization has long been explored in e-commerce as a way of pursuing changes that benefit both users and systems [42].

One way to approach personalization in PI systems to motivate engagement is to enable systems to better respond to user-driven strategies and to make recommendations for personalization. For example, [52] allowed users to either

create their own goals for daily steps or to follow suggested plans based on their performance over the previous two weeks. In addition to providing people with a way to deeply reflect on their goals, this feature resulted in people taking more steps than those who were using the standard FitBit system and dashboard.

*Proposed strategy: Mixed-initiation as a means of helping to achieve goals*

Another strategy to help users refine or change their goals over time is mixed-initiation [23], which combines prompts from both the system and user to accomplish a mutual mission, with initiatives and roles opportunistically negotiated. This strategy has been discussed with regards to developing an agent system that manages tasks for users, such as scheduling and meeting management [23]. Several pieces of research work have extended this notion to the design of PI systems that assist users make plans to achieve system and user goals [89, 43, 45]. Even basic systems initiative can be helpful: some research has shown that simple prompts from a system can increase self-logging frequency by a factor of five [3].

In discussing challenges for PI systems that promote energy savings, [88] illustrate how systems need to encourage users to make changes but to also be realistic about their own needs. In this work, Yang and Newman found that when the control was solely left to users, they often tended to prioritize their comfort goals over energy savings. As a result, energy savings remained unrealized as user relied on the system automation and their engagement decreased over time [89].

To address these challenges, it will be necessary for personal informatics systems to act proactively in getting users to reassess and refine their goals. For example, [70] provided users with three suggestions to configure their thermostat: a high comfort option, an energy saving option, and a balanced option, along with users' existing schedule. Then, the system left users to decide whether and how to implement the suggestions, engaging users to take control of decisions related to their potential energy savings, as opposed to relying on the PI system to make those decisions. The study results indicated that users who used this system saved more energy than those who did not [70].

By designing systems that promote responsibility and initiate interactions with users, systems can foster engagement and help users to readjust their goals with suggestions based on their current progress.

## Problem: Burden of System Use and Maintenance

After setting a goal, a person begins the process of working towards it. This work is, in a way, a collaboration between users and systems. As a part of this collaboration, users are responsible for generating data, for attending to system upkeep, and for engaging in routine use. Systems are responsible for tracking information, processing that information, and providing users with feedback about their progress.

*Proposed strategy: Motivational design as a mechanism to increase system use*

One way to address misalignment between perceived value of a system and the effort that system requires from users is to leverage motivational design strategies. Here, we use the term motivational design to refer to a combination of strategies from behavioral economics and features from game mechanics that can be used to motivate people to engage in more productive use of PI systems. As both behavioral economics and game design are entire fields of study, it is not our goal to be complete in our discussion of either discipline. Instead, we have identified several specific concepts that have inspired us to think about how they might be employed as design strategies for personal informatics systems.

We are not the first to note that these disciplines contain valuable insights for designers interested in supporting engagement — prior research from persuasive technology has shown that feedback about one's interactions with a system can foster engagement with it [25]. Our prior research has demonstrated ways in which we can leverage thoughtful presentation and timing of information to encourage people to make self-beneficial decisions that will help them make progress towards their goals [51].

Though many systems use rewards to try to motivate users, the way these features are implemented makes a difference in whether they hamper or support people. Research on the use of rewards in PI has illustrated that many people find rewards to be good motivation to complete tasks that ultimately support one's goals [26]. Not surprisingly, many systems have implemented rewards as a way to motivate and engage users. For example, Strava, a GPS app used by bicyclists and runners to track and improve progress in their workouts, features game mechanics such as badges and leaderboards to foster engagement and inspire long-term use of the system [81]. While some users undoubtedly feel motivated by these challenges, research on the direct effects of employing game mechanics and rewards indicates that the application of these concepts is nuanced and context-specific [91].

In order to effectively put these ideas into practice, work from behavioral economics and game design can help designers develop rewards that capitalize on users' desires to compare themselves to others with particular characteristics and affiliations. Research that examined how to persuade people to engage in resource-saving behaviors found that evoking provincial norms — norms based on one's situational context — was a powerful motivator [30].

