Exploring Non-pragmatic Visualizations for A Residential Water Conservation Game

by

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Abstract

Residential water conservation is an ongoing challenge in which eco-feedback techniques can play a significant role. To promote water conservation among residents, especially children, we propose an engaging and informative approach that combines pragmatic and non-pragmatic visualizations, with gamification techniques. We target school-age children because they are beginning to learn about water conservation at school, and they have the influence on their parents at home. To explore the effectiveness of this approach, we conducted two user studies. We conclude that the non-pragmatic visualization is a promising approach in affecting users’ water conservation attitudes. Combining both pragmatic and non-pragmatic visualizations can bring more possibilities to the eco-feedback design. Also, the gamification strategies prove to be effective in motivating water-wise actions and promoting learning. Moreover, we also extract the insight for future design, including the aspects of aesthetic attributes of visualizations, the ambience requirement, and collaborative decision making.

Keywords: Residential water conservation; eco-feedback; pragmatic visualization; non-pragmatic visualization; gamification; sustainable HCI
Dedication

To my parents,

for instilling the importance of an incessant inquiry for knowledge.

And to my husband,

for inspiring me and supporting me every step of the way.
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Lastly, I would like to show my gratitude to my family for all their love and encouragement. For my parents who raised me with a love of science and supported me in all my pursuits. And most of all for my loving, supportive, encouraging, and patient husband Jianyu Fan whose faithful support during my research experience is so appreciated. Thank you.
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## List of Acronyms

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<th>CRD</th>
<th>Cued-Recall Debrief</th>
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<tbody>
<tr>
<td>HCI</td>
<td>Human Computer Interaction</td>
</tr>
<tr>
<td>Infographics</td>
<td>Information Graphics</td>
</tr>
<tr>
<td>Infovis</td>
<td>Information Visualization</td>
</tr>
<tr>
<td>PICS</td>
<td>Pacific Institute for Climate Solutions</td>
</tr>
<tr>
<td>UI</td>
<td>User Interface</td>
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## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Display</td>
<td>“Ambient displays are abstract and aesthetic peripheral displays portraying non-critical information on the periphery of a user’s attention.” (Mankoff, Dey, Hsieh, Kientz, Lederer, &amp; Ames, 2003)</td>
</tr>
<tr>
<td>Calm Technology</td>
<td>A type of information technology where the interaction between the technology and its user is designed to occur in the user’s periphery rather than constantly at the center of attention. “Calm technology engages both the center and the periphery of our attention, and in fact moves back and forth between the two.” (Weiser &amp; Brown, 1997)</td>
</tr>
<tr>
<td>Residential resource use</td>
<td>The use of electrical energy, natural gas, and water in the home in support of daily activities.</td>
</tr>
<tr>
<td>Sustainability</td>
<td>A term used in this context to signify intergenerational equity and indefinite coexistence regarding our use and management of environmental resources. “The present generation meeting its needs without prejudicing the ability of future generations meeting theirs.” (World Commission on Environment and Development, 1987)</td>
</tr>
<tr>
<td>Ubiquitous Computing</td>
<td>Wikipedia defined Ubiquitous computing (or &quot;ubicomp&quot;) as a concept in software engineering and computer science where computing is made to appear anytime and everywhere. In contrast to desktop computing, ubiquitous computing can occur using any device, in any location, and in any format.</td>
</tr>
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1. Introduction

Water is a vital resource to people’s livelihoods and health. Due to the increasing population, fast urbanization, and higher living standards, the tremendous growth of demand for clean water exceeds the limitation of natural replacement rate of the ecosystem. Moreover, the consequences of industry expansion and climate change will continue to impact negatively on global usable water sources. The clean water scarcity has been the global concern for the modern era, and half a billion people around the world face severe water scarcity throughout the whole year (Hoekstra, 2016). Thus, rather than increasing freshwater production to meet the current demand, better water conservation efforts must be made to avert water crises shortly.

Water consumption can be curbed by both large-scale regulatory and individual conservation efforts in the home and community. The government plans primarily target water conservation and protection from a macroscopic view. In Canada, the government has promoted the Canada Water Act since 1985. The British Columbia government has also made necessary steps in the modernization of provincial water law, which include the Living Water Smart Act, B.C.’s Water Plan (BC Provincial Government, 2008), and the B.C.’s Water Sustainability Act (BC Provincial Government, 2016). Despite such policies, Canada consistently ranks among the world’s highest users of water, with per capita water use well above that of European and many other industrialized nations (OECD Factbook, 2008). The second method which involves domestic water conservation relates more directly to one’s daily life. At home, people use clean water in drinking, cooking, garden irrigating, clothes washing, shower, toilet flushing, and many other aspects. They may use it economically or wastefully, consciously or blissfully unaware of how and where it is being consumed. To maintain greater water sustainability in urban centuries, the need for implementing strategies that result in motivating individual behaviour in water conservation becomes increasingly apparent.
The water conservation strategies should specifically focus on our future generations -- school-age children for several reasons. Firstly, knowledge of water resource and conservation is becoming a part of the science curriculum from as early as Grade 2 (Abbotsford Mission Water & Sewer Commission, 2013; BC Ministry of Education, 2016). In addition, from the perspective of home education, children can perform as the intermediary agent in promoting environmental sustainability, whose awareness and behavioural changes have a significant influence on the adults in their homes (Mandel, 2013).

Scholars and practitioners across Canada have focused on water metering as a central strategic element and a top municipal priority to conserve household water in the long term (Renzetti 2009, Brandes et al. 2010, BCWWA 2012). Environment Canada reported the decrease of water use after the conducting of water metering policy. Compared to 52% in 1991, 58% of Canadian households were equipped with water meters in 2011. Over the same period, average daily water use dropped by 27% (Environment Canada, 2014). However, the BC Municipal Water Survey 2016 (Water Planning Lab, 2016) conducted a similar survey in the province, which demonstrated that there is not a significant difference in water consumption.

Noted by these different results of surveys, water metering may introduce new opportunities to inform and guide water conservation to some degree. However, it could not always succeed. It collects information on water consumption and conveys this information to the residents, but a gap exists between the numerous information of water consumption and the residents’ awareness of changing behaviours towards domestic water conservation. To bridge this gap, consumption information must be coupled with technologies that can deliver the right information at the right time efficiently and successfully, to encourage residents to make wise decisions on water use.

1.1. The Problem

Our research has been driven by the constellation of questions: “What is the right information to present to the residential consumers?” “How to deliver the water information?” and “Where would be the appropriate places to present such information?”. 
To answer these questions, we spare much efforts in reviewing relevant literature, surveying existing technologies and, in addition, engaging in designing, developing and evaluating new techniques.

**What is the right information to present to the residential consumers?**

Making residents aware of resource consumption information should be the first step to motivate behavioural changes in conservation. Most people usually have no helpful means in judging their water use situation other than waiting for the monthly (or bimonthly) water bills or reading their water meter (Figure 1-1(b)). Even then, they can only obtain aggregate information of total usage, and the data is expressed in units that many homeowners do not intuitively grasp. Yet, it reveals no information about which rooms, appliances or activities comprise the most significant usage, or which members of the household are responsible for peaks of consumption. Lacking this detailed information, residents are not able to economize and judge the relative merits of individual conservation practices (Dennis, 1990). Kempton and Layne (1994) drew the analogy of not receiving an itemized bill at checkout to depict the need of more detailed information on resources we consume in our lives (Figure 1-1(a)).

