Development of a Water Feedback System to Reduce Consumers Water Use

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A Project

Presented

to the Faculty of

California State University, Chico

In Partial Fulfillment

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Master of Arts

in

Interdisciplinary Studies:
International Cognitive Visualization

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by

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DEVELOPMENT OF A WATER FEEDBACK

SYSTEM TO REDUCE CONSUMER

WATER USE

A Thesis

by

Jasen Henderson

Spring 2015

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The purpose of this project is to develop a water use feedback system designed to reduce the amount of water a user uses during the process of taking a shower. The system will be based on the behavioral principles of operant conditioning, (specifically, the principle of differential reinforcement low rates, token economies, and reward and punishment), and control theories. Through an understanding and application of these core principles concerning how people process, behave, and learn, we will develop a system that will effectively reduce consumers' water use habits to an acceptable level.

We have developed a system that will encourage continued use in three steps. First, the system will provide the user with immediate reinforcement for positive in-shower behaviors. Second, the user will earn points while showering that are redeemable for deals at local businesses. And third, the user will receive mobile notifications that serve two purposes: 1) to encourage progress towards shower goals and 2) to remind users of the value of the points they have earned.

CHAPTER I

INTRODUCTION

Purpose and Scope of the Project

The goal of this project is to develop a consumer product that can intelligently influence the showering behaviors of its users. This is particularly important at the time of its development because of the the severe droughts effecting states across the U.S. "In general, drought is defined as an extended period–a season, a year, or several years–of deficient rainfall relative to the statistical multi-year average for a region" (Graham, 2000). California in particular is suffering form a severe drought where 99.8% of the state is categorized as in severe drought by the United States Drought Monitor (Fuchs, 2016). The National Centers for Environmental Information published an updated Palmer Modified Drought Index (PMDI) in 2015. In Figure 1 below you can see a map of the PMDI, showing that the majority of the western states are considered to be in a state of moderate to extreme drought.

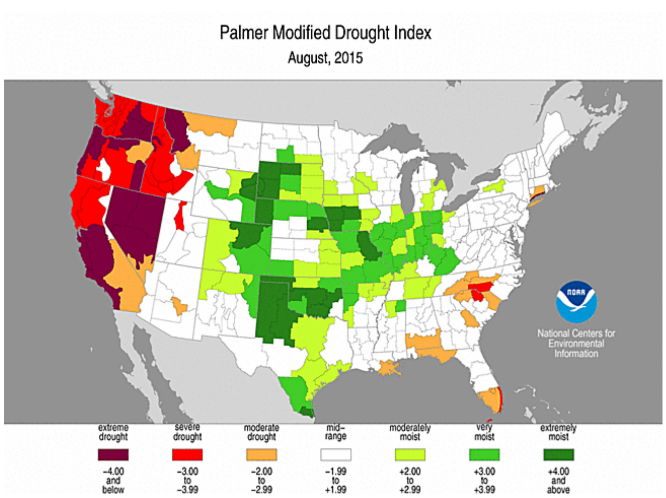

Figure 1 Palmer Modified Drought Index

It has become apparent that regulating and conserving water only during times of drought will lead to further droughts. As a society, we must find a way to be more vigilant about the use of our limited resources even when they are seemingly available in abundance. “Careful monitoring of drought can ease its impacts, allowing people to take early actions that prevent harsh impacts later” (Graham, 2000). In fact, the paleoclimatic (study of climate history) evidence suggests that the California we have known in modern times benefitted from what was likely a moderately above average wet period in the history of the region. In the relatively short history of observed climate in the west, we have become accustomed to a seemingly plentiful supply of water. This perception of an abundance of consumable water is, in fact, far from representative of the norm for the region. Research by Lynn Ingram, a paleoclimatologist, suggests that California may have had decade-long dry periods in its past (Ingram & Malamud-Roam, 2013). Ingram argues that, “the population has a collective idea of abundant water for consumption, despite what the region’s forests and waterways indicate.” (Ingram & Malamud-Roam, 2013, p. 7). Evidence from her research suggest that we may not emerge from the current drought for decades (Hockensmith, 2015). Because of this possibility, it is even more important that we find ways to change the way people perceive the availability of water and the effects of their use of it. The purpose of the system we are developing is to help change the ways people perceive the availability and consumption of water. Whether we are in a drought for ten more years or not, given the history of the region, it is crucial that we restructure the way our society utilizes this precious resource.

The system we are developing aims to change a user’s perception of water use in a couple of ways. First, the system will use the effectiveness of the concepts of rewards and punishment on human behavior to promote immediate and lasting behavioral change. Second, the system will provide a new graphical way to perceive water use. This new graphical representation is expected to influence humans’ ability and need to control their perceptions of the environment around them to establish a new norm for daily water consumption. For the purposes of this project, we will apply these concepts and representations of water use only in the shower, but this approach should be easily able to be expanded and duplicated to other areas of water consumption.

In the next chapter, we will review literature that supports the development of our system. In the third chapter, we will describe each component of the system, highlight the relevant literature that supports each component, and describe how the system and user will interact. In the final chapter, we will summarize the previous chapters and discuss future plans for development.

Significance of the Project

According to NASA, in December 2014, it was estimated that California would need 11 trillion gallons of water to get back to near normal water levels (Northon, 2015). It is imperative that changes are made in the ways that humans use water. These changes must come from farmers using water for agricultural purposes and the average consumer using water for daily tasks. As a society, we must find ways to be more efficient with our use of water. As the California Department of Water Resources has reported, we are currently facing a drought partially due to the fact that California has suffered 3 years of less than average rainfall as of 2014 (Jones, 2015); and, weather is unfortunately something humans cannot control. Another part of the problem is the lack of norms and measurements readily available to guide consumers in using an acceptable amount of water during their daily routines. It seems that there are a few obvious keys to emerging from our current drought and avoiding another one. A major key is to help consumers build sustainable habits and knowledge that outlasts a drought period. This may be able to be done by creating a class of consumers that understand the resource they are using and what the true cost of using such a resource is.

It is difficult for consumers to understand the cost of something when the consumers are billed long after they have already used the resource. A striking hypothetical example would be a consumer who purchases gasoline without the price or the volume of the gas pumped. Imagine a scenario where you go to the gas pump and fill your tank with gasoline, but are not billed immediately for the cost of that gas; but instead, you are billed at the end of the month for all of the gasoline you and your family used over the course of that month. On top of not knowing the cost there is also no information about how many gallons were purchased. It is not difficult to imagine how problematic it would be to regulate how much gas you used, how much the gas cost and how efficiently you were using it without the feedback about pricing and quantity readily available at the pump. Similarly, the immediate feedback about the price and quantity of water is absent from consumers' view during use. We aim to solve this difficulty.

Our system will be designed to help consumers understand water use in a new and more effective way. By giving the user the tools to perceive and control their water use, and the costs that use incurs, our system should be able to achieve it's goal of helping users better understand their water consumption—and, to control that consumption during the real-time period of use.

CHAPTER II

LITERATURE REVIEW

Behaviorism

The primary goal of the system we are developing is to foster change in the behavior of its users. Likely, people who purchase our system are conscious of the current drought conditions across the United States and are interested in reducing the impact of their water use. We intend to employ longstanding methods of behavioral change to help users reduce their water use in the shower. In this section, we will discuss operant conditioning, a method of reinforcement scheduling, token economies and behavioral consequences.

Operant Conditioning. Operant conditioning is a model of behaviorism in which behavior is thought to be a learned as a result of its consequences. B.F. Skinner introduced this model in his 1938 book The Behavior of Organisms: An Experimental Analysis. At the time, Skinner was a radical behaviorist who found that the use of reinforcements and punishments led to associations between a behavior and a consequence (Rholetter, 2013), (Skinner, The behavior of organisms: an experimental analysis., 1938). Beginning with conditioning experiments on rats, Skinner observed that animals accidentally pulling a lever, triggering dispensed food as a result, continued the behavior of pulling the lever. The association built between the behavior and the reinforcer ensured a repetition of a behavior.

Operant behavior has been defined by Catania (as cited by Pear & Eldridge, 1984) as a class of responses whose likelihood is modified by its consequences (Skinner, Science and human behavior., 1953), (Skinner, The behavior of organisms: an experimental analysis., 1938). Operant conditioning is the modification of operant behavior by reinforcing or punishing behavior (Catania, 1968 as sited in Pear, 1984). Operant Conditioning is founded on the Stimulus Response Theory, where behavior is seen as an organism's response to a certain stimulus. Skinner wanted to explore the relationship between a stimulus and response in order to understand and predict behavior (Chery & Farrell, 1998).

In operant conditioning, a stimulus in the environment prompts the subject to behave in a certain way because of learned rewards or consequences associated with the behavior. For example, a hungry rat which has associated the pulling of a lever with the delivery of food is likely to pull the lever to obtain food when it feels hunger. In this case, the dispensing of food is the reinforcement of the behavior of pulling the lever. If the lever were pulled without beneficial consequences, the rat would soon abandon the lever pulling effort. Conversely, if the rat were to pull the lever and an electric shock was delivered, the rat would be increasingly unlikely to pull the lever again, as the pain of electrocution would be associated with the behavior of pulling the lever.

In operant conditioning, an operant behavior can be modified by three different classes of environmental consequences: positive reinforcers, negative reinforcers, and neutral stimuli. Positive reinforcers strengthen the probability of increasing the behavior. Negative reinforcers are environmental aversive consequences whose disappearance increases the rate of response. Neutral stimuli are events that do not have an effect on the probability of an event occurring again or not. (DeVries & Jablonsky, 1971). It is important to note here that positive reinforcers and negative reinforcers are not the same thing as positive reinforcement and negative reinforcement, because of their similarities are often confused. We will discuss types of reinforcement and punishment in a later section.

Operant conditioning is primarily focused on external and observable reactions. Behaviorism focuses on the observed behavior and its reward or consequence, thus ignoring the internal mental processes that might explain why and how rewards make behaviors more likely to occur (Chery & Farrell, 1998). By focusing on these observable external events, Skinner was able to develop a model for behavior modification that was easily observed and applied in real world settings. Based on the research done by B.F. Skinner and others, operant conditioning found a place in many diverse fields of study and application. Educators have turned to operant conditioning to motivate and capture the attention of students (Kazepides, 1976), (McAllister, Stachowiak, Baer, & Conderman, 1969), (Harris, Wolf, & Baer, 1964), (MacPherson, 1972), as have special educators working with the disabled (Pedrini & D.T., 1972), and businesses have taken notice of the methods to motivate and increase productivity from their employees (DeVries & Jablonsky, 1971), (Komaki, Minnich, Grotto, Weinshank, & Kern, 2011), (Rubin, Bommer, & Bachrach, 2010).

Differential Reinforcement of Low-rates. Differential reinforcement of low-rates (DRL) is a behavioral schedule of reinforcement. A reinforcement schedule is a procedure that delivers a reinforcer based on a set of well-defined rules. (Catania & S., 1968). DRL is the reinforcement schedule that will best promote lasting behavioral change with our users because this method of reinforcement scheduling will allow us to gradually lower over time the number of minutes the user spends in the shower. DRL gradually reduces the occurrence of a behavior by reinforcing progressively lower rates of that behavior. DRL is especially well-suited to building self control of strong habits.

The DRL method of reinforcement distribution is best for behaviors that are generally considered acceptable but only at low rates of occurrence (Austin & Bevan, 2011). This kind of scheduling is perfect because we do not want to discourage users from showering all together. For example, it is certainly acceptable to take a shower for several minutes, but it is much less acceptable to shower for a half an hour. This is the kind of excessive problem behavior that can be modified by using a DRL behavior reinforcement schedule. DRL scheduling has been used to successfully reduce behaviors such as excessive requests for attention from students in classroom settings (Austin & Bevan, 2011).

In a differential reinforcement of low-rates schedule, the scheduler must first observe the participant to determine the average number of occurrences of the behavior. Once the average number of behaviors is determined, an initial goal limit for number of instances of the behavior is set that is below the average number of behaviors. The participant is rewarded every time they are able to successfully keep the number of behaviors on or below the limit that is set. As the participant is able to demonstrate that they can achieve targets, lower goal numbers are set until the number of behavior occurrences reaches an acceptable level in that situation.

In the system we are developing, every minute the person is in the shower will be treated as a behavior. If the user averages 30 minutes in the shower before using the system, the system will set a goal for showering at 29 minutes. For every shower the user takes that is 29 minutes or less, they will be rewarded. After a predetermined amount of time the goal shower limit will be lowered to, for example, 28 minutes. With the new lower goal limit, the user will only receive a reinforcer when he or she is at or below this new limit. This process will continue until the shower goal limit has reached an acceptable level.