Work from behavioral economics also describes other phenomena that can influence how a person understands their current context and makes decisions based on that understanding. For example, researchers have suggested

that asymmetric paternalism, a method of influencing people to make particular choices, and present bias, the tendency for people to place higher value on more immediate rewards, are powerful ways to influence people to make decisions that benefit their health [57]. Ways to approach applying motivational design could include convenience and salience (making the most important information the easiest to access and the most demanding of attention) and choice attractiveness (positioning the right choice about one's behavior with a less attractive choice so the optimal decision is easy). These rewards can be used to motivate people to work towards a goal, but also to engage with a system. There is also an opportunity to examine how existing rewards align with literature from behavioral economics that articulates what motivates people to engage in behavior change.

*Proposed strategy: Ambient awareness to increase system use with minimal attention*
Another way to reduce how a person perceives the overall burden of a personal informatics system is to leverage ambient awareness, where information is presented in a way that does not attract a great deal of attention [10]. This ambient information could display the status of the interaction between user and system, or give information relative to progress towards one's goals, without attracting much of the user's attention. Prior work in PI has investigated how to visualize and segment information so that it provides the greatest clarity and benefits for users [60, 80]. This information can be useful in fostering engagement in four ways: minimizing the time to answer questions, helping to generate insights and insightful questions, conveying the essence of the data, and generating confidence and knowledge about the data itself [80]. We can leverage this work and other research on ambient displays to reduce two reasons that people describe abandoning personal informatics systems: (1) the perception that a system is not useful and (2) the perception that a personal informatics systems requires too high a level of maintenance.

In order to convey usefulness, ambient information needs to be designed appropriately. Designs may exploit metaphors drawn from nature to subtly convey information — for example, using the rhythm of a heartbeat or respiration, or representations of water or wind. UbiFit, a personal informatics system designed to encourage physical activity found providing abstract, at-a-glance information on the background of a mobile phone was an effective way to support reflection on one's goals and behaviors [14, 15, 16]. In another example, [32] used a dynamic visualization of light along a lamp's power cord to show the energy used. The AMBIENTroom project explored representations of water and wind moving clouds in the sky to explore how awareness of an information display could be moved from the periphery to the center of attention and back [36, 37]. Further research could help determine how to utilize the topic of the data to make decisions about the visual design of a PI system.

*Proposed strategy: Improved social features*
We believe that systems can provide better opportunities for users to connect with other people who share their goals and who can provide them with support. Doing so would help motivate people to engage with a system and would lessen the perception that a system does not provide a worthwhile value to its users.

Prior work suggests that people are motivated to share information captured by PI systems because it helps them stay accountable, allows them to elicit support, and because it allows them to portray themselves in a particular light or align with a desired identity [20]. In addition to social interaction that is mediated by social networks, some systems offer people the ability to communicate with other users. Communicating with other people who have an understanding of what you might be experiencing can be very valuable; research suggests that social interaction between people in similar circumstances can help encourage people to seek out useful information, to offer support to others, and to share their experiences [27]. Additionally, research on online support networks has demonstrated that participating in these networks can have a positive impact on a person's well-being [71].

Many current systems offer users the opportunity to connect with other users, but it is often up to the individual to seek out and find these people through existing social networks. For example, FitBit allows users to search their Facebook friends list for other people who are also FitBit users. While being able to see your friend's activity can be motivating, it can also discourage people to log data that may reflect badly on their image or their ability to accomplish their goals. Another difficulty is that it can be challenging for some users to communicate information about their experiences in a way that elicits that desired support from other people [20].

Systems can address this issue by leveraging their ability to analyze user data to help people connect with other people who can provide support. Some examples of how this might work include matching users with similar goals, who have overcome similar challenges, or who are using the same methods. In addition, as systems become increasingly sophisticated in their ability to analyze user data, they might be able to match people who are working towards a particular goal with users who have already accomplished similar goals as a way of providing mentoring to new users. This strategy would help engage users at all stages of the process.

**DISCUSSION**
In this paper, we draw from our prior work and from related literature to identify a set of overarching problems that hinder engagement with achievement-based personal informatics systems — inadequate support for goal-setting,

misalignment of user and system goals, and burden of system maintenance. We then propose a set of seven strategies to explore for mitigating these problems. It is our hope that designers working in this space will experiment with the strategies we have presented, and build on this work to concretely illustrate how the strategies might be applied over different domains, different PI systems, and different use cases.