While most residential water resource use is invisible, running water from tap is one of the exceptions. It explains why traditional conservation campaigns regularly focused on this context. Other points of invisible water consumption -- toilet flushing, washing machine, and leak water also should be presented in to reflect the comprehensive water consumption situation. Therefore, the aggregate information of total water consumption alone is inadequate to drive residents in making informed decisions. The disaggregated usage data is actually in demand to provide detailed usage information at the level of rooms, individual water fixtures, even water consumption activities.
How to deliver the water information?

Historically, media campaigns, monetary incentives, advertising, training and promotional products all are important components of an effective resource conservation program. Compared with these strategies, the feedback has proved to be one of the most effective one in greatly connecting the information, behaviours and environmental impact (Geller, 1982). In the domain of environmental impact, we call it eco-feedback technology (see Chapter 2.2.4). Feedback appears to work because of its both informational and motivational properties (Aitken et al., 1994). Investigations over 30 years revealed that feedback on electricity consumption can significantly reduce consumption, depending on the specificity, frequency and duration.

Not only the presence of feedback, but also how that feedback is presented are essential in changing residents’ behaviour. Advance of technology enables a variety of computerized means such as information visualizations to feed related information back. Currently, commercially available tools include inlet point device and online information visualization dashboard such as WaterOn™ (Figure 1-2) water monitor and Lotik™ (Figure 1-3). To different degrees, they offer precise quantitative analysis of water expenditures, historical and predictive charting facilities, cost breakdowns, and performance tracking in a user-friendly visual screen. The problem is that these traditional tools do not provide the feedback on what exact measures can be implemented to conserve water and lower the environmental impact. Furthermore, they
sometimes fall short in sparking residential consumers’ curiosity motivating their engagement in the feedback.

Other types of eco-feedback should create a rich space of opportunities in engaging residents and fostering their awareness in unexpected and novel ways. They should be personalized, interactive, increasingly motivating, and tied to specific activities (e.g., watering the garden, taking a shower, washing dishes). For example, ambient and artistic approaches present a promising possibility of sustaining consumers’ attention with their appealing elements and supporting immediate awareness of the information with low visual complexity (Rogers, 2011).

Figure 1-2 Dashboard of WaterOn™.
Figure 1-3  Sample screenshot for Lotik™.

Where would be the appropriate places to present the information?

Depending on the content and function, water information can be displayed either publicly or privately. As one aspect of personal information, people would prefer to have their residential water consumption shown in their home privately or through the website with the user authentication (Sun, 2014). In the domestic context, a multitude of constraints should be considered into the design process. For example, we should consider that how the factors of placement, visibility, aesthetic choices, and interactive elements of the feedback technology can integrate coherently in the home (Roger, 2011).
Besides, water feedback can also be designed for educational purposes, which should be distributed publicly, and proper sharing the consumption information or feedback among friends or families might lead to positive competitions towards water conservation (Darby, 2010).

Much research has taken efforts into the design and evaluation of feedback on environmentally relevant behaviour, especially most of them on energy consumption. Our thesis aims to designing and developing eco-feedback technologies to link residents’ activities, awareness and behaviour change together towards water conservation. In general, the compound problems here are: What granular level of water consumption information can we present? How could we implement or design novel forms of engaging and actionable feedback? Where would be the appropriate places to present the information? These problems comprise of the focus of our research in this thesis.

1.2. Our Approach

To address the problems discussed above, we firstly decompose the primary and nuclear problem of “How water information should be delivered?” into two main challenges: “How to convey consumption information to users and increase their awareness?” and “How to enable and induce residents to change their consumption behaviours?” (Micheel, 2015). The first challenge is often addressed by visualizing consumption information. We employed one of the non-pragmatic visualizations -- the artistic visualization to maintain long-term interest, which is more attractive and engaging than the pragmatic one and integrates appropriately into the home environment. Also, we applied gamification to raise their awareness, and further encourage them to adopt more sustainable lifestyles upon presented consumption information and tips.

1.2.1. Why Non-pragmatic Visualization?

Kosara (2007) defined the opposite side of pragmatic visualization in the gamut of data-based visualization as artistic visualization, which transforms data in visible and interesting ways rather than showing data readily readable. In our research, we
implemented artistic visualization as the feedback of water usage at home based on two advantages over the pragmatic one. First, artistic visualization applies various depictive and narrative-related forms of representation to communicate a concern about the underlying information (Kosara, 2007). Our research was to design an educational tool to make people, especially children, aware of water consumption situation. The artistic display could arouse their interest and curiosity, and furthermore, enhance their engagement. Second, the property of ambient enables the visualization to remain periphery to people’s attention and integrate well with the home environment (Ljungblad, Skog, & Holmquist, 2004). They can gain the at-a-glance awareness of the information with less effort to notice and less knowledge to interpret the data. Taken together, we regard the non-pragmatic visualization as a great potential tool in attracting people to be engaged more with its high aesthetic value, enabling at-a-glance awareness, and enhancing the connection between residential water consumption and the daily water consumption activities at home explicitly.

1.2.2. Why Gamification?

In principle, the feedback alone could drive increased awareness on water usage, but the motivations for behaviour change are mostly hidden. Gamification, the use of game design techniques and game mechanics to enhance traditional applications and drive behaviours of its users, has emerged over recent years, and has proved to be a useful tool to tackle this problem. It can be defined broadly as “The use of game elements and game-design techniques in non-game contexts (Werbach & Hunter 2012)” or more specifically, as “The use of game mechanics and experience design to digitally engage and motivate people to achieve their goals (Burke 2014)”. Game-like elements could trigger specific behaviour and powerful motivation to complete tasks. Different game elements have different effects on people depending on their user type traits and what motivate them. As Risvad argues, two game mechanics appear more effective than others -- points and progression. Points or player scores can cater to people’s extrinsic motivation whereas progression satisfies people’s intrinsic motivation (Risvad, 2015). Generally, gamification with its game-like elements could be a promising approach in inducing increasingly awareness and sustaining persistent behaviour changes.
1.2.3. **Research Overview**

In our research, we aim to design an eco-feedback approach that combines pragmatic and non-pragmatic visualizations with gamification techniques, and we are interested in exploring whether and how this can encourage and sustain residents’ learning in water conservation. We target school-age children as users of our research. This is the key factor in the decision to make a game and to explore visualizations that may appeal to their aesthetic and media sensibilities rather than the traditional pragmatic visualizations that are typically used by adults. Through this research, we also hope to contribute to concluding design insight for developing more novel methods for a residential water-conservation feedback system in the future.

We design a web game that can simulate a real-life environment and real water usage, assisted with both pragmatic bar chart visualization and non-pragmatic artistic visualization to show information. Then, we complete two rounds of exploratory user studies to answer our research questions. Driven by our research questions, we ask for both numeric analysis and contextual factors provided by the players; thus, we employ a mixed method. The first user study was with individual children. Based on findings of the first user study, we modified the research focus from exploring how the single visualization can affect users’ awareness of water conservation to how these visualizations could be used together. And the process of the second user study was modified accordingly. It was held with groups of children in the form of workshops.