Token Economies. A token reinforcement system or token economy is a system where tokens can be accumulated and exchanged for reinforcers. “A token economy is merely a miniature version of the system we all live under” (Redd, Porterfield, & Andersen, 1979). The token takes the place of an immediate reinforcer. An example of this would be if someone answered a question correctly in class, the teacher would reward the student with a wooden coin that could be later exchanged for a prize. Token economies have been increasingly used in fields such as the military, mental health, and education. Tangible items given as rewards immediately can be replaced with tokens which can be exchanged for certain privileges and rewards later (Doll, McLaughlin, & Barretto, 2013).

Token systems are primarily built on the concepts of operant conditioning (Kazdin, 1977 as cited in Doll, McLaughlin, & Barretto, 2013), (McLaughlin & Williams, The Token Economy, 1988 as cited in Doll, McLaughlin & Barretto, 2013). Tokens are neutral stimuli which by themselves do not have reinforcing qualities. Tokens often come in the form of points or other stand-in items. This neutral stimulus is repeatedly presented alongside or preceding the presentation of a reinforcing stimulus. The process of repeatedly presenting the neutral stimulus before the reinforcing stimulus makes the neutral stimulus reinforcing in itself (Doll, McLaughlin, & Barretto, 2013). Token economies are useful and powerful in modifying behavior because of this process of associating neutral tokens with rewarding stimuli and creating secondary reinforcers out of the neutral stimulus. This process and its effectiveness has been described by Miller and Drennen (1970) in their research on pairing procedures as reinforcers.

Participants in a token economy have shown that they are willing to work for something of value, called a “backup reinforcer.” The backup reinforcer is the item or privilege for which the token can be redeemed, and it gives the token its value. The more value in the backup reinforcer, the more powerful the reinforcing strength of the token. Token economies which have a wide variety of backup reinforcers are more likely to engage participants and change behavior (Williams & Williams, 1989), (Redd, Porterfield, & Andersen, 1979). Our financial economy is an excellent example of a strong token economy. We can trade a number of dollars we earn for following societies constructs for anything we want assuming we have enough dollars. This token economy has a vast number of backup reinforcers to support the power of the dollar.

Tokens can also be taken away from participants in the economy. The removal of tokens from the participant is called a response cost system. When a predetermined rule is violated, tokens are taken away. Combining token reinforcement and response cost systems has proven to be more effective than either system operating alone (McLaughlin, 1976). Programs that are reliant on response cost systems to suppress undesired behaviors are less likely to develop pro-social behaviors than programs that reinforce desirable behaviors to replace less desirable ones (Kazdin, 1977 as cited in Doll, McLaughlin, & Barretto, 2013). In society, we encounter response cost whenever we receive a parking ticket. If we park somewhere not permitted, then the government will give us a ticket, taking away dollars we earned.

In the water-use system we are developing, it will be necessary to reward users for completing and maintaining their water-use goals. We will implement a Token Economy system plus a Response Cost system that will include a large variety of back-up rewards. In our token economy, we will use points accumulated as “tokens” while showering that will be exchangeable at partnering local businesses. As users shower and remain under their goal time, they will earn points; but, once they reach and pass the goal time, they will start to lose points at the same rate that they were earning them prior to passing the goal time.

Reinforcement & Punishment. In the system we are developing, we have chosen to use forms of positive reinforcement along with negative punishment (also known as response cost). Both of these principles will function within the token economy. It is important that users are reinforced so that they have positive feelings toward using the system, but it is also the purpose of the system to reduce the amount of water that they use, and they should not be rewarded for spending time in the shower beyond the imposed time limit. In the token economy described above, the user will earn points for showering (positive reinforcement) but as soon as they surpass the time limit for shower length, they will begin to lose points at the same rate (negative punishment).

Positive reinforcement is when a participant receives stimuli that they find reinforcing after a behavior, and as a result the future likelihood of that behavior is increased (Skinner, The behavior of organisms: an experimental analysis., 1938). Positive reinforcement has been shown to be particularly effective in increasing the likelihood of targeted behaviors. In the context of our system and token economy, the user will be rewarded continually as they shower as long as they remain in the shower while they are below the goal time for showering. For ending the shower before the goal time has been reached, the user will be rewarded the full points as if they had stayed in the shower until the goal limit was reached. In addition to being awarded full shower points, the user will be awarded additional bonus points to further reinforce ending a shower before the goal. These awarded points represent positive reinforcement. First, by giving users points for showering, we increase the likelihood that they shower for the full amount of time. Second, by further rewarding them for getting out of the shower before the goal time we increase the likelihood that they will get out of the shower early in the future.

Negative punishment is where there is a decrease in the probability of a behavior occurring in the future because of the removal of something that a participant finds reinforcing (Skinner, The behavior of organisms: an experimental analysis., 1938). Punishment can be a dangerous tactic to use when trying to eliminate a behavior. Often instead of eliminating a behavior, punishment simply temporarily suppresses the behavior (Skinner, The behavior of organisms: an experimental analysis., 1938). The participant is often likely to continue the punished behavior as soon as the punishment has stopped. Punishment can also be dangerous when used alone because it can foster feelings of resentment towards the environment where punishment occurs. In the token economy, we will set up negative punishment that occurs as soon as the user passes the goal shower time limit. Since the user has spent the first part of the shower earning points that they find rewarding (positive reinforcement), taking those same points away for going past the time limit acts as negative punishment in the form of removing something they find reinforcing. This will reduce the likelihood that the user passes the shower goal in the future.

By setting up the system in this manner, we have effectively created an agreement between the system and the user. The system will give the user points that are redeemable for rewards as long as the user follows the shower time limit rules. If the user cannot follow the time limit rules agreed upon, then the system will take back the points that it had previously awarded.

Summary. These methods of behavioral modification play a key role in the system described in this chapter. By setting and scheduling attainable goals for users, and rewarding them for successfully completing these goals, we will be able to motivate users to reduce their water usage to an acceptable level. In order to maintain this eco-conscious behavior, the user will continue to be reinforced for maintaining his new behavior.

We will implement a token economy that reinforces users for ending their shower at or before a pre-set goal. Users will be reinforced with points that are continually accumulated as the user showers. A response cost will come into effect when the user showers in excess of the pre-set goal time. After the goal time, the user's points will be deducted as the user continues to shower past the goal.

This token reinforcement and response cost system will reward users on a differential reinforcement of low-rates schedule. The goal times set by the system will be systematically lowered as the user is able to achieve the goals. Once the average shower length has reached an acceptable level, the user will continue to be reinforced for staying at that level.

Control Theories

Control theory is an interdisciplinary branch of engineering that deals with the behaviors of dynamic systems, their inputs, and how feedback into a system is able to control an environment. Control theory began as a theory only used in engineering machines. It was not long before the application of this theory was observed outside of the engineering field in the actions and behaviors of humans. Control theory, both in the engineering and behavioral sense, is integral to the functioning of the water feedback system we are developing. The physical system we are developing must record and compare the time the user has been showering to what the system has set as the goal shower time; and, the user must compare what the in-shower graphic is currently displaying to what the ideal state of the graphic is. This comparison is essential for determining when to end the shower in order to earn a reward. In the following two sections, we will review the literature for two types of control theory—Engineering Control Theory, and Perceptual Control Theory.

Control Theory: Engineering. Control systems can be credited with enabling humans to have the technologies that they are afforded today. Without control systems and control system design, we would not have cars, computers, or regulated environments. In order to understand what a control system is we will define the meaning of the word 'control'. Control means to act and implement decisions that make a device behave in a desired manner (Andrei). A control system is able to achieve control because of its use of a negative feedback loop. A negative feedback loop is defined as "a system that detects a change from a constant, and then stimulates various effectors which then attempt to restore the system to the constant in the beginning." (Carver & Scheier, 2002). The feedback loop is dubbed "negative" because the system is working to reduce a discrepancy between a predetermined ideal state and the current state.

Feedback, in a mechanical sense, is where a signal to be controlled is compared to a desired reference signal, and the difference is used to determine a control action to correct the discrepancy, bringing the controlled environment to equilibrium. A great example of this action feedback loop is an air conditioner thermostat present in many homes. The modern thermostat has a sensor that is able to perceive how hot or cold it is in the surrounding environment, and is able to quantify its perception of the environment as a temperature. When a person sets their thermostat to the desired temperature of their house, the person is setting the thermostat control system's reference value. For instance, suppose a person sets their thermostat to 75 degrees but the temperature in the house is 85 degrees. In this instance, the control system senses the room's air temperature, compares that value with the person's desired temperature of 75 degrees, and then recognizes that there is a discrepancy in the desired temperature and the room's air temperature. This discrepancy prompts the system to make an adjustment to the environment by activating its cooler function which will run steadily until the system senses that the the actual temperature of the room is equal to the desired temperature. The modern thermostat controlling temperature is a fairly simple example of a control system and will be used throughout this paper to exemplify the principle.

In the book "Feedback Control Theory", a textbook for beginning and advanced engineering students, the typical process involved in designing a control system is outlined. The book explains that the typical control system design process has eleven steps (Doyle, Francis, & Tannenbaum, 1992)

1. Study the system to be controlled and decide what types of sensors will be used and where they will be placed.
2. Model the resulting system to be controlled.
3. Simplify the model so that it is traceable.
4. Analyze the resulting model; determine its properties.
5. Decide on performance specifications.
6. Decide on the type of controller to be used.
7. Design a controller to meet the specifications.
8. Simulate the resulting controlled system.
9. Repeat from step 1 if necessary.
10. Choose hardware and software and implement the controller.
11. Tune the controller on-line, if necessary.

The steps outlined above of designing a control system are crucial to the understanding and proper development of any system that is designed to maintain equilibrium within a variable system. In chapter 3, we will use these steps as a checklist to ensure that the proper steps have been taken to develop a functioning water use monitoring and control system.

In figure 2 , a simple mechanical control system is shown. The squares in the diagram represent different components of the system and the yellow circles are signals passed along to each of the components. Beginning with the green square, the system is concerned with maintaining control over an environment. “y” is the output value of the environment that serves as a signal that will be perceived by sensors and must be controlled. The sensors in the system, represented by the blue square, take in the “y” value and convert it into something that is perceivable by the rest of the system. The sensors send the perceived value of “Y” to the controller. In the controller, represented by the purple square, the quantified “Y” value is compared to the “r” value. The “r” value is a predetermined value that represents the ideal state of the environment that would ensure equilibrium in the system. “r” and “Y” are compared and the controller determines if there is a discrepancy between the two values and in what direction the discrepancy exists. Using the information on any discrepancy in the system, the controller determines what action should be taken to bring the system into equilibrium. The determined action is sent to the actuators, represented by the yellow square, which act on the environment to reduce the discrepancy between “y” and “r”. The entire process continues as long as the system operates to ensure that the environment remains controlled.

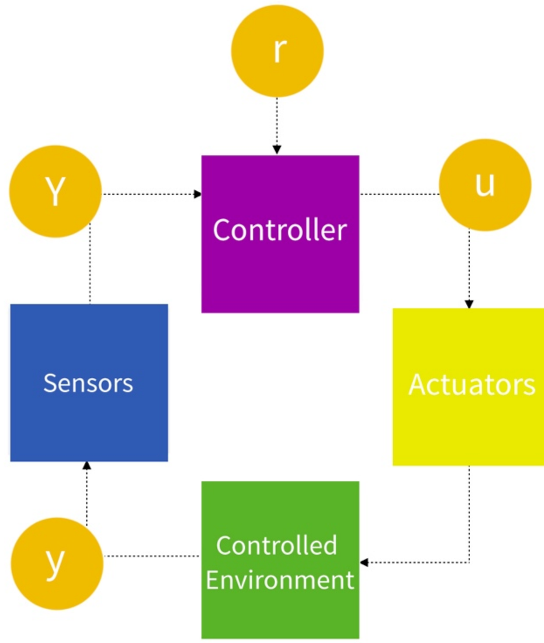

Figure 2 Simple Negative Feedback Control Loop

Perceptual Control Theory. Mechanical control systems are not unlike the control systems that operate with biological organisms. With biological organisms, control theory is referred to as "Perceptual control theory (PCT)". The most basic concept of PCT is that living organisms exert control over their environment by means of their behavior (Chery & Farrell, 1998) (Marken, Mansell, & Khatib, 2013) (Powers, Abbott, & Carey, 2011). Thus, the cornerstone of PCT is control, with a comparison of expected outcomes to observed outcomes playing the most important role (Chery & Farrell, 1998) (Marken R. S., 1988) (Marken, Mansell, & Khatib, 2013).