### Beyond Achievement-Based Goals
The strategies we presented in this paper focused on achievement-based goals. Prior work has illustrated that while achievement-based goals are one of the primary motivators for people to start using personal informatics systems, people are also motivated by other types of goals, such as the desire to document, reflect, and learn more about one's behaviors, to look for links between experience and behavior, to collect in-system rewards, and as a way of exploring one's interest in technology and information [74]. In reality, engagement with a system combines many of these activities, and it is worth exploring how systems could use the strategies we've described to support these different types of goals.

Although the focus on engagement and abandonment may not be a useful framing for all types of goals, we believe that the strategies we have outlined could support many of the goals that motivate the use of personal informatics tools. Systems could better serve the needs of users by allowing users to set goals and understand what motivates their use of the system. Systems could then use that information to personalize the information they capture about users and the feedback they provide over time. In addition, periodic reflection on those goals could help people take stock of how they've progressed and could potentially be used to foster meaningful outcomes.

### Post-Achievement Use of Personal Informatics Systems
It can seem as though achieving a goal is the end of a person's journey with a PI system. In reality, the process of creating long-term behavior change is not so straightforward. Even if a person accomplishes the goal they set out to achieve, maintaining that change over time can be immensely challenging. People who lose weight, for example, often regain that weight [18]. This issue is attributable to a number of factors, some which are behavioral, and some that are tied to social and biological influences.

The reality of long-term behavior change presents a challenge for personal informatics systems, but it is also an opportunity to explore how we can utilize these ubiquitous systems to have a lasting impact on people's lives. Most personal informatics systems allow people to continue using the system in a maintenance mode after they've achieved their goals, but don't often support different needs a person has after achieving a goal. From a marketing standpoint, it makes sense that systems would emphasize their ability to help people achieve some behavior change.

However, this focus may not benefit users in the long-term. Systems could offer additional functionality that allows for maintenance activities as a part of the larger effort to achieve and sustain a goal over the long term. In addition, systems could utilize the strategies we have outlined to help people develop new goals that reflect their evolving understanding of their life, values, and needs.

### Potential Problems with Implementing the Strategies
Our community has identified a number of issues that could potentially make it difficult to implement the strategies we have listed here. The first is the fact that it may be hard to increase engagement with PI systems overall. Many people already feel as though the expected degree of system use is too high. If a system were to ask people to reflect on their goals or progress but did not explicitly appear to make use of this information, this might contribute to the feeling that a system requires too much interaction relative to the benefits people get from the system. The second is that it might be hard to make use of data generated from systems that employ the strategies. It might be difficult for systems to parse and utilize information derived from reflections on their goals, experiential aspects of the data, or social commentary about the data. Finally, meaningful personalization of a PI system may be difficult to achieve. Systems may also be unable to also leverage emerging computational abilities to personalize systems in a way that aligns with user needs.

Each of these issues represents an opportunity for researchers and system designers to better understand how to capture and make use of user data.

### Limitations
We do not believe that our goal of fostering engagement is useful for all systems or for all people. There are many situations in which a person does not need or want to continue using a PI system. There may be situations in which abandonment or non-use of technology may be beneficial to users. In addition, self-tracking can be detrimental when it enables harmful behavior, when it contributes to feelings of anxiety or unease, or when it works against a person's ability to achieve a healthy goal [67]. While avoiding all negative effects is likely impossible for any system, our intention is to understand how achievement-oriented PI systems can use information collected over the long term to support practices that improve a person's life in some way. Therefore, our goal is not to eliminate abandonment of PI systems or to champion their universal usefulness, but to instead support people who are motivated to accomplish a goal but whose needs are not being met by existing systems.

### CONCLUSION
In this paper, we gleaned findings from the literature and our own work to identify a number of problems that hinder engagement with achievement-based personal informatics systems — problems related to inadequate support for goal-setting, misalignment of user and system goals, and burden

of system maintenance with achievement-based personal informatics systems. We then propose a set of seven strategies to explore for mitigating these problems. While each of the strategies have been discussed in other literature, we contribute the collection of strategies as a means to advance research and development of personal informatics systems that will improve people's lives. These strategies are not intended to be complete or exclusive. Instead, they offer an overview of salient concepts that can be applied from a number of disciplines. Future work can explore these strategies to better understand the situations in which they ought to be applied and the ways they can be used to uncover further nuances regarding how people use personal informatics systems.