This work contributes to developing novel water feedback from three aspects. First, we demonstrate that a non-pragmatic visualization with a reward mechanism is effective in affecting children’s understanding water and encouraging conservation with or in place of the pragmatic visualization. It attracts the users’ attention continuously with aesthetic attributes and supports immediate understanding. Second, our findings prove that the game itself serves as a useful platform to elicit where people do not understand or remember about water consumption. Gamification elements, including player scores, badges, and conservation tips, demonstrate their potential to engage people in changing their behaviour toward water conservation. Moreover, out of an extensive list of design attributes related to eco-feedback technology (Rodgers, 2011;
1.3. Methodology

Our studies focus on studying user experience of prototype designs of residential water consumption feedback, which involves all statistics, interviews and observations. Therefore, we take a design-oriented research perspective and utilized mixed methods throughout our research process.

Design-oriented research and research-oriented design exist as two poles on a spectrum in the Human-Computer Interaction (HCI) field. The former one has an emphasis on research. “The knowledge that comes from studying the designed artifact in use or from the process of bringing the product into being should be seen as the primary contribution—the ‘result’—while the artifact that has been developed becomes more of a means than an end (Fallman, 2007)”. In contrast, research-oriented design has an emphasis on design. The creation of products is the primary outcome of the efforts undertaken, while research is mainly used to facilitate the design (Fallman, 2007).

This conceptualization has helped us to characterize our approach as design-oriented research and has influenced our selection of methods. Design-oriented research strives to explore possibilities outside of current paradigms, which could be style, technology, or economical boundaries (Fallman, 2007). In this context, we primarily seek to explore a new approach to residential water consumption feedback and undertaking design-oriented research enables us to explore the practical implications of a proposed design solution, and evaluate assumptions concerning how prototype designs will be used and understood.

We conducted our research through two user studies. User studies, which consider questions of understanding people, are the core of design-oriented research. As Fallman (2007) argues that looking into and trying to grasp the complex interplay between people, technologies, and society and how this ‘now’ changes of a new artifact is as important as developing the technology. More specifically, user studies offer a scientifically sound method to evaluate visualization techniques. Kosara et al. (2003)
points out that, the importance of conducting user studies includes “to evaluate the strengths and weaknesses of different visualization techniques”, “to show that a new visualization technique is useful in a practical sense”, “to seek insight into why a particular technique is effective” and “to show that an abstract theory applies under certain practical conditions”.

In both user studies, we collected and analyzed both quantitative and qualitative data as evidence to reflect on the research questions encompassing the interaction of humans and technological systems. A diversity of data including both interviews and observation notes of participants, and statistical results of participants’ performance and questionnaires is required to answer whether the visualization and gamification affect residential water use. Mixed-methods, the blending of qualitative and quantitative approaches at many phases in the research process, could provide the most complete analysis of research problems than either approach alone (Creswell & Plano Clark, 2011). They seek to, “bring together the differing strengths and non-overlapping weaknesses of quantitative methods (large sample size, trends, generalization) with those of qualitative methods (small n, details, in-depth) (Creswell & Plano Clark, 2011).” According to these advantages, mixed methods are becoming more common within the fields of information visualization, human-computer interaction, and ubiquitous computing (Connolly et al., 2012).

1.4. Document Organization

This thesis is organized into 7 chapters:

Chapter 1: Introduction. It highlights the research problem and my motivation and states the methodological perspective guiding this research.

Chapter 2: Background. We reviewed literature to establish the theoretical background of our research in this chapter. It highlights four primary domains. First, to address the understanding of water consumption in the home, we survey the findings from residential consumer perception on water conservation and the studies on strategies to motivate sustainable behaviours. Second, the review of the broader research field of interactive research on Sustainable HCI situates the genesis of our
research discussed within this rapidly evolving domain. Third, with the review of existing work, we explore the ambient and artistic approaches which focus on design requirements and evaluation methods. Finally, we examine the essence of gamification, including its key concepts, psychological supports and applications in the area of water conservation and support of sustainable living.

Chapter 3: Research Design. We firstly investigate current available water feedback technologies, and how their drawbacks that have informed us to explore a novel and viable feedback system in water consumption. Then, our research goals in this thesis are addressed. Furthermore, we focus on the introduction of our research questions and the description of our research approaches including game prototype design and two-staged studies.

Chapter 4: Water Conservation Game Design. The main purpose of the design is to explore the potential of realistically representative simulations, gamification techniques and the non-pragmatic visualizations as feedback in motivating awareness, decision-making and positive actions regarding the water use at home. This chapter describes the design guidelines, approaches and frameworks of our water conservation game. Special attention is given to the design and implementation of gamification elements and both pragmatic and non-pragmatic visualizations as the residential water use feedback.

Chapter 5 & Chapter 6: User studies. These two chapters cover detailed descriptions of planning and execution of our user studies, both with individuals in public space and in workshops within a learning context. The results of the study are presented in both quantitative and qualitative forms, together with visualizations of the collected data to enhance clarity and draw attention to key results. Also, the implications of these preliminary results are discussed.

Finally, Chapter 7: Contributions and Future Work. Revisiting the research questions, we summarize the findings and contributions of this research. Implications are addressed to detail the contributions that this research makes towards the design of residential water use feedback. In addition, opportunities and open questions to future work are outlined.
2. Background

In this chapter, we investigate existing approaches and projects on Environmental Sustainability, specifically on water conservation, and establish the theoretical background to our research. Four main areas are addressed in this literature review. We first provide background on water as a resource, and explore existing strategies for promoting residential water conservation, with particular attention to the effective feedback. Second, to expand our knowledge in the related area, we conduct a survey of recent interactive research projects on sustainability. These works help us to situate our research into the broader research field of Sustainable HCI and support our research with the theoretical background of the behaviour motivation. Furthermore, we review various research works on ambient and artistic approaches covering those in casual information visualization and informative art techniques. Design requirements for such techniques and discussion of the challenges of evaluation are addressed with examples of existing work. Finally, the definition of gamification techniques is introduced. The psychological theory and successful applications in various domains are explored to support why gamification can be an effective approach in attracting residents and sustain sustainable behaviours.

2.1. Understanding Water Consumption in the Home

This section elaborates on the background on water consumption and conservation, in general, to better contextualize our research. Findings of residential consumer perceptions on water consumption and conservation are addressed. It is critically important for the eco-feedback designers or researchers to understand users’ opinions on the issue. We also argue for the importance of conservation-related research around residential water usage, and reviewed water management programs and strategies, especially feedback strategies. The implications of this literature
demonstrate the promise of eco-feedback in reducing water usage as well as open opportunities.

2.1.1. **Perceptions of Residential Water Use**

Increased water demand from the growing population and the concentration of populations in urban areas are exacerbating the issue of water scarcity. For an urban water provider, residential demand often accounts for the greatest proportion of water use and always involves more residential customers than any other customer class for any given utility. A per capita residential water use of 320 liters per day (L/day) in Canada (Statistics Canada, 2010) is much larger than the reasonable goal of 43-45 gallons (around 163-170 liters) for a water-efficient household calculated by scientists (Vickers, 2001). Unfortunately, most people are typically lack of awareness of their water consumption situations and environmental consequences caused by their consumption.