PCT is built on the same principles as traditional Control Theory (CT). In CT, mechanical devices exert control over certain targeted aspects of their environment by comparing the ideal state of the environment to what the devices sense about the actual environmental state. Similarly, PCT says that organisms exert control over their environment by comparing an organism's expectations of the environment to what the organism is perceiving about the environment and reducing any discrepancies (Carver & Scheier, 2002) (Marken R. S., 1988) (Powers, Abbott, & Carey, 2011).

In diagram 3 below, an example of PCT is shown as a simple negative feedback control system, similar to, but slightly different than the CT system described above (Powers, Abbott, & Carey, 2011). In the PCT control system, two independent variables: 1) the reference signal and 2) the disturbance, are conflicting forces that prevent balance into an equilibrium state (Powers, Abbott, & Carey, 2011). In gist, the goal of PCT is to bring the organism into equilibrium by reducing the effect of the disturbance so that the original state of the reference signal is achieved. The reference signal is the predetermined ideal state, or expectation, of the system as perceived by the organism. The disturbance is any force in the environment acting to effect the environment at hand. The goal of the system is to keep the system in balance by acting on the environment to control it.

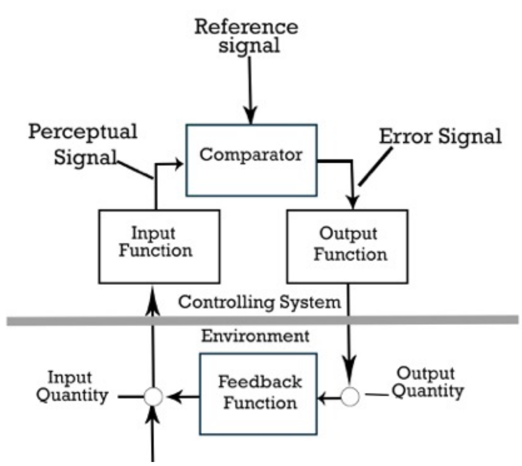

Figure 3 Perceptual Control Feedback Loop

The reference signal (R) represents an organism's predetermined expectations or standards about the organism's environments or situations. (i.e. ideal internal body temperature). A disturbance (D) is any variable that can have an effect on an environment (i.e. a gust of wind). Disturbances have an effect on the input quantity. The input quantity (Qi) is whatever the control system is tasked with monitoring (i.e. actual internal body temperature). The perceptual signal (P) represents the magnitude of one dimension of the environment (i.e. how cold it is). The comparator takes R and P as inputs and compares them. The error signal (E) is the result of the comparison in the comparator and indicates the amount and direction of the difference between the R and P (i.e. how much colder actual body temperature is compared to the ideal body temperature). The output function converts E into an output quantity. The output quantity is the measure of the system's physical output or observable behavior (i.e. Putting on a jacket). The feedback function is the physical properties that convert a behavior into an effect on the input quantity. (i.e. the way in which wearing a jacket increases actual body temperature). This is an example of the way a human is able to regulate internal body temperature by his or her behavior.

Summary. The two theories of control—CT and PCT—are critical to the functioning of the system proposed in this project. The mechanical control system we will develop must accurately display a representation of the elapsed time spent showering so that the user can use his perception of the display to control the time spent in the shower.

The representation of elapsed shower time will be a circle that fills at a rate corresponding with the goal shower time. With the goal shower time serving as the reference signal, the circle should fill at a rate corresponding with the goal time until one minute before the goal time. Once the elapsed time reaches a minute before the goal time, the display will change colors to indicate that the user is reaching his or her shower-time goals. Once the elapsed time has passed the goal time, the display should begin to empty at the same rate that it had filled.

In the system we have designed here, there are sensors that will determine if the shower is running and for how long. If the shower is running, then the elapsed time showering will be continually compared to the goal shower time to determine if the in-shower display should fill or empty. In figure 4 below, a diagram is shown of the control system in action.

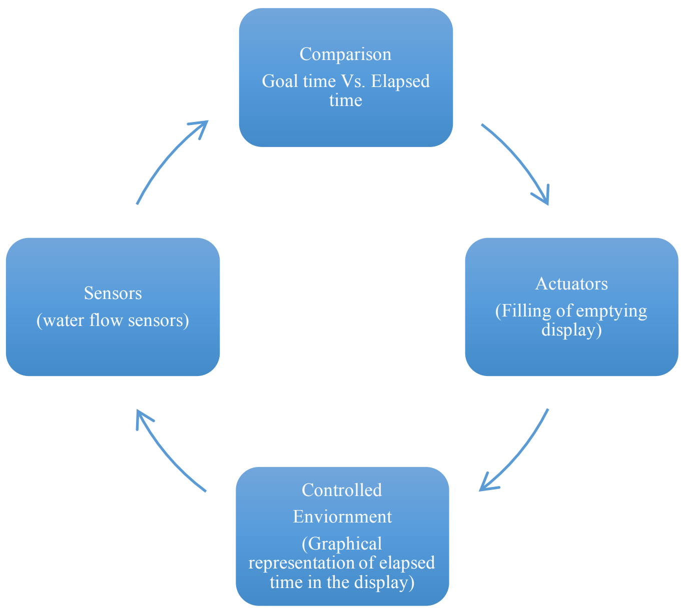

Figure 4 Splashes Control Loop

The shower device's control system will serve as the perceptual input for the user's perceptual control system. While showering, the user will look at the graphic displayed by the system. The user will compare what the graphic is displaying to the user's ideal state throughout the shower and make the determination to continue showering or stop. The graphic and the user's perception of time should remain constant as the shower's goal time is reduced. The in-shower display will look the same when the goal time is 25 minutes or 5 minutes. This is important because the user will only have to learn one set of rules and the reference signal for the user will not change; the goal will always be to have a completed circle. In this way, as the shower goal is gradually reduced; the user will not have a concrete way to perceive that he or she is showering for a shorter time, only that the user is completing the same goal even though the time is actually reducing.

The principles of PCT predict that the user will use his behavior to control the perceived environment. In this case, both the in-shower display and the points earned from staying in the shower are the perceived environment to be controlled. The user will control the state of the display by getting out of the shower on, before, or after the goal time. After successfully completing a shower on or before the goal time, on multiple occasions, users should become conditioned to end the shower when the graphic indicates they should, regardless of the time goal.

Reconciling PCT and Operant Conditioning

The diagram in Figure 5 below depicts two separate components of the PCT system, the “controlling system” and the “environment”. The top half of the system (the controlling system) is a proposal of what may be occurring within an organism that exerts control over the organism’s perceived environment. The bottom half of the diagram (environment) depicts what is observable outside the system. This division is important, because we can identify the findings of operant conditioning and its place within a control system.

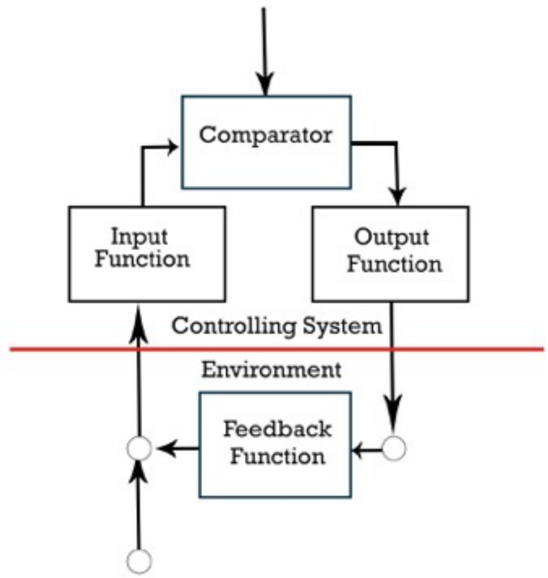

Figure 5 Two Part Control Loop

Operant conditioning is wholly focused on what is able to be observed about behaviors and how the consequences of those behaviors affect future behaviors. Behavior and external consequences can be identified in the bottom half of the model, labeled "environment". The top half of the diagram is where PCT focuses on explaining how perception and behavior are used by an organism to control the observable environment emphasized in operant conditioning.

We believe it can be argued that these two perspectives on behavior—PCT and operant conditioning—are in fact two sides of the same coin, and with a bit of perspective adjustment can be seen as such. The first perspective we discussed is operant conditioning. In operant conditioning, a behavior's occurrence is made more or less likely by a consequence (a reward or punisher) that follows it. PCT explains the same phenomena of behavior from a different perspective. In PCT, behavior is viewed as the means by which an organism is able to maintain control over it's environment. The consequence or reward is seen as a result of a given behavior. These are contrasting interpretations of the same results. In this section, we will reconcile these differing perspectives on behavior, and show how they can coexist to explain more about the ways in which organisms behave and why. We will look at the regulation of body temperature in the way that operant conditioning would explain the behavior of a person who is cold. Then, we will look at the regulation of body temperature in the way that PCT would explain the behavior of a person who is cold.

An Operant Conditioning Perspective.

A person who is cold (antecedent) will put on a jacket (Behavior). If the jacket is successful in making the person feel warm (consequence), then in the future when the person is cold, he will be more likely to put on the jacket the next time, because feeling warmth when cold is reinforcing to him (see figure 6). The operant conditioning perspective on this scenario purposefully ignores what is going on in the mind of the user. Given a certain stimulus an observer can reasonably predict the response. It is enough to know that there is concordance between the occurrence of stimuli, behaviors and rewards. While this perspective has been widely functional and applicable to many fields, its exclusion of the participant's perspective leaves a large part unexplained of a participant's ability to function. Behaviorism largely implies that behavior is under external control (Chery & Farrell, 1998). Where presented, stimuli directly dictate behavior because of the learned consequences of behaviors.

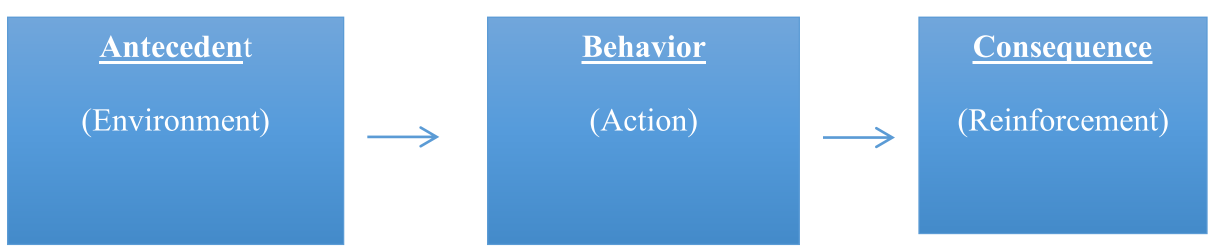

Figure 6 Stimulus Response Model

A PCT Perspective.

If we view the same scenario from the PCT perspective, we will invariably see the same results. In regulating temperature, the body is constantly sensing the temperature through its nerve endings that are dedicated to task of temperature sensing(sensors). For example, the human body has a predetermined internal temperature of 98.6 degrees Fahrenheit. When the body senses its internal temperature is 96 degrees and compares it to the ideal 98.6 degrees, it is able to sense that it is too cold. This prompts the person to find a way to be warmer. One way to get warmer is to put on a jacket (see Figure 7). The behavior of putting on a jacket results in the person becoming warmer. Warmth when one is cold is reinforcing. In this example, from the PCT point of view, the behavior (putting on a jacket) is a tool for controlling part of the perceived environment (internal temperature). The equilibrium of body temperature caused by the behavior of putting on a jacket is rewarding to the person.