## ACKNOWLEDGMENTS

## REFERENCES

1. Meredith A. Barrett, Olivier Humblet, Robert A. Hiatt, and Nancy E. Adler. 2013. Big data and disease prevention: From quantified self to quantified communities. *Big Data* 1, 3: 168 – 175.

2. Eric P.S. Baumer, Phil Adams, Vera D. Khovanskaya, Tony C. Liao, Madeline E. Smith, Victoria Schwanda Sosik, and Kaiton Williams. 2013. Limiting, leaving, and re(lapsing): An exploration of Facebook non-use practices and experiences. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '13)*. ACM, New York, NY, USA, 3257 – 3266.

3. Frank Bentley and Konrad Tollmar. 2013. The power of mobile notifications to increase wellbeing logging behavior. . In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '13)*. ACM, New York, NY, USA, 1095 – 1098.

4. Shlomo Berkovsky, Jill Freyne, and Harri Oinas-Kukkonen. 2012. Influencing individuality: Fusing personalization and persuasion. In *ACM Transactions on Interactive Intelligent Systems* 2, 3, Article 9.

5. Jeremy Birnholtz. 2010. Adopt, adapt, abandon: Understanding why some young adults start, and the stop, using instant messaging. *Computers in Human Behavior* 26, 6: 1427 – 1433.

6. Jan O. Blom and Andrew F. Monk. 2003. Theory of personalization of appearance: Why users personalize their pcs and mobile phones. *Human-Computer Interaction* 18, 3: 193 – 228.

7. Simon Elias Bibri. 2015. Implicit and natural HCI in AmI: Ambient and multimodal user interfaces, intelligent agents, intelligent behavior, and mental and physical invisibility. *The Human Face of Ambient Intelligence,* 159 – 318.

8. Jed R Brubaker, Mike Ananny, and Kate Crawford. 2014. Departing glances: A sociotechnical account of 'leaving' Grindr. *New Media and Society,* 1 – 18.

9. Lora E. Burke, Jing Wang, and Mary Ann Sevick. 2011. Self-monitoring in weight loss: A systematic review of the literature. *Journal of the American Dietetic Association* 1, 92 – 102.

10. Panagiotis Chatzitsakyris, Goncalo Ducla-Soares, and Alejandro Zulas. 2004. IN-Visible: Perceiving invisible urban information through ambient media. In *CHI '04 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '04). ACM, New York, NY, USA, 1348 – 1350.

11. Eun Kyoung Choe, Nicole B. Lee, Bongshin Lee, Wanda Pratt, and Julie A. Kientz. 2014. Understanding quantified-selfers' practices in collecting and exploring personal data. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '14). ACM, New York, NY, USA, 1143 – 1152.

12. James Clawson, Jessica A. Pater, Andrew D. Miller, and Elizabeth D. Mynatt. 2015. No longer wearing: Investigating the abandonment of personal health-tracking technologies on craigslist. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '15). ACM, New York, NY, USA, 647 – 658.

13. Sunny Colsolvo, Predrag Klasnja, David W. McDonald, Daniel Avrahami, Jon Froehlich, Louis LeGrand, Ryan Libby, Keith Mosher, and James A. Landay. 2008. Flowers or a robot army?: Encouraging awareness and activity with personal, mobile displays. In *Proceedings of the 2008 Conference on Ubiquitous Computing* (UbiComp '08). ACM, New York, NY, USA, 54 – 63.

14. Sunny Consolvo, David W. McDonald, Tammy Toscos, Mike Y. Chen, Jon Froehlich, Beverly Harrison, Predrag Klasnja, Anthony LaMarca, Louis LeGrand, Ryan Libby, Ian Smith, and James A. Landay. 2008. Activity sensing in the wild: A field trial of UbiFit garden. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '08). ACM, New York, NY, 1797 – 1806.

15. Sunny Consolvo, Predrag Klasnja, David W. McDonald, and James A. Landay. 2009. Goal-setting considerations for persuasive technologies that encourage physical activity. In *Proceedings of the 4th International Conference of Persuasive Technology.* ACM, New York, NY, USA.

16. Sunny Consolvo, David W. McDonald, and James A. Landay. 2009. Theory-driven design strategies for technologies that support behavior change in everyday life. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '09). ACM, New York, NY, 405 – 414.