To finally achieve the goal of fostering residents to take actions on water conservation, it is important to learn about their opinions first and build their awareness on water consumption and conservation accordingly.

The Arizona Municipal Water Users Association (AMWUA) with BBC Research & Consulting conducted a survey with 1,400 single-family homes in 2006 (BBC Research and Consulting, 2007). The study was designed to “gauge current awareness” of the water conservation, attitudes toward Use It Wisely Campaign and other programs, and expected water use behaviours. Additionally, the relationship between such awareness and “conservation attitudes”, as well as the relationship between “conservation attitudes” and actual water use patterns were explored. Findings from the studies are summarized below (Table 2-1):
In summary, as reflected in Table 2-1, a gap exists between residential consumer perceptions and their actual knowledge of water use. The information campaign for water conservation raised awareness and increased knowledge, but its effect on practices was insignificant. Another study of a three-year water conservation campaign in the Kingdom of Jordan stated the similar findings that the campaign succeeded in heightening knowledge of water and slightly affecting attitudes, however failed to impact behaviour (Abu-Taleb & Murad, 1999). These studies provide insight into developing more effective and carefully implemented water conservation strategies. The strategies should seek to inform people the knowledge of water, raise their awareness of conservation and ultimately encourage the sustainable behaviour.

### 2.1.2. Strategies for Motivating Water Conservation

To curb excessive water use, a number of social and environmental studies have explored strategies and campaigns that provide water consumption information and education to residents. In this section, we introduced different types of strategies with the focus on their advantages and disadvantages within the context of eco-feedback. We also explored some water feedback related work. Finally, the methods and criteria for evaluating these strategies and feedback are addressed.

#### Strategies Types

Intervention strategies for water conservation usually are split between pricing and non-pricing strategies.Traditionally, eco-feedback would be categorized into the
latter one, but it sometimes intersects with the former category for providing cost information. We discuss both strategies in this section.

Water pricing specifically refers to using market instruments to control demand, including economic incentives and disincentives. Water rate structures have been developed to target conservation such as excessive use rates, seasonal rates and marginal cost rates (Kenney et al., 2008; Brookshire et al., 2002; Vickers, 2001). The study undertaken by Glennon (2009) found that increasing water price can affect single-family residential water use consume less water. However, there are three challenges with pricing strategies: (1) many individuals cannot understand their rate structure clearly and they don’t know which price signals in the water bill they actually respond to (Jordan, 1999); (2) real-time feedback of current consumption and rate are not available to most residents; (3) in order to implement any of the rate structures, water use must be measured with water metering while most multifamily dwelling units are not metered in Canada.

Due to equity concerns, legal limitations and a host of other reasons, water utilities are frequently reluctant to rely completely on price to control for demand (Kenney et al., 2008). Thus, some non-pricing strategies are often implemented to reduce consumption, which is generally grouped into three types: educational, legislative, and technological.

Via school visits, residential audits, workshops or the use of other media, educational programs have great potential in achieving short-term water conservation (Michelsen et al., 1999; Syme et al., 2000). Eco-feedback presents its educational potential by providing “tips” or educational materials explicitly in the display. Such active feedback could be personalized to consumption patterns of residents which are usually latent and inaccessible.

Legislation classified into mandatory and voluntary restrictions can be used to mandate new fixture/appliance efficiency measures. The literature is consistent in showing significant (sometimes 30% or more) savings from mandatory restrictions; however, findings from voluntary restrictions are much more variable (Kenney, 2008). Although there isn’t a traditional link between the eco-feedback and legislation, depending on the great success of eco-feedback system, it is not impossible to imagine
that the consumer-oriented water eco-feedback become a mandatory part of the future building as odometers for vehicles.

Technological measures or retrofit programs have been successful in saving water, particularly in long-term, because they only require a one-time installation and no further efforts are needed for maintaining conservation (Vickers, 2001). For example, a low-flow toilet (1.6 gallons per flush), compared with a traditional model, considering the average lifespan as 20 years, could save around 71,000 gallons of water (Vickers, 2001). Certain legislation can assist to accelerate the adoption of such technologies. However, the main obstacle to promote such measures is that they require extra time, effort and investment on the part of the homeowner.

**Water Feedback**

There is little published research available on disaggregated water consumption data systems for residential use. Thus, we mainly paid special attention to either point-of-consumption water feedback systems or systems that present information of aggregate water usage.

The point-of-consumption feedback systems measure water usage directly at the individual fixture and provide immediate feedback about that usage via an ambient display. Most of these systems disproportionately focus on faucet and shower usage (Vickers, 2001). For example, as Figure 2-1(left) shows, UpStream, a custom-design orb display can light up in green, orange and red colors depending on how long a faucet or shower is used. Also, the LED graph embedded in the display reflects how much water this fixture used so far for the day (Kuznetsov & Paulos, 2010). Another feedback system is the Shower Calendar (Laschke et al., 2011). A projected display on a shower curtain shows usage amounts over time. The colors of the dots represent different people and larger dots mean less water usage during that shower (Figure 2-1(right)). Point-of-consumption feedback proves its potential in reducing usage at the installed fixture (Willis et al., 2010; Staake et al., 2011). However, the difficulty of promoting such feedback systems is that the systems have to be dependent on the physically joint sensors. In other words, to convey broader patterns of water use across fixtures, installation at each fixture is required. Pragmatic issues should be considered, including the change in the aesthetic of the fixture (Jeffrey & Geary, 2006) and increased
maintenance for the inserted sensors. Even water-based smart meters are introduced and proliferated recently in some fashion, they are still far less accessible to most households.

Figure 2-1  (left) UpStream Prototypes for Faucets and Showers (Kuznetsov & Paulos, 2010); (right) The Shower Calendar (Laschke et al., 2011).

In addition, the consumption information provided by existed systems is usually the aggregate information, which is not real-time rather than at intervals. IBM Research designed and implemented a pilot feedback program (Figure 2-2) using smart water meter, and their user study results proved the significant reduction of water usage compared to the control group (Naphade et al., 2011). But the system only presented water usage patterns and trends over time rather than cross fixtures. Froehlich (2011) used pragmatic visualizations such as standard bar charts (Figure 2-3), line charts or pie charts to visualize data at the granularity of individual fixture level or fixture category. His research identified that the data at fixture level can facilitate long-term sustainable behaviour in water domain (Froehlich, 2011).
Figure 2-2  The IBM Smarter City Water Pilot (Naphade et al., 2011).

Figure 2-3  The fixture Category View by gallons (Froehlich, 2011).
Evaluating Water-Based Eco-Feedback Systems

Environmental psychologists and HCI researchers are two groups focused on exploring different research purposes on water eco-feedback systems. The Environmental psychologists have more interests in studying how and in what ways simple water use feedback can change behaviour (e.g., Aitken et al., 1994; Willis et al., 2010) and they often conduct large scale of the field. However, deploying large scale of field is pretty rare to see in HCI community, whose focus is creating novel water feedback prototypes. HCI studies are often meant to evaluate the potential of the feedback system rather than scientifically demonstrate or prove the effectiveness of it. Indeed, a lot of literature shows that eco-feedback designs have been evaluated on merits such as evocativeness, engagement, understandability, and usability with several week pilot studies in demonstrating potential. For example, in visualization system, the pragmatic, ambient, aesthetic and ecological requirements (Rodgers, 2011) are typically evaluated rather than the effect of the system on behaviour. Even there are a few intervention-based studies (e.g., Kappel & Grechenig, 2009; Kuznetsov & Paulos, 2010; Laschke et al., 2011), they are usually in small scale and not always with rigorous methodology.