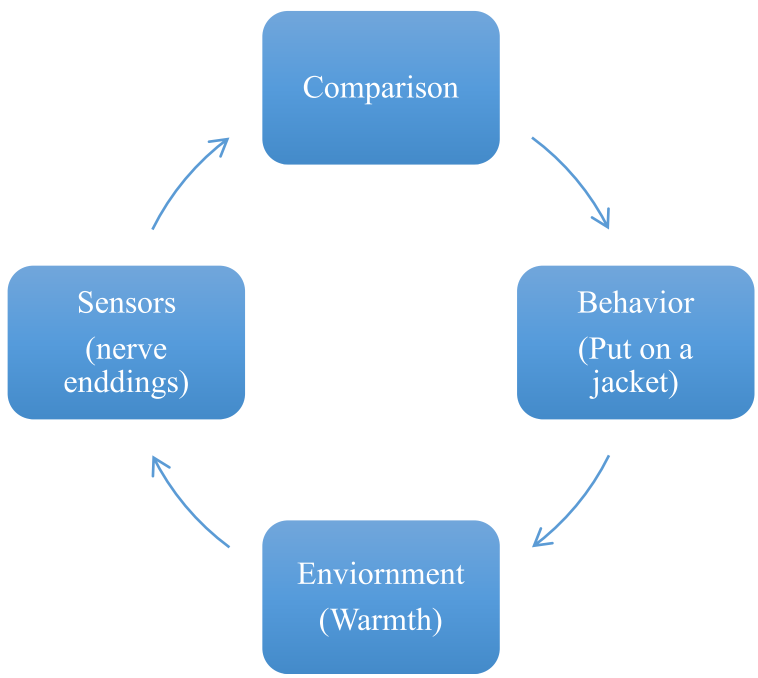

Figure 7 PCT Model of Behavior

Examples of Classic Behaviors from a PCT Perspective. After careful consideration, it has been suggested that all behavior involves control (Carver & Scheier, 2002) (Marken R. S., 1988) (Powers, Abbott, & Carey, 2011). If we look at almost any instance of a behavior, we can see how the rewarding component of a situation is simply the achievement of equilibrium within a control system. Likewise, something that is aversive, or punishing, can be attributed to a control system that is detecting an error. Here, we will demonstrate how nearly every instance of an organism's behavior can be viewed in terms of a control system. If an organism is deprived of food for a significant period of time, there is an error detected; that error is called hunger. If the same food-deprived organism obtains food by pulling a lever food, the error in the 'hunger control system' will be reconciled, resulting in equilibrium within the hunger control system and the organism will learn that the behavior of pulling the lever when hungry results in food.

Yet another example of a behavior that is a result of a control system error detection would be if a student is "misbehaving" to gain attention from a teacher. The student perceives that she is not getting all of the attention she wants (control system discrepancy). In order to correct this discrepancy, she performs some disruptive behaviors that will gain her attention from the teacher. By performing these disruptive behaviors, the student gets attention from the teacher and resolves the conflict she was perceiving. The student now knows that by acting out she will be able to solve her need for attention whenever an error in attention is detected.

Reinterpretation of Operant Conditioning within the PCT Framework. Operant Conditioning and PCT take two different perspectives on the nature of behavior. Proponents of each respective viewpoint would likely argue that if one is true the other must not be. We believe when viewed objectively, common ground can be found between Operant Conditioning and PCT.

PCT tries to explain every component and step involved in a behavior, while the stimulus response model of operant conditioning seems to be lacking in specifics (Chery & Farrell, 1998). A stimulus response model simply does not account for the fact that actions are motivated by intentions. From at PCT point of view, intentions and goals are integral to understanding human behavior.

From an operant observer's point of view, the observer can make the user perform a behavior by reinforcing that behavior with something pleasant. But from the user's more egocentric point of view, by performing a certain behavior, the user will receive something pleasurable. The participant is constantly seeking to correct perceived errors such as hunger, warmth, or attention. In other words, it is the occurrence of the behavior that makes the consequence more or less likely, from the user's point of view. Thus, detection of an error produces the consequent behavior following error detection; however, without error detection, there is both little to no chance of a behavior and consequence or reward for that behavior.

PCT, taking into account an entire experience—both observable and unobservable—argues that the effect is not that the reinforcement makes the behavior more or less likely in the future, but rather that the behavior makes the likelihood of receiving a reinforcer or punishment more or less likely. Taking both points of view together, it seems that the primary motivation guiding all organisms is survival. Survival means maintaining appropriate levels of things like hunger, body temperature, and social interaction. Thus, the appropriate reference state for controlled measures such as hunger varies from organism to organism. Since organisms are actively working to control their environments to be as pleasant for themselves as possible, it makes sense that we would observe that a person would be more likely to perform a behavior that results in something pleasurable happening (positive reinforcer). Likewise, it is understandable that an organism would be less likely to perform a behavior that resulted in something displeasing happening to them (Positive Punishment). Since these observations are only a portion of the entire process and are viewed from the perspective of an observer, it is difficult to determine by simple outside observation whether the behavior makes the consequence more likely, or vice-a-versa.

The point is that the perspective from which one views an organism's behavior is conceptually different depending whether it is viewed from an Operant Conditioning or PCT paradigm (Chery & Farrell, 1998). Marken (1988) writes about the illusion of the presence of a simple stimulus response paradigm in behavior. Often a dramatic disturbance to a controlled environment will be misinterpreted as the controlled environment itself. Marken's abstracted example of this is the relationship between the sun, room temperature and a thermostat. When the sun goes up or down, a furnace responds by a dramatic increase or decreases in output. It may seem that the sun is a stimulus that causes output responses from the thermostat. In reality, the thermostat has no way of sensing the sun; therefore, the sun cannot be a stimulus, only a disturbance on the controlled environment—the controlled environment being the room temperature. The thermostat does not concern itself with the presence of the sun and is therefore not responding to it as a stimulus; instead, the thermostat is concerned with maintaining a constant environmental room temperature despite disturbances such as the appearance or disappearance of the sun. In short, it is critical to observe behaviors in their totality and to correctly identify the environment that is sensed and controlled along the forces that act to disturb perception of that environment.

Often the expectations of organisms positively contribute to their own happiness. Happiness is a composite of many variables that must be controlled; organisms are in a constant pursuit of happiness. PCT works to explain this pursuit and how behaviors are used to control sensed environments representing variables that constitute overall happiness.

All the methods and findings of operant and classical conditioning hold up unchanged under this reorganization of perspective. That is, the same results can be accomplished by the Behaviorists' methods, but it is important, that the users experience, intentions, goals, and needs are taken into account when designing a system such as ours. PCT allows us to open the framework and findings of classical behaviorism to take the perspective of the user and understand what the motivation for behaviors are, rather than just what the behaviors are, when they will occur, and the probability that they will occur again. PCT provides for how needs are detected and information about a behavior's results are fed back and associated as the result of a certain behaviors in a certain situation (error detection).

Summary

In the system we are developing, the users will be presented a circular graphic while showering that fills as time passes. The ideal state of the graphic is to be moving towards being a closed circle, and at the end of showering, a completely closed circle. Along with the graphic, the users will be shown the number of points they are earning. An error would occur when the circle passes the full mark; at this point, the circle begins to retreat, opening up, and the points start to decrease. As users shower, they will check the graphic to determine their status in comparison to the goal state. As the graphic approaches a closed circle, the users will see that they have reached the ideal state and shut off the shower in order to earn the full amount of points provided by the token economy in place.

CHAPTER III

METHODOLOGY

Terminology

Terminology used will be defined as it is encountered in the description of the system.

Procedure

During the conceptual development of this system, we wrote, modeled, and rejected multiple versions. The system was first developed and defined by its components, how they interact with one another and finally how they interact with the user to positively effect behavior. Each component was built with principles of behavioral psychology, feedback loops, and control theories in mind. These guiding principles combined with the necessary components, eventually formed the system described below.

In order to identify the components and outline the how the system will function, we followed the steps laid out by the book "Feedback Control Theory". First, we analyzed the process and environment of showering; this helped us identify the sensors that would be necessary for delivering the pertinent information into the system and to the user. Next, the system was modeled, then simplified to its basic components: the reference variable (shower goal), the variable to be controlled (shower time/ graphical representation), the actuators for controlling (the user) and the sensors involved in perceiving the environment (thermometer and water flow sensor). Next, the performance specifications, or rules for determining the system's reference value, were chosen (dictated by DRL scheduling). We identified the controller of the system, which will be the user.

Target Group

This system is targeted at consumers who are eco-conscious, trying to find ways to reduce their impact on the domestic water deficit. As a sub-target group, this system is built for people who are interested in the Internet of Things— for example, home automation, and personal data collection. This system could be especially useful for groups such as families and college dorms to enforce shower time restrictions while rewarding users for building more sustainable shower habits.

System Description

System Overview. The system will consist of six components, two located in the physical shower environment, and four located in a mobile application environment. Each component has its own distinct functions, while also dependent on interactions among each component to carry out individualized specific tasks. The six components of the system are:

1. An in-shower data recorder.
2. A central processing server.
3. A feedback loop.
4. A reward system.
5. An in-shower display.
6. A mobile application consisting of three sub-components:
    a. Mobile application notifications.
    b. Visualizations of usage data.
    c. Deals and coupons.

In-shower Data Recorder. The in-shower data recorder will collect information about a shower event. The data to be collected during the shower will consist of:

1. Duration of the shower.
2. The temperature of the water.

The data will be collected at the showerhead. These data will be sent to a central processor and an LCD display in the shower. These data are crucial for determining the information used by the rest of the system.

Central Processor. The central processor will collect, store, manipulate, and distribute all of the data used throughout the system. Specifically, the processor will collect data from two sources— the data collection unit in the shower, and data manually entered into the mobile application by a user. Storage refers to the amount of time data will be held in the central processor— a period expected not to exceed three months. Data manipulation refers to the variety of calculations the processor is designed to make from the four components of the system. Specifically, the processor will calculate 8 variables:

1. Total water volume used.
2. Cost per minute of showering.
3. Average shower length in minutes and seconds.
4. Projected cost savings. (The total amount of money a user will save at the end of the year if the user continues to shower daily at his current length.)
5. Current cost savings. (The amount of money a user has saved on his/her water bill to date because of modifications in behavior.)
6. The cost of a single shower in dollars.

7. The goal shower time. (The goal time to reduce a user's shower time.)

8. Single shower total elapsed time.

Finally, the central processor will deliver the results of these calculations to the relevant components of the system so each component can carry out its individual respective task.

Feedback Loop. The feedback loop function of the system is how the user's data about behavior is captured and then relayed back to the user. Data is collected at the in-shower data recorder. This information is then fed back to the user at two different components of the system: the in-shower display, and the mobile application. The feedback loop quantifies and delivers information otherwise unavailable to the user.

Reward System. The reward system is how the user will be incentivized for successfully reducing his/her time showering. Points will be earned at a constant rate as the user showers under the shower-time goal. When a shower is ended before the goal time, the user will be awarded the full amount of points, as if they had showered until the end of the goal time. In addition to receiving the full number of points, the user will also be awarded bonus points. When the shower is run past the goal shower time, points will start to be deducted at the same rate the user earned them. Points will be redeemable for deals and coupons provided by local businesses, which participate in our program.

Rewards will be negotiated with, and will come from, local businesses. For a local business like a restaurant, it is easy to promote water conservation by only providing water when a customer asks for it. By participating in our reward program, businesses, which do not have such a simple way to promote and participate in conservation, will be able to. By participating in our reward system, businesses will be able to attract customers to their store to make purchases with the deals while helping to directly influence water conservation in a much broader way.

The mobile application will have a number of deals from various businesses. Points will be earned while showering which are redeemable for different deals. Each deal has a cost in points. Bigger better deals cost more points than smaller less valuable deals.

In-Shower Display.

The in-shower display will be a small waterproof LCD screen that displays a single graphical representation along with a numerical point value to the user in the shower (See figures 8, 9, 10 above). The graphical representation will be a single circle, which will fill in two distinct phases over the length of the shower and empty in a third. The circular graphic is divided into three phases identifiable by changes in color-coding. The first phase of the circle fills blue and the second phase fills green; finally, the circle will empty in red. Each of these colors used in the graphic will represent three pieces of information that will be displayed on the LCD display:

1. The elapsed time showering.
2. The current goal time for the next particular shower.
3. Points being earned or lost during the shower.

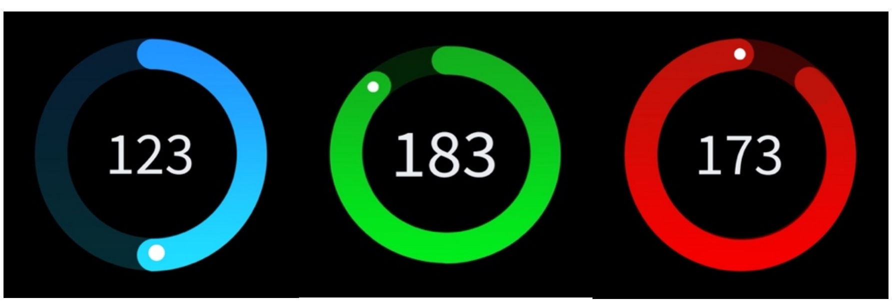

Figure 8 *Figure 9* *Figure 10*

Display Graphic

The numerical point value displayed in the shower represents the tokens the user is earning while showering. These points will be redeemable for deals and coupons at local businesses supporting the system. These coupons function as the backup reinforcer for the points users earn for completing showers in the token economy we have built.