17. Felicia Cordeiro, Daniel A. Epstein, Edison Thomaz, Elizabeth Bales, Arvind K. Jagannathan, Gregory D. Abowd, and James Fogarty. 2015. Barriers and negative nudges: Exploring challenges in food journaling. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '15). ACM, New York, NY, 1159 – 1162.

18. Kristina Elfhag and Stephan Rössner. 2005. Who succeeds in maintaining weight loss? A conceptual review of factors associated with weight loss maintenance and weight regain. *Obesity Review* 6, 1: 67 – 85.

19. Chris Elsden and David Kirk. 2014. A quantified past: Remembering with personal informatics. In *Proceedings of the ACM Conference on Designing Interactive Systems* (DIS '14). ACM, New York, NY, 45 – 48.

20. Daniel A. Epstein, Bradley H. Jacobsen, Elizabeth Bales, David W. McDonald, and Sean A. Munson. 2015. From "nobody cares" to "way to go!": A design framework for social sharing in personal informatics. In *Proceedings of the 2015 ACM Conference on Computer Supported Cooperative Work* (CSCW '15). ACM, New York, NY, USA, 1622 – 1636.

21. Daniel A. Epstein, An Ping, James Fogarty, and Sean A. Munson. 2015. A lived informatics model of personal informatics. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '15). ACM, New York, NY, USA, 731 – 742.

22. Debra Ferreday. 2003. Unspeakable bodies: Erasure, embodiment, and the pro-ana community. *International Journal of Cultural Studies* 6, 3: 277 – 295.

23. Eric Horvitz. 1999. Principles of mixed-initiative user interfaces. In *The Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '09). ACM, New York, NY, USA, 159 – 166.

24. Fitbit Tracker Sales. Retrieved from: http://www.wareable.com/fitbit/tracker-sales-q2-2015-financial-results-1488.

25. B.J. Fogg. 2002. Persuasive technology: Using computers to change what we think and do. In *Ubiquity* 5. ACM, New York, NY, USA.

26. Thomas Fritz, Elaine M. Huang, Gail C. Murphy, and Thomas Zimmermann. 2014. Persuasive technology in the real world: A study of long-term use of activity sensing devices for fitness. In *The Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '14). ACM, New York, NY, USA, 487 – 496.

27. Jeana H. Frost and Michael P. Massagli. 2008. Social uses of personal health information within PatientsLikeMe, an online patient community. *Journal of Medical Internet Research* 10, 3.

28. Jillian P. Fry and Roni A Neff. 2009. Periodic prompts and reminders in health promotion and health behavior interventions: Systematic review. *Journal of Medical Internet Research* 11, 2.

29. Julia EWC van Gemert-Pijnen, Nicol Nijland, Maarten van Limburg, Hans C Ossebaard, Saskia M Kelders, Gunther Eysenbach, and Erwin R Seydel. 2011. A holistic framework to improve the uptake and impact of eHealth technologies. *Journal of Medical Internet Research* 13, 4.

30. Noah J. Goldstein, Robert B. Caldini, and Vladas Griskevicius. 2008. A room with a viewpoint: Using social norms to motivate environment conservation in hotels. *Journal of Consumer Research,* 472 – 482.

31. Ruben Gouveia, Evangelos Karapanos, and Marc Hassenzahl. 2015. How do we engage with activity trackers?: A longitudinal study of Habito. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '15). ACM, New York, NY, UA, 1305 – 1316.

32. Anton Gustafsson and Magnus Gyllenswärd. 2005. The power-aware cord: Energy awareness through ambient information display. In *CHI '05 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '05). ACM, New York, NY, USA, 1423 – 1426.

33. Sajanee Halko and Julie A. Kientz. 2010. Personality and persuasive technology: An exploratory study on health-promoting mobile applications. *Persuasive Technology,* 150 – 161.

34. James D. Hess and Arnold C. Bacigalupo. 2011. Enhancing decisions and decision-making processes through the application of emotional intelligence skills. *Journal of Management Decisions* 49, 5: 710 – 721.

35. Ellen Isaacs, Artia Konrad, Alan Walendowski, Thomas Lennig, Victoria Hollis, and Steve Whittaker. 2013. Echoes from the past: How technology mediated reflection improves well-being. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '13). ACM, New York, NY, USA, 1071 – 1080.