2.2. Investigating Sustainable HCI in Motivating Pro-environmental Behaviour

In this section, we will introduce an emerging area of research within Human-Computer Interaction (HCI) -- “sustainable HCI”, and situate our primary focus of feedback technologies within this field. Moreover, the theories in psychology and sociology about what motivates action and behaviour are reviewed, with a focus on what techniques may be applied to eco-feedback technology.

2.2.1. Sustainable HCI

Broadly speaking, sustainable HCI involves applying HCI methods, perspectives, and techniques to achieve sustainability by creating awareness, informing decisions, and promoting pro-environmental behaviour (Mankoff et al., 2007). The issues that Sustainable HCI are interested in including energy consumption (Rodgers, 2011; Sun,
2014), water usage (Froehlich, 2009; Kuznetsov & Paulos, 2010), air quality (Kuznetsov et al., 2011), and waste disposal practices (Paulos and Jenkins, 2006).

Goodman (2009) was the first to categorize the contributions in this field with her review of 120 papers on related to “nature”, “the environment” or “sustainability”. She (2009) identified “three environmental discourses in human-computer interaction (Goodman, 2009):” sustainable interaction design, re-visioning consumption and citizen sensing. Sustainable interaction design attempts to influence technology consumers to make informed environmental decisions through manufacturing, use and disposal practices, and designing persuasive technological interventions (Goodman, 2009). As opposed to developing technological interventions, re-visioning consumption is dedicated to exploring people’ beliefs, characterizing their attitudes and provoking critical reflection about issues of sustainability (Goodman, 2009). Finally, citizen sensing is primarily concerned with exploring the sensors in collecting environmental data to affect environmental changes (Goodman, 2009). Notably, in Goodman’s terms, our work is classified as sustainable interaction design. The primary goal of our research is to motivate better decision-making with effective feedback design.

More recently, to catalog the approaches that are being taken in sustainability HCI, DiSalvo et al. (2010) conducted a review of 83 related papers and identified five emergent, non-mutually exclusive genres. These genres include persuasive technology, ambient awareness, sustainable interaction design, formative user studies and pervasive & participatory sensing (DiSalvo, Sengers, & Brynjarsdóttir, 2010). This definition finely categorizes our own Sustainable HCI research pursuits, which fall under three of the five genres: persuasive technology, ambient awareness, and formative user studies.

The persuasive technology is “an interactive product designed to change attitudes or behaviours or both by making the desired outcome easier to achieve” (Fogg, 2002). Seven common elements are contained in persuasive technologies: tunneling, self-monitoring, surveillance, conditioning, reduction, suggestion and tailoring. It accounts for 45% of the entire corpus of sustainable HCI research of DiSalvo et al.’s review (DiSalvo, Sengers, & Brynjarsdóttir, 2010). Either strong persuasion (Bang et al., 2006) or passive persuasion (Gustafsson & Gyllensward, 2005) is used to persuade users to behave in a more sustainable way. The strong persuasion directly informs
people of the degree to which their behaviour is or is not sustainable. While the passive one implicitly provides users with information related to sustainability such as how consumption might affect the environment.

Ambient awareness systems can persuade residential consumers to behave sustainably with ambient displays (Mankoff et al., 2003) and calm computing (Weiser, 1991). Visualizations, physical artifacts and other intelligent intuitive interfaces that are embedded in all kinds of objects can recognize and respond to the presence of different individuals in a seamless, unobtrusive and often invisible way (IST Advisory Group, 2001). In encouraging the reduction of energy, such systems showed their advantages of requiring less cognitive load and achieving stronger persuasive effects over a numerical feedback (Maan, Merkus, Ham, & Midden, 2011). As DiSalvo et al. stated, ambient awareness accounts for 25% of the sustainable HCI research (DiSalvo, Sengers, & Brynjarsdóttir, 2010).

Formative user studies consist of large-scale quantitative studies (Hanks et al., 2008), qualitative interviews (Huang et al., 2009), and ethnography (Chetty et al., 2008) which can reflect users’ attitudes to the sustainable design.

2.2.2. Models of Behaviour Change

Numerous theoretical models of pro-environmental behaviours have been developed and studied to offer the insight into why people do act environmentally and provide direct implications for the design of eco-feedback technology.

Stern (1992) developed a high-level causal model of environmentally relevant behaviour, which helps to identify the variables determining every day and long-term consumption patterns (Stern, 1992). Variables at each level of causality in the model act as a possible influence on those listed below (Figure 2-4). For example, a resident’s general attitudes about energy use (level 5) will influence her resource-using behaviours (level 1). The model also indicated that feedback could cause influence to flow in the opposite direction through learning and self-justification (Stern, 1992). The impact of resource-saving behaviours can influence general attitudes and beliefs about resource use with self-justification: “I’ve made the effort to change all of my light bulbs to high-efficiency CFLs. I’m going to encourage my neighbors to do the same (Stern, 1992).”
Fogg built the Fogg Behaviour Model (Figure 2-5), in which behaviour is a product of three factors: motivation, ability and triggers (Fogg, 2009). All these factors must occur at the same time to change behaviour. Motivation especially refers to the intrinsic motivation; ability reflects whether the person can easily carry out the behaviour; triggers are to stimulate people to take the action with the increased likeness. He also pointed out that people with low motivation may perform a behaviour if the behaviour is simple enough (Fogg, 2009).

Another critical model to understand behaviour change in the context of resource use is the Transtheoretical model, also called Stages of Change model (He, Greenberg, & Huang, 2010). The authors emphasize that behaviour change occurs as a process in a series of stages, not an event. Specific feedback should be designed to motivate people to move from one stage to the next following the process of precontemplation, contemplation, preparation, action, and maintenance of the resulting change (Table 2-2). They note that the design of feedback of each stage should vary according to an individual's readiness, willingness, and ability to change (He, Greenberg, & Huang, 2010).
Within sustainability research, Emergent Dialogue Model is another model of behaviour change we reviewed (Robinson, 2004). This model suggests that user engagement should be seriously considered in the process of exploring the sustainable issues. Providing information alone is not sufficient to motivate behavioural change, and the feedback should also encourage people to generate their personal perspectives on the issue (Robinson, 2004).

Table 2-2 The Transtheoretical Model of behaviour change stages progress (He, Greenberg, & Huang, 2010).