Mobile Application. The mobile application is designed to be used on a smartphone and is comprised of three different sub-components which use the data calculated in the central processor. These three sub-components are:

1. The mobile application notifications.
2. The visualizations of data.
3. Deals and coupons.

The mobile application notification will be delivered to the user as a push notification approximately one minute after a shower is ended. The notification will appear on the lock screen of the smartphone and will be a brief statement accompanied by the application logo. The brief statement will tell the user when s/he was on or below his/her goal shower time, and how many points the user earned during a shower. (See figure #11 above). These notifications function to praise the user and provide positive reinforcement to go along with the token reinforcers.

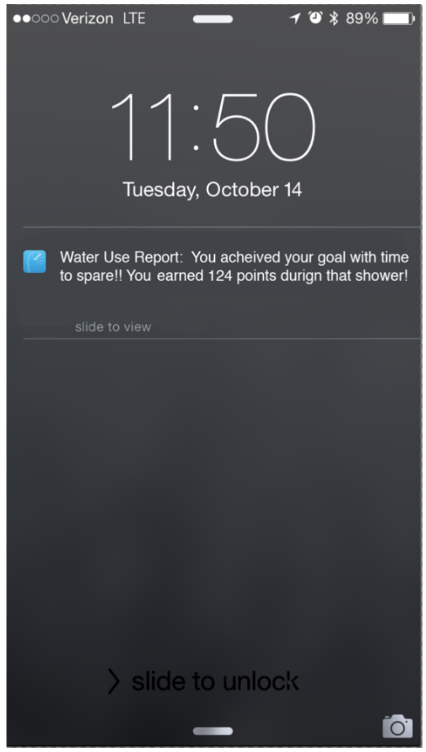

Figure 11 Mobile Push Notification

The visualizations of data use are organized into five categories:

1. Rewards.
2. Data concerning the most recent shower event.
3. Goal oriented data.
4. Water use oriented data.
5. Costs and savings oriented data.

The initial page of the mobile application will consist of six tabbed pages; each tab is designated by a different color and an accompanying title. (See figure #12 above). The pages' titles and color designation are as follows:

1. Rewards (Purple)
2. Last shower (Yellow).

3. Goals (Coral).

4. Water Used (Blue).

5. Savings (Green).

6. Settings (Grey).

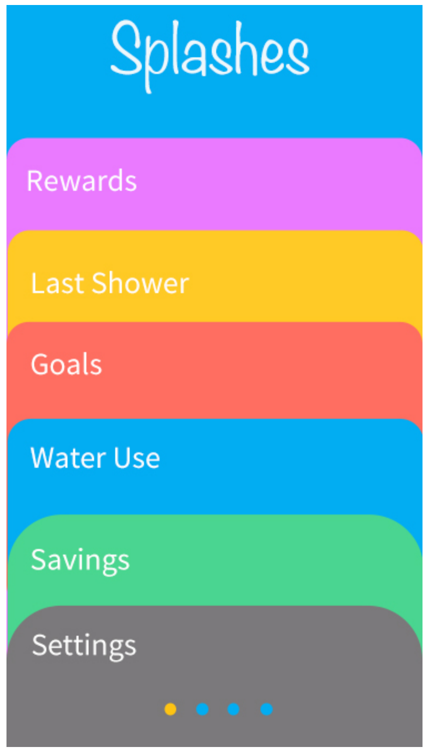

Figure 12 Mobile Application Home Screen

When the app is opened for the first time, the settings tab will automatically open so the user can perform the necessary initial setup of the application. (See figure #13 above) In the initial setup, the user must enter key information manually. The manually entered information includes three things:

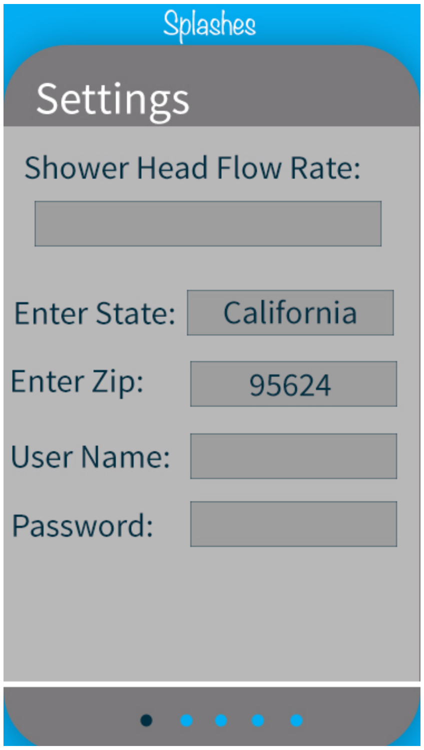

Figure 13 Settings Page

1. The showerhead flow rate, in gallons per minute.
2. Geographic location (state and zip code) will determine two variables:
    a. The average cost to heat a gallon of water.
    b. The cost of a gallon of water.
3. Login information
    a. Username
    b. Password

After entering their settings and preferences, users will be able to explore data organized into the five different categories detailed below.

Each data category will be organized on the home screen in tabs, which expand to full pages when clicked. Each page will display data relevant to the specific category.

The first page will have information on the rewards the user has earned. On this page, there is information on two things:

1. Total number of points earned.
2. Rewards available for redemption.

The second page will have the data concerning the last shower, organized into five subcategories:

1. Goal completion.
2. Shower time.
3. Gallons used.
4. Cost of the shower.
5. Cost to heat water used.

The third page will have the data concerning the user's goal:

1. The user's current shower time goal.
2. A history of accomplished goals.

The fourth page will have data concerning water use, organized by:

1. Total gallons used.
2. Average gallons used per shower.
3. Gallons used in last shower.

Finally, the fifth page will have the data concerning cost and savings, organized by:

1. Cost of a single shower.
2. Total dollars saved.
3. Projected amount of dollars saved by the end of the year if the program is completed.
4. Total cost of the last shower.

Visualizations of Usage Data. Usage data will be shown to the user in the form of multi-colored graphs, charts, and figures designed to best display the specific nature of the data for each category.

The first page depicting rewards will contain the total number of points available for redemption and a gallery of available deals (see Figure #14 above). The number of redeemable points will be represented by a number at the top of the page below the title "Available Points". The gallery of available deals will be under the title "Rewards". The gallery will display one deal at a time. The deal will include the logo of the sponsored company, the number of points necessary to redeem the deal, and a description of the specifics of the deal.

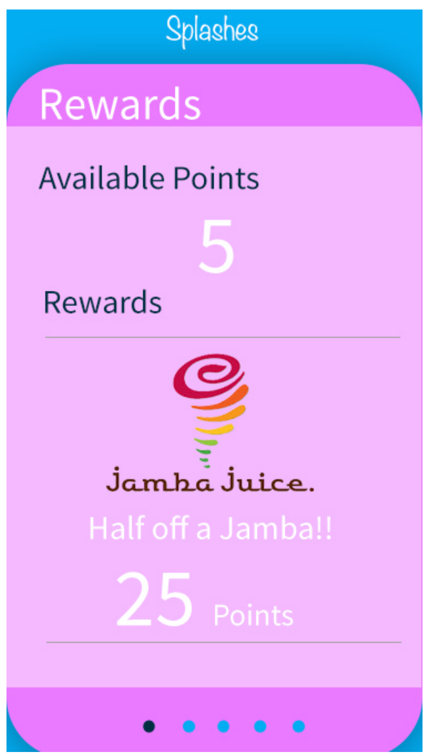

Figure 14 Rewards Page

The second page will have data from the last shower, and will be displayed according to the descriptions below (See figure #15 above). Goal completion will be shown as a numerical representation of time next to a box that is either filled with a green checkmark, a red line, or empty. The checkmark means the user was at or below the goal time; the red line means the user went over the goal time; and, an empty box means a shower at this goal has not been attempted. Shower time will be represented as a numerical value for time in minutes and seconds. Gallons used will be shown as a numerical representation of gallons with one decimal place. Cost of the shower will be shown in dollars and cents. Cost to heat water used will be shown in dollars and cents.

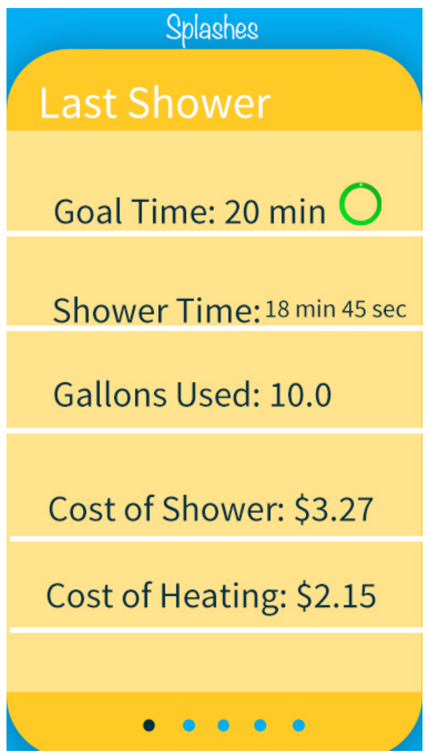

Figure 15 Last Shower Page

The third page will have the data concerning the user's goals (See figure #16), including the users current shower time goal and a list of the goals they have completed. The user's current shower time goal will be represented in minutes with a grey circle next to it. Completed shower goals will be below the current goal and will be represented in minutes with a green circle next to it.

Figure 16 Goals Page

The fourth page will have data concerning water use (see figure #17, #18, #19), including total gallons used, average gallon's used per shower, and gallons used in the last shower. Total gallons used will be shown using a bar graph. The y-axis will represent gallons of water used. The x-axis can be viewed on four different levels, selectable by the user: daily, monthly, weekly and yearly. Average gallons used per shower will be shown numerically in gallons of water represented on a bar graph with a single bar. Gallons used in the last shower will be shown in gallons of water represented on a single bar graph.

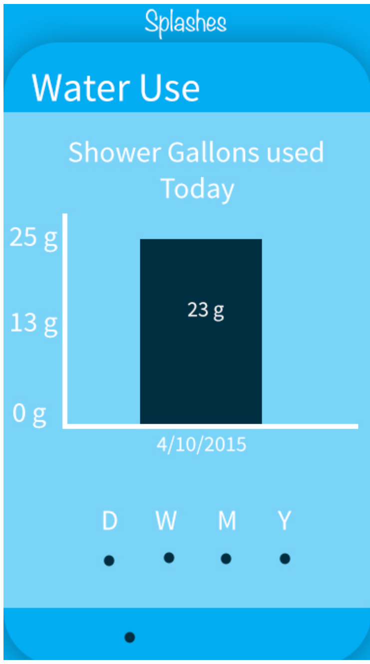

Figure 17

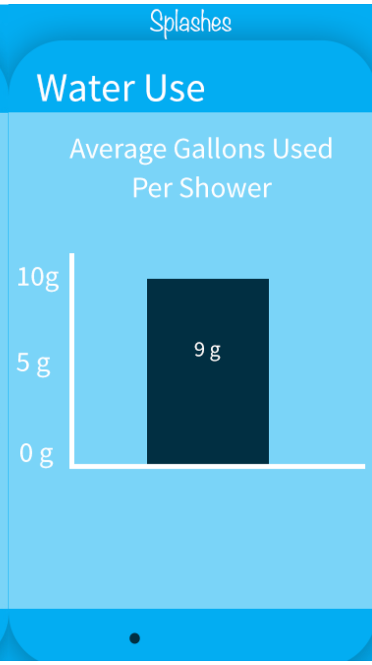

Figure 18

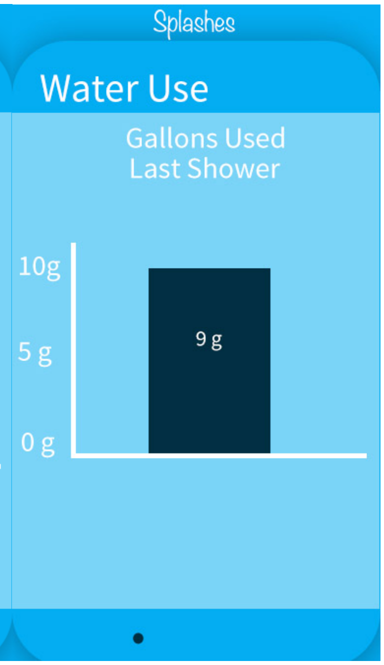

Figure 19

Water Use Pages

The fifth page will show the data concerning cost and savings (see figure #20), including average cost of a shower, cost of the most recent shower, total dollars saved, and the projected amount of dollars saved by the end of the year if the program is completed. All figures on this page will be represented in dollars and cents.