36. Hiroshi Ishii, Sandia Ren, and Phil Frei. 2001. Pinwheels: Visualizing information flow in an architectural space. In *CHI '01 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '01*).* ACM, New York, NY, USA, 111 – 112.

37. Hiroshii Ishii, Craig Wisneski, Scott Brave, Andrew Dahley, Matt Gorbet, Brygg Ulmer, and Paul Yarin. 1998. ambientROOM: Integrating ambient media with architectural space. In *CHI '98 Conference Summary*

*on Human Factors in Computing Systems* (CHI '98). ACM, New York, NY, USA, 173 – 174.

38. Sheena S. Iyengar and Mark R. Lepper. 2000. When choice is demotivating: Can one desire too much of a good thing? *Journal of Personality and Social Psychology* 79, 6: 995 – 1006.

39. Frederick H. Kanfer. 1970. Self-monitoring: Methodological limitations and clinical applications. *Journal of Consulting and Clinical Psychology* 35, 2: 148 – 152.

40. Evangelos Karapanos, Ruben Gouveia, Marc Hassenzahl, and Jodi Forlizzi. 2016. Need fulfillment and experiences with wearable trackers in prolonged use. *To appear in Personal and Ubiquitous Computing*.

41. Maurits Kaptein, Boris De Ruyter, Panos Markopoulos and Emilie Aarts. 2012. Adaptive persuasive systems: A study of tailored persuasive text messages to reduce snacking. *ACM Transactions on Interactive Intelligent Systems* 2, 2, Article 10.

42. Clare-Marie Karat, Jan O. Blom, and John Karat. 2004. Designing personalized user experiences in eCommerce. *Human-Computer Interaction Series*.

43. David V. Keyson, Marc P.A.J. de Hoogh, Adinda Freudenthal, and Arnold P.O.S. Vermeeren. 2000. The intelligent thermostat: A mixed-initiative user interface. In *CHI '00 Extended Abstracts on Human Factors in Computing Systems.* ACM, New York, NY, USA, 59 – 60.

44. Vera Khovanskaya, Eric P.S. Baumer, Dan Cosley, Stephen Voida, and Geri Gay. 2013. "Everybody knows what you're doing": A critical design approach to personal informatics. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '13). ACM, New York, NY, USA, 3403 – 3412.

45. Christian Koehler, Brian D. Ziebart, Jennifer Mankoff, and Anind K. Dey. 2013. TherML: Occupancy prediction for thermostat control. In *Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing.* ACM, New York, NY, USA, 103 – 112.

46. Sherrie Y. X. Komiak and Izak Benbasat. 2006. The effects of personalization and familiarity on trust and adoption of recommendation agents. *MIS Quarterly* 30, 4, 941 – 960.

47. Judith N. Lasker, Ellen D. Sogolow, and Rebecca R. Sharim. 2005. The role of an online community for people with a rare disease: Content analysis of messages posted to a primary biliary cirrhosis mailinglist. *Journal of Medical Internet Research* 7, 1.

48. Amanda Lazar, Christian Koehler, Joshua Tanenbaum, and David H. Nguyen. 2015. Why we use and abandon smart devices. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '15). ACM, New York, NY, USA, 635 – 646.

49. Min Kyung Lee, Daniel Kusbit, Evan Metsky, and Laura Dabbish. 2015. Working with machines: The impact of algorithmic and data-driven management on human workers. In *Proceedings of the 33$^{rd}$ Annual ACM Conference on Human Factors in Computer Systems* (CHI '15). ACM, New York, NY, USA, 1603 – 1612.

50. Min Kyung Lee, Jodi Forlizzi, Sara Kiesler, Paul Rybski, John Antanitis, and Sarun Savetsila. 2012. Personalization in HRI: A longitudinal field experiment. In *Proceedings of the Seventh Annual ACM/IEEE International Conference on Human-Robot Interaction* (HRI '12). ACM, New York, NY, USA, 319 – 326.

51. Min Kyung Lee, Sara Kiesler, and Jodi Forlizzi. 2011. Mining behavioral economics to design persuasive technology for healthy choices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* ACM, New York, NY, 325 – 334.

52. Min Kyung Lee, Junsung Kim, Jodi Forlizzi, and Sara Kiesler. 2015. Personalization revisited: A reflective approach helps people better personalize health services and motivates them to increase physical activity. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '15). ACM, New York, NY, USA.