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precontemplation</td>
<td>The individual may be unaware, uninformed, unwilling or discouraged to change the problem behaviour. They do not believe the negative aspects of the current behaviour outweigh the positive.</td>
</tr>
<tr>
<td>Contemplation</td>
<td>The individual acknowledges that their behaviour is a problem and begins to think seriously about solving it. While they can be open to information about the problem behaviour, they still may feel ambivalent, and as such, may be far from making an actual commitment.</td>
</tr>
<tr>
<td>Preparation</td>
<td>The individual is ready to change. They aim to develop a plan they can commit to in the near future.</td>
</tr>
<tr>
<td>Action</td>
<td>The individual takes action by overtly modifying their behaviour.</td>
</tr>
<tr>
<td>Maintenance, Relapse, Recycling</td>
<td>The individual works to sustain the behaviour change, and struggles to prevent relapse. If relapse occurs, individuals regress to an earlier stage and begin to progress through the stages again.</td>
</tr>
</tbody>
</table>
2.2.3. **Motivation theory**

One important psychological theory to change behaviour is about human motivation. Motivation is defined as “the driving force that causes the flux from desire to will in life” and categorized into two types: intrinsic (internal) motivation and extrinsic (external) motivation. Intrinsic motivation drives people to undertake an activity by the interest or enjoyment in the task itself or out of a personal commitment to excel. In contrast, extrinsic motivation relies on external rewards, the threat of punishments and competition that come from the result of doing the task rather than the process of performing it (Kapp, 2012).

A range of studies explored both motivations and presented the advantages of intrinsic motivation. First, internal motivation offers more excitement, interest, and confidence in people compared with external control (Ryan, 2000). Second, behaviours motivated by intrinsic motivation can last for long period of time, because people engage in those behaviours out of responsibility. Whereas, behaviours that were extrinsically motivated often cease soon after the reinforcement ends (Osbadiston and Sheldon, 2003).

Deci and Ryan (1985) posited self-determination theory to address that extrinsic motivational factors can be transferred to internalized ones. People are willing to be engaged in sustainable behaviours, not only for the environmental responsibility but also out of self-interest and satisfaction (De Young, 2000). Intrinsic satisfaction can derive from extrinsic factors including competence (feeling good about knowing what to do and doing it) and participation in a community feeling part of a broader effort (De Young, 2000).

Geller et al. (1990) concluded two-prong taxonomy of strategies for promoting environmental behaviour change (Table 2-3): antecedent and consequence. Studies in antecedent have shown that these techniques result in consumption reduction in varying degrees. Commitment has a long-term effect on energy saving and goal setting is effective when combined with feedback (Abrahamse, Linda, Charles, & Talib, 2005). Feedback and rewards are two primary strategies in consequence. Especially, feedback plays a crucial role in most conservation studies due to its duty of informing users both of their usage situation and of actionable tips on reducing usage. The effectiveness of
feedback can be increased when combined with other interventions such as the reward and penalty (Abrahamse, Linda, Charles, & Talib, 2005).

### Table 2-3  
**Geller et al.’s taxonomy of techniques for promoting environmental behaviour change (Geller et al., 1990).**

<table>
<thead>
<tr>
<th>Antecedent</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commitment</td>
<td>A written or oral pledge or promise by a subject to behave in a specific way.</td>
</tr>
<tr>
<td>Discussion</td>
<td>Bidirectional communication between agents on generating consensus regarding the behaviour change technique.</td>
</tr>
<tr>
<td>Written/Oral Activator</td>
<td>A written or oral communication that attempts to prompt or activate desired performance or behaviour.</td>
</tr>
<tr>
<td>Individual/Group Goal</td>
<td>A goal is set to reach a certain behaviour by a certain time, which may be self-assigned or set by an intervention agent.</td>
</tr>
<tr>
<td>Competition</td>
<td>Promoting competition to see who will accomplish the desired performance level better.</td>
</tr>
<tr>
<td>Incentive</td>
<td>An announcement to specify the availability of a reward that is dependent upon the occurrence of a desired behaviour by the individual.</td>
</tr>
<tr>
<td>Disincentive</td>
<td>An announcement to specify the possibility of receiving a penalty contingent upon the occurrence of a particular undesired behaviour.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Consequences</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedback</td>
<td>Information presentation concerning level of performance regarding desired or undesired behaviour.</td>
</tr>
<tr>
<td>Reward</td>
<td>Presentation of a ‘pleasant’ or the withdrawal of an ‘unpleasant’ item/event to a desired behaviour.</td>
</tr>
<tr>
<td>Penalty</td>
<td>Presentation of an ‘unpleasant’ or the withdrawal of a ‘pleasant’ item/event to an undesired behaviour.</td>
</tr>
</tbody>
</table>

### 2.2.4.  
**Eco-Feedback Technology**

This section addresses the important and popular form of sustainable HCI -- eco-feedback technology. Feedback plays an essential role in bridging the gap between people’ awareness of their resource consumption and the actual impact that their activities on the environment (Froehlich, Findlater, & Landay, 2010). Researchers also highlighted the necessity of visualizing real-time resource consumption in easily understood units (Chetty, Tran, & Grinter, 2008), and defined eco-visualization (EV) as “Methods to inspire environmental stewardship through dynamic data visualization in media art (Holmes, 2007)".
Design spaces

Froehlich (2011) identified and structured the design space of eco-feedback. This design space categorized the underlying various eco-feedback techniques into a solid structure. It enables the designers to compare the strengths and weaknesses of different design decision. Moreover, this space helps to define common vocabulary which allows designers to discuss, analyze and evaluate eco-feedback designs. Potential design possibilities for eco-feedback may also be uncovered with the exploration of the design space.

Table 2-4  The eight dimensions of the eco-feedback design space with sub-dimensions.

<table>
<thead>
<tr>
<th>Information Access</th>
<th>Update frequency</th>
<th>Data Representation</th>
<th>Aesthetic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spatial proximity to behaviour</td>
<td>Time window</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Attentional demand</td>
<td>Temporal grouping</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Effort to access</td>
<td>Data granularity</td>
<td></td>
</tr>
<tr>
<td>Interactivity</td>
<td>Degree of interactivity</td>
<td>Visual complexity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interface customizability</td>
<td>Primary visual encoding</td>
<td></td>
</tr>
<tr>
<td></td>
<td>User additions</td>
<td>Measurement unit</td>
<td></td>
</tr>
<tr>
<td>Display Medium</td>
<td>Manifestation</td>
<td>Primary unit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ambience</td>
<td>Data grouping</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Size</td>
<td>Social Aspects</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Target</td>
<td></td>
</tr>
<tr>
<td>Actionability/Utility</td>
<td>Degree of actionability</td>
<td>Private/public</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decision support</td>
<td>Data sharing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Personalization</td>
<td>Social-comparison</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Information intent</td>
<td>Comparison</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Automation/control</td>
<td>Comparison target</td>
<td></td>
</tr>
<tr>
<td>Motivational/ Persuasive Strategies</td>
<td>Such as rewards, punishment, reputation</td>
<td>Comparison by time</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Social-comparison target</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Goal-setting strategy</td>
<td></td>
</tr>
</tbody>
</table>

The design space is broken down into eight high-level dimensions, each of which has a series of sub-dimensions, shown in Table 2-4. The dimensions emphasize on different aspects of design: Display Medium and Data Representation focus on how the eco-feedback data visualization; Information Access and Interactivity deals with how to
access and interact with data; Actionability/Utility scopes ways to acting data; and Social Aspects, Comparison, Motivational/Persuasive Strategies take considerations of motivational factors (Froehlich, 2011).