Figure 20 Savings Page

How The System Works

The four components described in the section above (the in-shower data recorder, the central processing server, the in-shower display, and the mobile application) work together to actively reduce the user's water consumption. There are ten distinct steps among these components, which will facilitate a reduction in a user's water consumption.

In step one (below), data about the user's water bill will be manually entered into the mobile application. Manually collected data include the gallons per minute and geographic location (this is used to determine the cost per gallon, and the cost to heat a gallon of water). The user will also be prompted to set up an account; this includes creating a username and password.

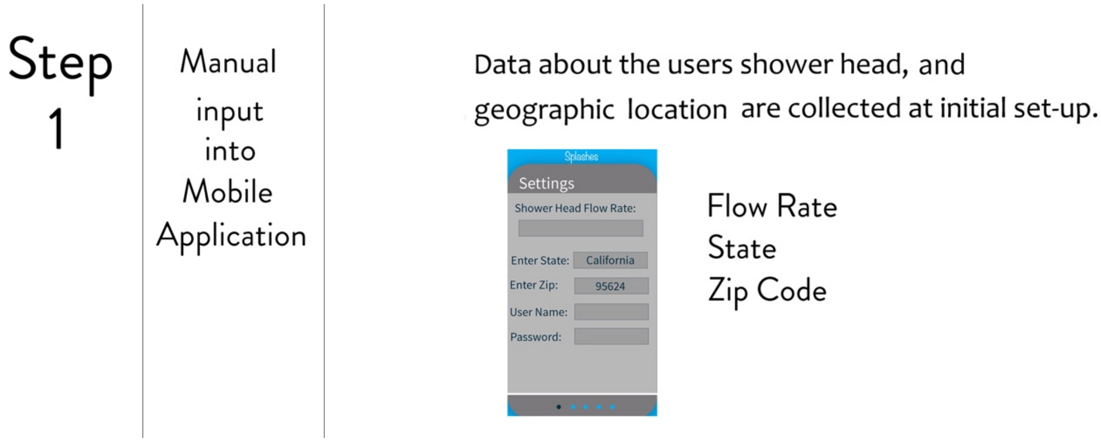

Figure 21 System Step 1

In step two (below), the manually inputted data are sent to the central processor where they are used to calculate variables. These variables will be distributed and used by the other components of the system. Next, the process of usage data collection begins in the shower where the temperature and time data will be collected.

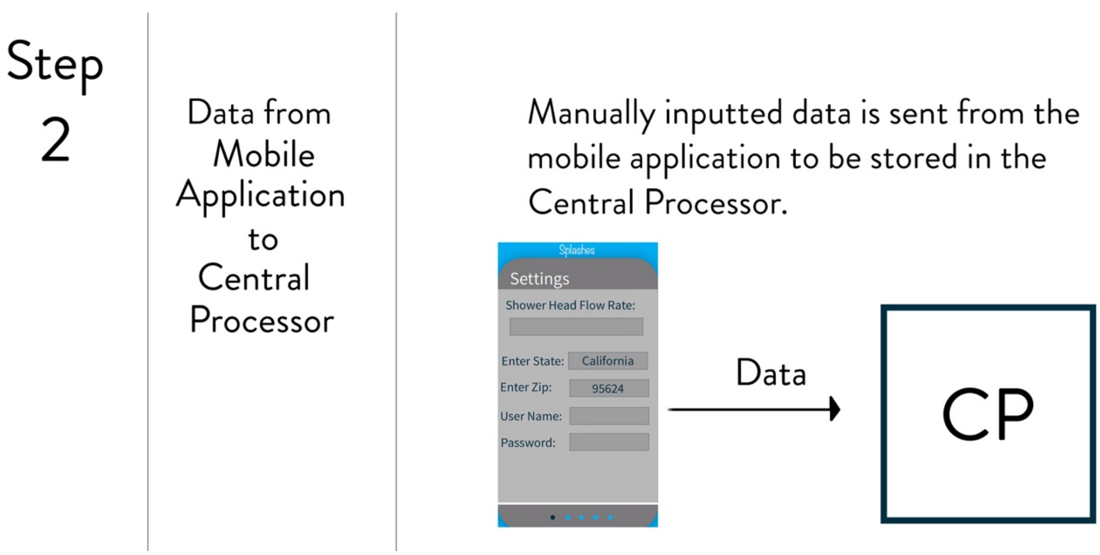

Figure 22 System Step 2

In step three (below), the in-shower data recorder begins recording the temperature of the water over the course of the shower at the point the shower is turned on. The in-shower data recorder will also capture the time the shower was started. In the first week of use, the system will record data on the user's average usage. This is done so the central processor will have a baseline usage level from which to determine the initial goal times.

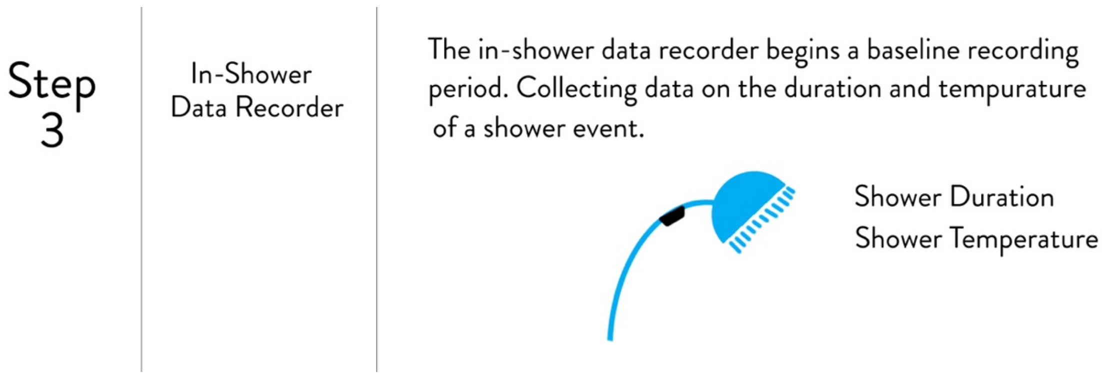

Figure 23 System Step 3

In step four (below), after the first week of use, the in-shower data recorder will transmit the data on temperature and shower start and end times to the in-shower display.

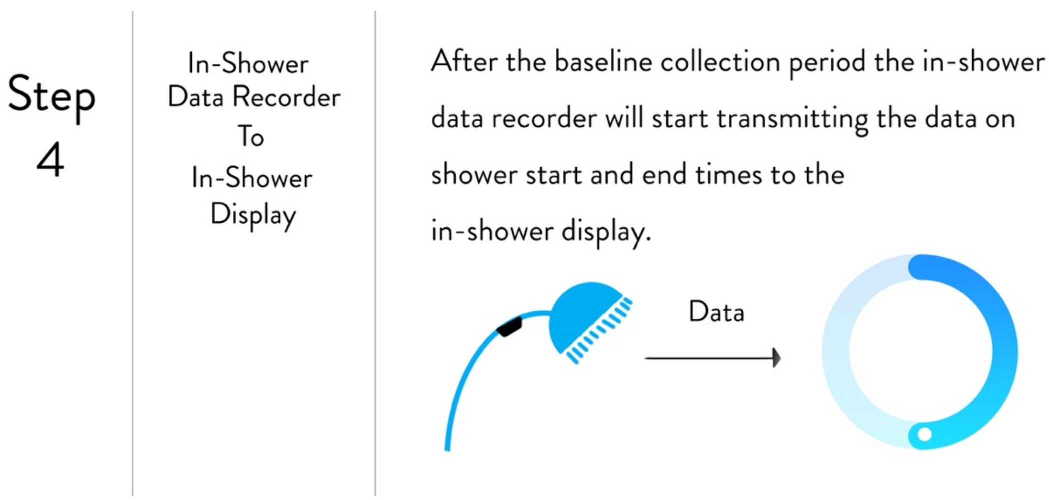

Figure 24 System Step 4

In step five (below), the in-shower display will be activated once the shower is started. On the display, the elapsed time showering, the goal time, and the token reinforcer are shown on a circular representation. This circular graphic on the screen will begin filling at a continual rate. The display graphic fills a blue phase until one minute before the goal time is reached. Once one-minute before the goal time is reached, the graphic begins filling a green phase. While the graphic fills in the blue and green phases, numeric points will accumulate in the middle of the graphic. At the end of this minute, the graphic begins to fill a red phase, denoting that the goal time has passed. During this red phase, the points in the middle will begin to decrease at the same rate they were earned.

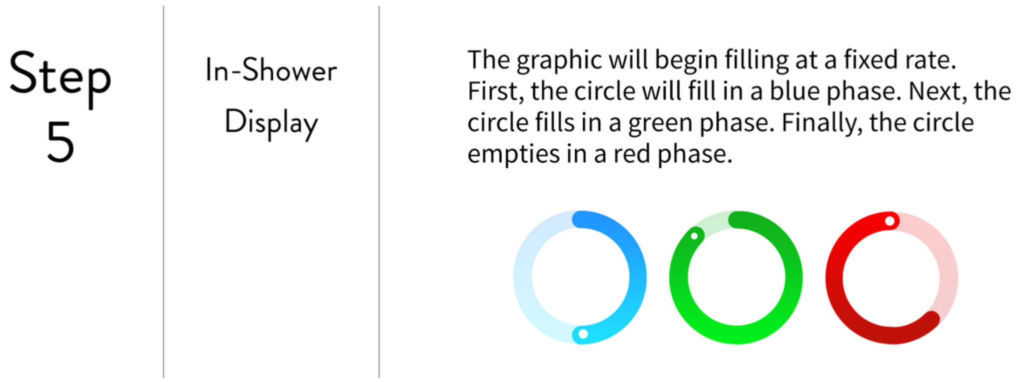

Figure 25 System Step 5

In step six (below), when the user turns the shower off, the in-shower recorder stops recording the water temperature and transmits temperature data and the final shower time to the central processor. A signal is sent to the in-shower display to stop the graphic from filling.

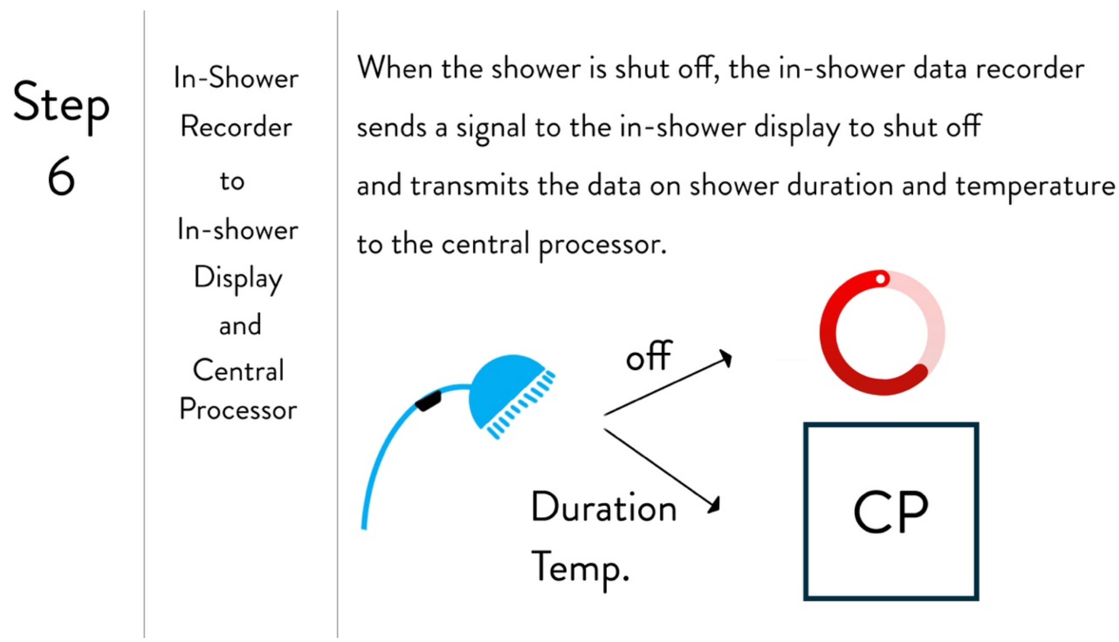

Figure 26 System Step 6

In step seven (below), the central processor combines all the data collected during the shower event, which includes the data entered manually at setup by the user and the data collected by the in-shower data collector. With these data, the central processor calculates the eight variables, which are sent to the mobile application (e.g. Total water volume used, cost per minute of showering, average shower length in minutes and seconds, projected cost savings, current cost savings, the cost of a single shower in dollars, the goal shower time, and the single shower total elapsed time).