53. Ian Li, Anind K. Dey, and Jodi Forlizzi. 2010. A stage-based model of personal informatics. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '10). ACM, New York, NY, USA, 557 – 566.

54. Ian Li, Anind K. Dey, and Jodi Forlizzi. 2011. Understanding my data, myself: Supporting self-reflection with ubicomp technologies. In *Proceedings of the 13$^{th}$ International Conference on Ubiquitous Computing* (UbiComp '11). ACM, New York, NY, USA, 405 – 414.

55. Ting-Peng Liang, Hung-Jen Lai, and Yi-Cheng Ku. 2007. Personalized content recommendation and user satisfaction: Theoretical synthesis and empirical findings. *Journal of Management Information Systems* 23, 3(3): 45 – 70.

56. Edwin A. Locke and Gary P. Latham. 2006. New directions in goal-setting theory. *Current Directions in Psychological Science* 15, 5: 265 – 268.

57. George Loewenstein, Troyen Brennan, and Kevin G. Volpp. 2007. Asymmetric paternalism to improve health behaviors. *Journal of the American Medical Association* 298: 20, 2415 – 2417.

58. Deborah Lupton. 2014. Self-tracking cultures: Towards a sociology of personal informatics. In *Proceedings of the 26ᵗʰ Australian Computer-Human Interaction Conference.*

59. Lena Mamykina, Andrew D. Miller, Elizabeth D. Mynatt, and Daniel Greenblatt. 2010. Constructing identities through storytelling in diabetes management. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '15). ACM, New York, NY, 1203 – 1212.

60. Tara Matthews and Jennifer Mankoff. 2005. A toolkit for evaluating peripheral awareness displays. From the *Awareness Systems Workshop at CHI 2005.*

61. Sean Munson. 2012. Mindfulness, reflection, and persuasion in personal informatics. In *Extended Abstracts of the SIGCHI Conference on Human Factors in Computing Systems* (CHI EA '12). ACM, New York, NY, USA.

62. Sean A. Munson, Erin Krupka, Caroline Richardson, and Paul Resnick. 2015. Effects of public commitments and accountability in a technology-supported physical activity intervention. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '15). ACM, New York, NY, USA, 1135 – 1144.

63. Dawn Nafus and Jamie Sherman. 2014. This one does not go up to 11: The quantified self movement as an alternative big data practice. *The International Journal of Communication* 8, 1784 – 1784.

64. Nest Tracker. Retrieved from: https://nest.com/thermostat/meet-nest-thermostat/

65. Paul Nobles. 2015. Fitbit, you're doing it wrong. Retrieved from: http://www.eattoperform.com/2015/07/22/fitbit-youre-doing-it-wrong-by-paul-nobles/

66. Melody Powers Noland. 1989. The effects of self-monitoring and reinforcement on exercise adherence. *Research Quarterly for Exercise and Sport,* 60, 3: 216 – 224.

67. Carly R. Pacanowski, Jennifer A. Linde, and Dianne Neumark-Sztainer. 2015. Self-weighing: Helpful or harmful for psychological well-being? A review of the literature. *Current Obesity Reports* 4, 1: 65 – 72.

68. Chris Paton, Margaret Hansen, Luis Fernande-Luque, and Annie Y.S. Lau. 2012. Self-tracking, social media, and personal health records for patient empowered self-care. *Nursing and Health Professionals Faculty Research.*

69. Afarin Pirzadeh, Li He, and Erik Stolterman. 2013. Personal informatics and reflection: A critical examination of the nature of reflection In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '13). ACM, New York, NY, USA, 1979 – 1988.

70. Devika Pisharoty, Rayoung Yang, Mark W. Newman, and Kamin Whitehouse. 2015. Thermocoach: Reducing home energy consumption with personalized thermostat recommendations. *BuildSys2015,* 201 – 210.

71. Bernd Ploderer, Wolfgang Reitberger, Harri Olnas-Kukkonen, and Julia van Gemert-Pijnen. 2014. Social interaction and reflection for behavior change. *Personal Ubiquitous Computing* 18: 1667 – 1676.

72. Bernd Ploderer, Wally Smith, Steve Howard, Jon Pearce and Ron Borland. 2012. Things you don't want to know about yourself: Ambivalence about tracking and sharing personal information for behavior change. In *Proceedings of 24ᵗʰ Australian Computer-Human Interaction Conference* (OzCHI '12). ACM, New York, NY, USA, 489 – 492.