This design space concluded different aspects to classify the eco-feedback systems. Visualizations are categorized into pragmatic and aesthetic visualization based on the aesthetic attributes of data representations. The scale of the data also is explored by different groups of researchers. For example, the Power-Aware cord (Gustafsson & Gyllenswärd, 2005) represents relatively small scale of data that is limited to power use of a single outlet. Compared with the Power-Aware cord, Nuage Vert reflects larger scale of data -- power consumed by the city’s inhabitants (Evans, Hansen, & Hagedorn, 2009). Additionally, feedback can be classified by use-context, which considers the features of the target audience and the location to place the visualization (Pierce, Odom, & Blevis, 2008). Most of the current research is aimed at residential homes such as the Adaptive Living Interface System (Bartram, Rodgers, & Muise, 2010).

Besides these most important design elements for eco-feedback technology, additional considerations exist, including incorporating education theory with the designs and selecting proper data logging system support for evaluation (Froehlich, 2011).

Design guidelines

Micheel et al. (2008) applied both visualization and gamification into the design of effective eco-feedback and extracted a set of preliminary design guidelines for resource consumption awareness feedback (Table 2-5). Through a series of visual prototype design in the SmartH2O project which combines smart water meter consumption readings with visualization and gamification, the applicability of these guidelines were further explored and refined. More profound and practical insight were concluded to help future designers in both aspects of visualization and gamification, including “Use visual metaphors relating to user’s consumption context”, “Overview of consumption should trigger awareness, and detailed information should point out concrete actions”, “Separate views for pragmatic & hedonic users should be considered”, “Goals should be related to concrete actions that user can perform”, and “Feedback on consumption should be action-oriented and include saving tips embedded in the visualization” (Micheel et al., 2008).
2.3. The Approach of Aesthetic Visualization with Ambient Displays

This section draws on research in casual information visualization and informative art to motivate the approach under consideration. Advantages of the aesthetic visualization, as opposed to the pragmatic one, are discussed. Infographics as one of the aesthetic visualization approaches is specifically introduced. Examples of using ambient and aesthetic visualizations to promote behaviour change are surveyed. Four design requirements for ambient and artistic visualizations are highlighted to provide guidelines for design and evaluation. Finally, concerning previous work, we address the challenges involved in evaluating ambient and aesthetic visualizations.

2.3.1. Casual information visualization

Information visualization, use computer-supported, interactive, visual representations of abstract datasets in order to convey meaningful patterns and trends hidden them (Moere, Tomitsch, Wimmer, Boesch, & Grechenig, 2012). This field has been traditionally split into two major areas: “scientific visualization” and ”information visualization” (Infovis). Whether the application area is scientific or non-scientific, whether the data is physically based or abstract, or whether the spatialization of the data is intrinsic or applied decide which one of these two categories a visualization should be
classified into (Tory, 2004). For the eco-feedback systems, the data is physically based while the intended audience could be everyday people without necessarily a technical background. Thus, eco-feedback systems fall somewhere in the middle of two categories rather than directly under either established category.

To link the eco-feedback to the discipline of visualization properly, Pousman et al. (2007) defined a new sub-domain of Infovis -- Casual Information Visualization (or Casual Infovis). It refers to the “use of computer-mediated tools to depict personally meaningful information in visual ways that support everyday users in both everyday work and non-work situations (Pousman, Stasko, & Mateas, 2007).” It could be a good fit for residential resource (e.g., water and energy) feedback systems and allows for multiple ‘correct’ interpretations of the latent, invisible or ambiguous data -- something cannot be achieved by pure analytic visualization. Besides analytic perspective, Casual Infovis also can provide the insight from the awareness perspective, social perspective, and reflective perspective, all of which are possible with eco-feedback systems (Pousman, Stasko, & Mateas, 2007).

**Artistic vs. Pragmatic visualization**

According to Kosara’s (2007) distinction between artistic (also called as aesthetic) and pragmatic visualization, these two broad areas lie on the two extremes of the information visualization spectrum (Figure 2-6). Where, pragmatic visualizations are recognizable and readable and to “explore, analyse, or present information in a way that allows the user to thoroughly understand the data”. Whereas, artistic visualizations primarily aim to “communicate a concern by transforming data in visible and interesting ways, rather than to show data readily readable (Kosara, 2007).” Artistic visualizations are described by Jafarinaimi et al. (2005) as “giving meaningful presence to information that is not readily explicit for the user (Jafarinaimi et al., 2005).” The underlying problem may not be visible and the data is with a degree of ambiguity, but artistic visualizations can make it visible through the piece (Kosara, 2007). Visual efficiency is not the primary goal of artistic displays and a period of learning may be required to read accurately (Kosara, 2007). As such, this strategy appears uniquely suited to providing feedback on residential resource use and inform our prototype designs.
Figure 2-6  The gamut of data-based visualization (Kosara, 2007).

Skog et al. highlight that visualizations intended for non-desktop spaces will have to both provide readable information to allow easy understanding, and present a visually pleasing and engaging addition to the environment - they must balance between usefulness and aesthetic appeal (Skog, Ljungblad, & Holmquist, 2003). As the Figure 2-6 shows, such middle area between pragmatic and artistic visualization is defined as - the Informative Art (Kosara, 2007). The design of informative art can be inspired by the appearance and function of paintings, posters and other objects that people use to decorate their living spaces (Redström et al. 2000). Different from merely presenting a static image, an informative art visualization could continuously update dynamical changes of information and meanwhile keep its display visually appealing (Ljungblad, Skog, & Holmquist, 2004). Besides aesthetics and usefulness, another primary property of informative art is ambience. The display is necessary to blend into the surroundings and require minimal attention and cognitive load (Ljungblad, Skog, & Holmquist, 2004).

Information Graphics

Information graphics, commonly called “infographics”, are one form of artistic visualizations. They refer to graphical visual representations of information intended to communicate complex data in an engaging manner (Smiciklas, 2012). Infographics are an effective means of providing readers with an overview of a topic and telling stories about data. The strengths of infographics are that they use principles of graphic design to capture a reader’s attention (Smiciklas, 2012). Infographics are now widely implemented to convey a concern of the environment and numerous examples can be found on the Internet (such as Figure 2-7). However, those designs are static and do not support interaction. Updates on data are not real-time, and are not directly connected with users’ actions. Sun (2014) designed a tree with berries as rewards to visualize the energy consumption (Figure 2-8), and the data changes with the residential
consumers’ activities in the simulated home environment. This research inspires our research in designing engaging feedback with an appealing visual metaphor for residential water use.

**Figure 2-7**  Infographics on Water Conservation.

**Figure 2-8**  Abstract Tree with Berries to Represent Energy Consumption (Sun, 2014).
Ambient and Artistic Visualization for Behaviour Change

Recently, the design factors of ambient and artistic feedback have been explored in various domains, including energy, recycling and water feedback to promote behavioural change. With the introduction of these examples, we will also attempt to distill some of the key findings related to the design of ambient and artistic feedback from these findings.

The Show-Me shower (Figure 2-9(a)) uses a string of LED lights, which illuminate in a progress-bar like fashion as water flows from a showerhead (Kappel & Grechenig, 2009). The authors are interested in environmental attitudes contributing to behaviour change. Findings revealed that long-term changes of behaviours in saving water occurred among people who are ecologically conscious. However, people without favorable environmental attitudes only showed an initial change in behaviour when the feedback was introduced and did not maintain such behaviours for the long time (Kappel & Grechenig, 2009).