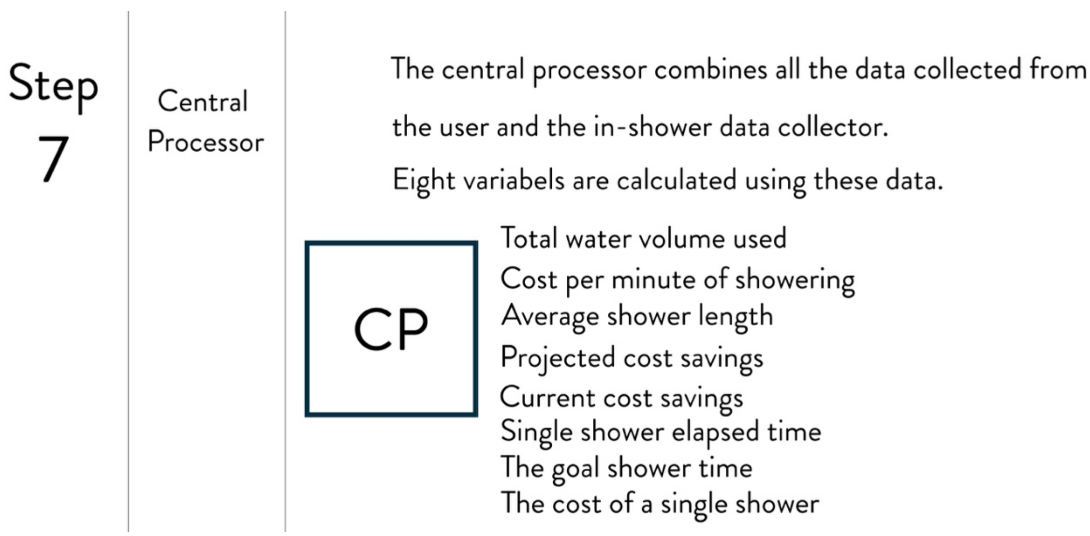

Figure 27 System Step 7

In step eight (below), the data collected and calculated in the central processor are sent to the mobile application to be displayed.

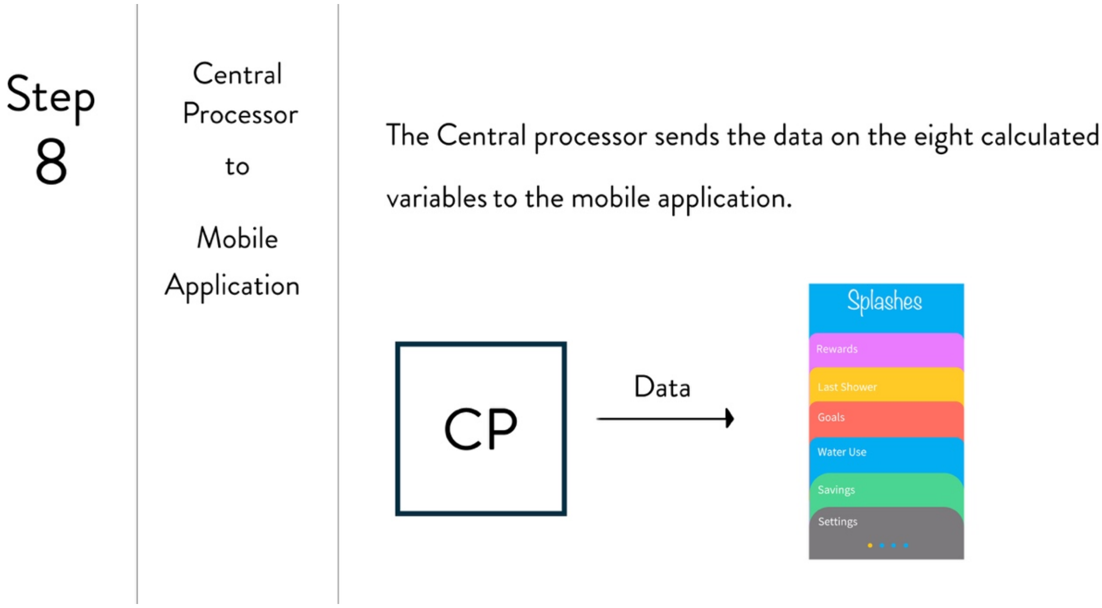

Figure 28 System Step 8

In step nine (below), the mobile application will compare the goal time for a single shower event with the total time of the shower which most recently ended. If the actual shower time is less than or equal to the current goal shower time, then the mobile application sends a push notification to the user on their smartphone. This notification contains the time elapsed during the last shower and the projected savings for the year.

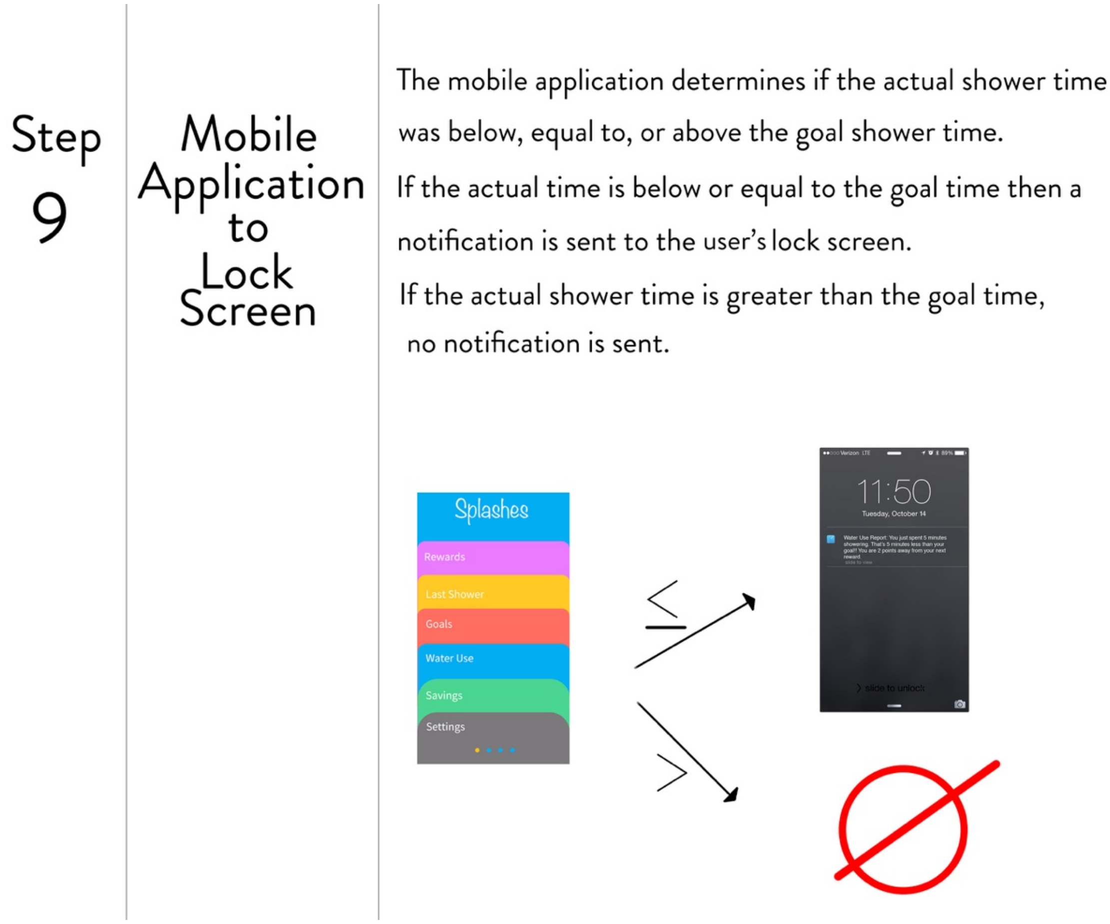

Figure 29 System Step 9

Finally, step ten (below) will display the information calculated in the central processor to the user in the mobile application. The user will be able to explore data covering all aspects of his/her shower activity. The user can view data about his/her last shower, goals, water use, and savings in this part of the application.

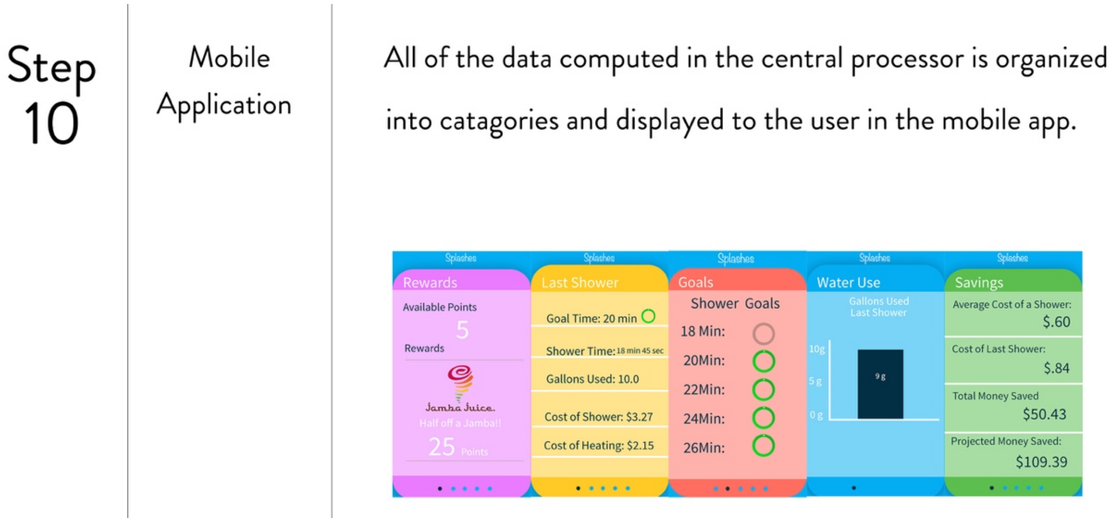

Figure 30 System Step 10

How the User Interacts with the System

In the section above, we detailed how the system's components work independent of the user. In the present section, we will discuss how the user interacts with the components of the system. The user will regularly interact with two components of the system—the in-shower display, and the mobile application—in a series of steps.

First, once the hardware of the system has been installed, the user will input data about their showerhead flow rates and geographic location into the mobile application (depicted in step one below).

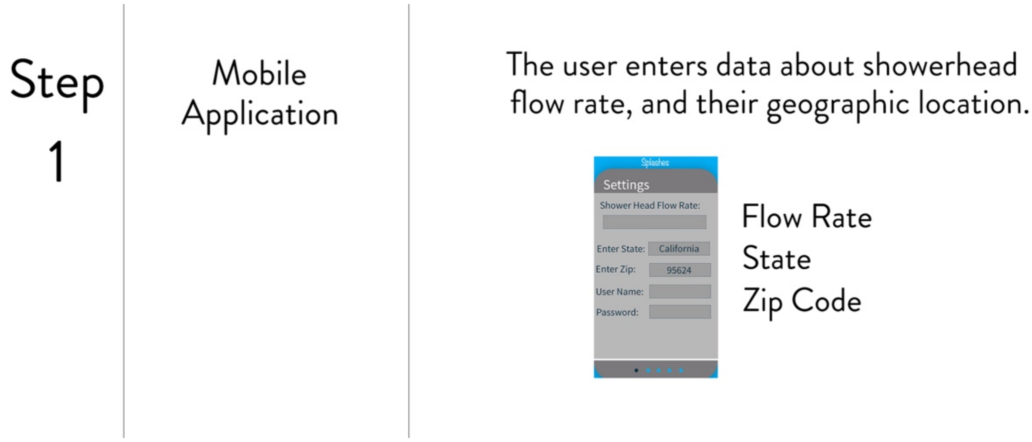

Figure 31 User Step 1

For the first week, the baseline collection period, the users will receive no information about their shower habits. During this period, the system is observing and calculating the "average use" habits of the user.

Following the first week, when the user turns on the shower, the in-shower display begins to fill its circular graphic in the blue phase (depicted in step two below). The filling of the blue phase will indicate to the user that s/he should continue showering.

Figure 32 User Step 2

When the elapsed time showering comes to a minute before the goal stop time, the icon depicting the user's long-term savings goal will appear and the graphic will begin to fill the green phase (depicted in step three below).