73. D. Scott Ridley, Paul A. Schultz, Robert S. Glanz, and Claire E. Weinstein. 1992. Self-regulated learning: The interactive influence of metacognitive awareness and goal-setting. *The Journal of Experimental Education* 60, 4: 293 – 306.

74. John Rooksby, Mattias Rost, Allistair Morrison, and Matthew Chalmers. 2014. Personal tracking as lived informatics. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '14). ACM, New York, NY, USA, 1163 – 1172.

75. Sarita Yardi Schoenebeck. 2014. Giving up Twitter for Lent: How and why we take breaks from social media. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '14). ACM, New York, NY, USA, 773 – 782.

76. Victoria Schwanda, Steven Ibara, Lindsay Reynolds, and Dan Cosley. 2011. Side Effects and 'Gateway' Tools: Advocating a Broader Look at Evaluating Persuasive Systems. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '11). ACM, New York, NY, USA, 345 – 354.

77. Victoria Schwanda Sosik, Xuan Zhao, and Dan Cosley. 2012. See friendship, sort of: how conversation and digital traces might support reflection on friendships. In *Proceedings of the 2012 ACM Conference on Computer Supported Cooperative Work* (CSCW '12). ACM, New York, NY, USA, 1145 – 1154.

78. Patrick C. Shih, Kyungsik Han, Erika Shehan Poole, Mary Beth Rosson, John M. Carroll. 2015. Use and adoption challenges of wearable activity trackers. In *Proceedings of the 2015 iConference,* 1 – 12.

79. Itmar Simonson. 2005. Determinants of customers' responses to customized offers: Conceptual framework and research propositions. *Journal of Marketing* 69, 1: 32 – 45.

80. John Stasko. 2014. Value-driven evaluation of visualizations. In *Proceedings of the Fifth Workshop*

*on Beyond Time and Errors: Novel Evaluation Methods for Visualization.* ACM, New York, NY, USA, 46 – 53.

81. Strava Activity Tracker. Retrieved from: https://www.strava.com/

82. Victor J. Stretcher, Gerald H. Sejits, Gerjo J. Kok, Gary P. Latham, Russell Glasgow, Brenda DeVellis, Ree M. Meertens, and David W. Bulger. 1995. Goal-setting as a strategy for health behavior change. *Health Education Quarterly* 22, 2: 190 – 200.

83. Melanie Swan. 2012. Crowdsourced health research studies: An important emerging complement to clinical trials in the public health research ecosystem. *Journal of Medical Internet Research* 14, 2.

84. Jaime Teevan, Susan T. Dumais, and Eric Horvitz. 2010. Potential for personalization. *ACM Transactions on Computer-Human Interaction* (TOCHI) 17, 1(4). ACM, New York, NY, USA.

85. Yaacov Trope and Nira Liberman. 2010. Construal-level theory of psychological distance. *Psychological Review* 117, 2: 440 – 463.

86. Walgreens Balance Rewards Program. Retrieved from: https://www.walgreens.com/steps/appmarket.jsp

87. Kaiton Williams. 2013. The weight of things lost: Self-knowledge and personal informatics. From the *Personal Informatics in the Wild Workshop at CHI 2013.*

88. Rayoung Yang and Mark W. Newman. 2013. Learning from a learning thermostat: Lessons for intelligent systems for the home. In *Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '13). ACM, New York, NY, USA, 93 – 102.

89. Rayoung Yang and Mark W. Newman. 2014. Making sustainability sustainable: Challenges in the design of eco-interaction technologies. In *Proceedings of the 2014 ACM Conference on Human Factors in Computing Systems* (CHI '14). ACM, New York, NY, USA, 823 – 832.

90. Rayoung Yang, Eunice Shine, Mark W. Newman, Mark S. Ackerman. 2015. When fitness trackers don't 'fit': End-user difficulties in the assessment of personal tracking device accuracy. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '15). ACM, New York, NY, USA, 623 – 634.

91. Oren Zuckerman and Ayelet Gal-Oz. 2014. Deconstructing gamification: Evaluating the effectiveness of continuous measurement, virtual rewards, and social comparison for promoting physical activity. In *Personal and Ubiquitous Computing* 18, 7: 1705 – 1719.