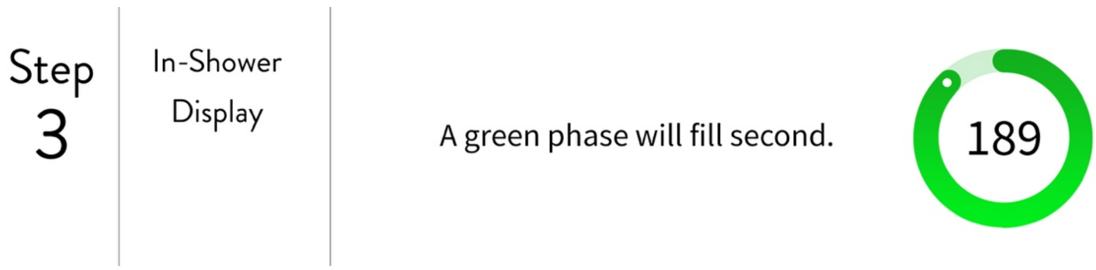

Figure 33 User Step 3

The green phase will indicate to the user that they are on track to reach their goal. The green section also indicates to the user when they should begin ending their shower. Points will continue to be accumulated during this phase in the middle of the graphic.

After this period, the goal stopping time will have passed and the graphic will begin filling red (depicted in step four above). This section will indicate to the user when they have passed the goal stopping time and they should stop their shower.

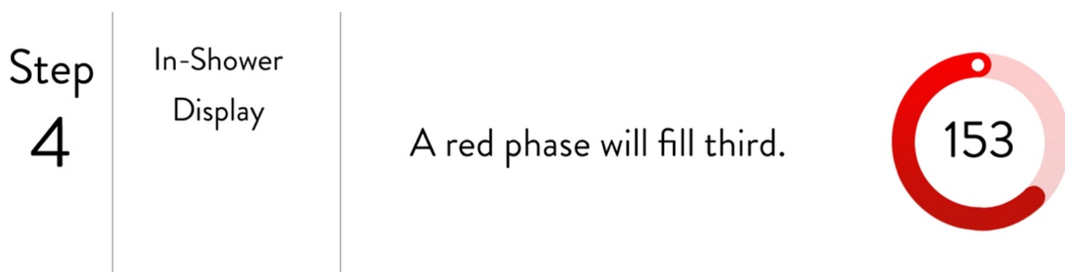

Figure 34 User Step 4

When the user stops their shower on or before their goal stopping time, the user will be sent a mobile application notification (depicted in step five below). This notification will tell the user the duration of their most recent shower and what the user's projected savings are for the year. If the user is over the goal time, they will receive no notification.

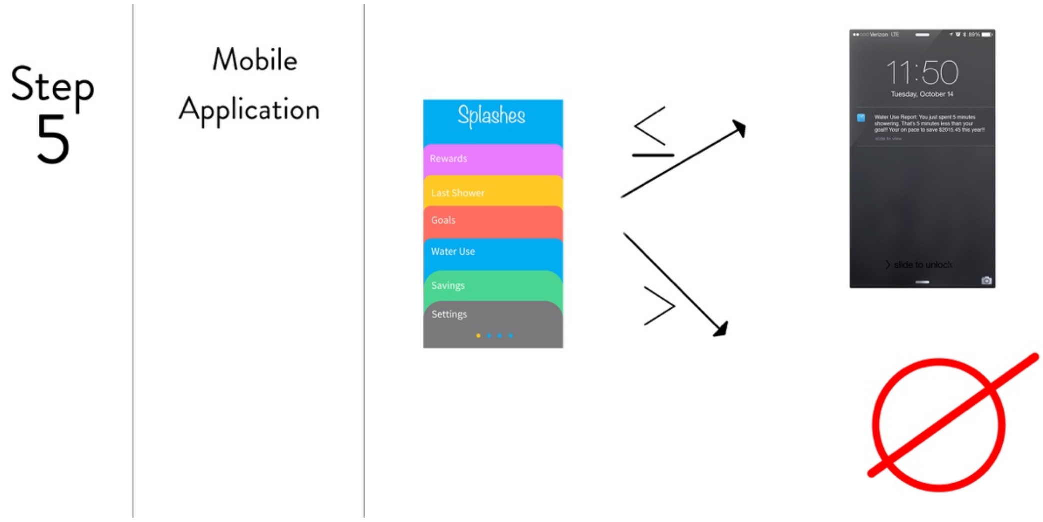

Figure 35 User Step 5

At this point, the system has completed its processes. The user will then be able to use the mobile application to explore the data regarding their shower, organized into five different categories (depicted in step six below):

1. Information on points and available rewards.
2. Data from the user's last shower.
3. Data on the user's goals.
4. Data on water use.
5. Data on monetary savings.

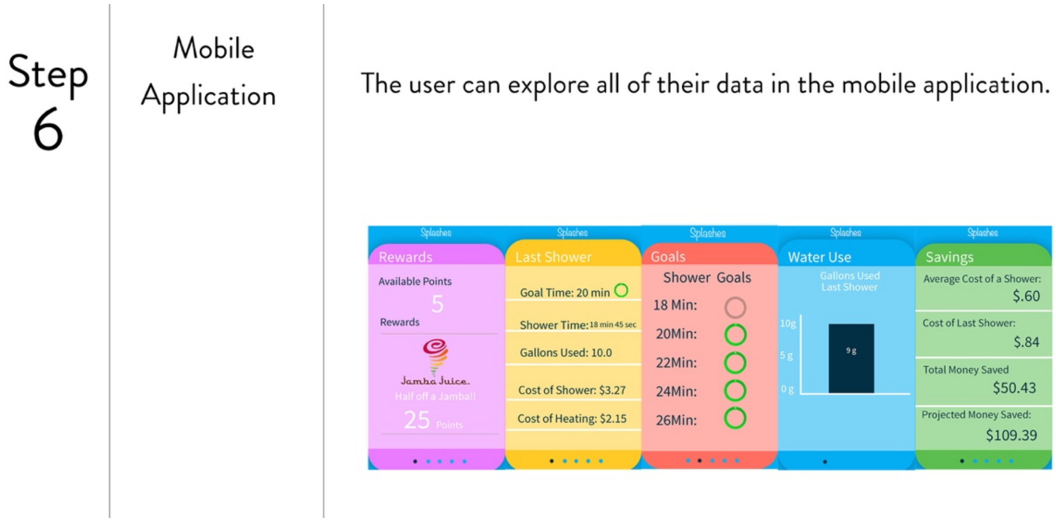

Figure 36 User Step 6

After the completion of this process, the system will not notify or interact with the user until the users begin their next shower.

Summary

With Splashes, we created a system that takes advantage of negative feedback loops, positive rewards, and response cost, to motivate users to reduce their water use while showering. We provided an outline for a mobile application that interacts with physical components to achieve the goal of using feedback about use to reduce and control the actual water use of users within the system. Each component of the system plays a crucial role in controlling and displaying relevant information, which is delivered to the user.

CHAPTER IV

SUMMARY, CONCLUSION AND FUTURE DIRECTIONS

Summary

In our review of the literature in Chapter II, we covered the implications of various fields of psychology, which will work concordantly to support behavioral change within the system. Two major fields of importance can be identified in our review: the Behavioral and Control theories. We summarized these two fields separately, and finally reconciled their similarities, differences, and implications. We then described in Chapter III the design and function of the system's components, along with identifying where elements from the literature will be implemented. In the present chapter, we will end with a summary of the review of the literature, description of the system and a discussion of future directions for the project.

Conclusion

In the first chapter, we introduced the project and summarized its relevance and importance in times of drought and times of abundance. In the second chapter, we outlined literature that is the foundation for the functioning of our system. In the first section of our review of the literature, we showed how various theories and practices of behaviorism would work together to change a participant's behavior. We explained research on operant conditioning and how, when a participant's behavior is reinforced properly, it will become more likely to occur in the future. Then, we showed how a differential reinforcement schedule of low rates could be used to slowly reduce the occurrence or length of a behavior by incrementally reducing the number of behaviors that would be reinforced. Finally, we detailed how rewards and response cost could be implemented within a token economy that distributes points to effectively motivate participants to continue with a behavioral program.

In the second section of our review, we explained two different applications of control theory: Mechanical Control Theory and Perceptual Control Theory. We briefly discussed how a Mechanical Control system is developed and what its components are. We then went into detail on Perceptual Control Theory, explaining the ways in which people use their behaviors to control their perception of their environment.

In the final section of our literature review, we discussed the differences between Operant Conditioning and Perceptual Control Theory. We then attempted to reconcile these differences and show how the seemingly competing theories are simply interpretations from different perspectives of the same findings. We explained how we believe these two theories should begin to work together to compile a more holistic representation of how humans behave and process.

In the third chapter, we combined all of the theories and practices from literature to describe a coherent system for behavioral change in a shower setting. Each component of the system is specifically designed with literature to support its functions. Token rewards, in the form of points, are distributed for achieving goal shower times, which are continually decreasing in length. The distributed points are then redeemable for primary rewards of the user's choosing. The in-shower representation of the elapsed time showering will help the user perceive the time they spend showering and compare it to their goal time, so they may use this visual information to determine the correct behavior to control the total time of their shower. The in-shower graphic also provides the user information on rewards and punishments for completing or not completing the user's shower goals.

Current Status of Development and Future Direction

This paper presents the theoretical, practical, and functional development of the system. However, beyond simple wireframes and mockups, no physical components have been actually developed. In order to realize the development of the whole system, it will be necessary to do much more development of both hardware and software.

The first step in building a full-fledged system as detailed above will be to prototype and build the necessary hardware components. Hardware components that need development include the in-shower data recorder and in-shower display. The in-shower data recorder should be a piece of hardware that is able to record and transmit elapsed time showering and the temperature of the shower water. The in-shower display should be a waterproof LCD screen capable of receiving and displaying real time data about a shower. These components have only been theoretically described and must be built in order to have a functioning product. The completion of the hardware components will require us to work with hardware and product designers to prepare and design a consumer product that meets our required specifications.

The second step in completing the system as it is described above will be to code a mobile phone application. The mobile application should be capable of acting as the central processor—collecting, calculating, and displaying pertinent information about the user's showers. The mobile application will also serve to set the user's goals and notify the user of goal completion and progress. To complete the mobile application development, it will be necessary to enlist a team of software developers to put together a refined and market-ready application.

The hardware requirements of the system we have presented pose some difficulties for the system's development. Hardware is often difficult to prototype and manufacture. Software, on the other hand, which is designed to take advantage of existing hardware, can allow for richer features, which are even cheaper to develop. As we develop the system further, we will look to take advantage of developments in consumer electronics. Mobile devices such as smartphones and wearable devices, which feature some of the most innovative and developed hardware available, present great opportunities for further development of our system.

Moving forward, we plan to take advantage of developments in current consumer electronics hardware by making software which can accomplish the same functions as some of the hardware we had planned on developing. An example of this will be to replace the planned in-shower display with a mobile application built to work on a waterproof wearable device with a color LCD display. A waterproof wearable device would fulfill the necessary functions of the in-shower display. In addition to being able to display the in-shower graphic and points in real-time, a mobile application would allow us to add more feedback features such as haptic feedback, which can notify users of the status of their shower with the physical feedback of taps on the wrist. Building an application for a wearable device would save us the costly design and production of a new in-shower waterproof LCD screen.

The second place where we would replace a feature from the hardware with software would be the starting of the shower timer. Instead of having the in-shower data recorder start and stop the timer and graphic, we could use our mobile application and the microphone to achieve the same feature. By using the microphone on the smartphone, the application could listen for the sound of running water to start, and then start the shower timer and signal the graphic to fill. When the phone's microphone no longer detects the sound of a running shower, the shower time and thus the filling of the graphic, would stop.

By making these adjustments to our development plan, we would be very close to eliminating all need for the development of hardware. The only feature that would hinge on the development of hardware, if we were to replace both the in-shower display and in-shower sensor with software, would be the ability to sense the temperature of the water. However, the hardware device to sense water temperature would be the simplest to develop.

On the other hand, it is important to note that the features, which are dependent on water temperature data, are not necessary for the basic functions of our system. Thus, we could build a basic version of our application that does not require the temperature data, offering later a more advanced version that utilizes data on shower temperature. The basic version would cost less for the consumer since the consumer does not need to buy any hardware. Consumers would simply need to download our app.

We believe there is great potential for this system and its ability to help consumers change their own behavior and lives. The principles used to develop the rationale for the system's features are transferable to other areas of consumer behavior. Beyond developing this system, we will look to develop similar systems to help consumers take control of their lives

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