The Energy AWARE Clock (Figure 2-9(b)) embeds electricity consumption feedback on the face of a clock. The information on real-time use and past consumption is presented by an abstracted circular graph (Broms, Katzeff, Bång, Nyblom, Hjelm, & Ehrnberger, 2010). The link between contextual design factors to behavioural change was sought in this study, including how information presentation relates to use context and how the physical attributes and location of feedback relate to everyday use contexts (Broms, Katzeff, Bång, Nyblom, Hjelm, & Ehrnberger, 2010). The choice of embedding the feedback in a clock addressed the identified contextual design factors, supported the comprehension of the ambient installation, and increased the visibility of energy use impacts.

Robotic plants are used to stimulate awareness of disposal behaviours in Infotropism (Figure 2-9(c)). Putting waste into the trash or the recycling will activate the bulb at the related side, and the bulb will encourage the growth of plants (Holstius, Kembel, Hurst, Wan, & Forlizzi, 2004). The authors explained why they choose plants for their ambient information as “Plants are constantly accumulating and displaying the effect of stimuli over time in a form that humans can interpret. For example, houseplants generally point toward the primary source of light in a room (Holstius, Kembel, Hurst,
The users’ emotional and affective responses the influence he capability of ambient and artistic feedback to integrate into use contexts (Holstius, Kembel, Hurst, Wan, & Forlizzi, 2004).

An abstraction of the ubiquitous pinwheel shape (Figure 2-9(d)) is used to convey the flow of power in the domestic energy use feedback (Rodgers, 2011). This design is inspired by the mechanics of a real pinwheel: the faster the wind is blowing, the faster the wheel spins. Ambient and artistic approaches are indicated as a promising method of providing real-time and at-a-glance awareness. Rodgers also discussed users’ confusion about the design that speed of rotation and number of pinwheels draw their most attention; however, most of them ignore the information of accumulative energy use represented by the amplitude of the scaling (Rodgers, 2011).

**Figure 2-9** Examples of ambient and artistic feedback: (a)The Show-Me Shower Display (Kappel & Grechenig, 2009); (b)Energy AWARE Clock (Broms, Katzeff, Bång, Nyblom, Hjelm, & Ehrnberger, 2010); (c)Infotropism (Holstius, Kembel, Hurst, Wan, & Forlizzi, 2004); (d) The Pinwheel Design for Energy Consumption (Rodgers, 2011).

The research indicates ambient and artistic feedback can raise awareness and motivate behaviour changes. During the design process of such feedback, contextual factors and user motivations should also be considered carefully as they may determine the effectiveness of the feedback significantly.

2.3.2. **Design requirements**

Ambient and aesthetic visualization is a helpful means of presenting and providing awareness of dynamic changes in a particular place. Based on previous research related to this topic, four features are specially considered as aesthetic,
pragmatic, ambient and real-time. We will mainly focus on the domain of natural resource feedback within the home.

**Aesthetic**

Whether the visualization is appealing is treated as one of the critical criteria in classifying between artistic and pragmatic information visualization (Kosara, 2007). Aesthetics apply various depictive and narrative-related forms of representation to communicate a concern of the information. Rogers and Bartram (2010) address that “aesthetics is an important factor as it expands the realm of visualization beyond analytical concerns toward a broader spectrum of representation and communication”. The integration of aesthetics typically aims to “stimulate the desire, positively influence the first impression, encourage repeated usage or even overwhelm its audience” (Cawthon & Moere, 2007). Aesthetic is not only an adhesive making things attractive, it is also part of the foundation to enhance readability and comprehension of data visualization (Cawthon & Moere, 2007).

**Pragmatic**

Same as the design criteria for pragmatic visualizations, users’ understanding of the feedback also need be valued. To take the balance between comprehensibility and visual appearance, designers should consider whether participants are aware of that information is being visualized, whether they can identify what specific information is being communicated, and finally whether they understand the relationship between the visualization and the underlying concern (energy or water) and make sense of that information (Rodgers, 2011).

**Real-time**

Real-time information is critical to motivate behaviour change within the context of the resource consumption feedback, because it enables users to link their behaviour to consumption situation as causes and effects (Pierce, Odom, & Blevis, 2008). Real-time is achieved by setting the update rate sufficient to meet the user’s requirements (Wood & Newborough, 2007). In behavioural terms, it is always better to have the most frequently updated information available (Wood & Newborough, 2007). Similarly, Fischer (2008) states “feedback is more effective, the more directly after an action it is
given”. However, a suitable rate should also consider users’ capability of perceiving the information and not being distracting (Skog, Ljungblad, & Holmquist, 2003). Moreover, the developer can affect the visual appearance by slowing down the changes or adding a small amount of animation (Skog, Ljungblad, & Holmquist, 2003).

**Ambient**

Five criteria has indicated the ambient attribute in details: the information they displayed is important but not critical; they can move from the periphery to the focus of attention and back again; they focus on the tangible (representations in the environment); they provide appropriate update rates and updates are reflected through subtle changes, which should be unobtrusively; and they take balance between aesthetic appeal and usefulness and place displays environmentally appropriately (Pousman and Stasko, 2006). Specifically contextualizing eco-feedback at home, the constraints of a residential environment bring further challenges to the design of information visualizations on integrating with the surroundings (Aipperspach, Hooker, & Woodruff, 2008; Skog, Ljungblad, & Holmquist, 2003). Audiences “lived with rather than used” such visualizations (Skog, Ljungblad, & Holmquist, 2003).

**2.3.3. Evaluation**

With exclusive features of it being aesthetically pleasing and peripherally to a primary task, evaluating ambient and artistic displays is inherently problematic (Mankoff, Dey, Hsieh, Kientz, Lederer, & Ames, 2003). Pousman & Stasko (2006) indicated the challenges of evaluating Casual Infovis: “First, the systems are less productivity focused, so even determining what to measure is difficult. Second, systems are meant to provide multiple varieties of the insight, and these are softer than analytic insight, which makes them difficult for researchers to gauge. Lastly, systems are also designed for more casual usage patterns, so traditional laboratory evaluations may be inappropriate for the long-term benefits that casual systems intend to bring about (Pousman & Stasko, 2006)”. Facing these challenges, traditional performance metrics are insufficient in this area, and several approaches have been proposed in the recent literature.

Nielsen’s usability of heuristic (Nielsen, 1994) has been adapted by Mankoff et al. (2003) for the evaluation of ambient displays. Cooperating with professionals in the
design process of ambient displays, researchers have yielded a set of design rules that proved to be useful in identifying usability issues in this domain. However, this method is only useful in the early stages of design with experts but not applicable to evaluating prototypes with “everyday” users in real-life settings.

User studies, “offer a scientifically sound method to measure a visualization’ s performance (Kosara et al., 2003),” “can be used to evaluate the strengths and weaknesses of different visualization techniques,” “show that a new visualization technique is useful in a practical sense,” and can reveal, “insight into why a particular technique is effective (Kosara et al., 2003).”

In assessing information visualization techniques, mixed methods user studies are proved to be viable that includes qualitative measures of user satisfaction alongside traditional quantitative measures of efficiency (Ellis & Dix, 2006; Pousman, Stasko, & Mateas, 2007; Sprague & Tory, 2009). From the combination of the two methods, researchers could not only know that the behaviour occurs and gain inspirations about why as well (Ellis & Dix, 2006). Rodgers and Bartram (2011) adopt a mixed methods approach to evaluate their design of three different ambient visualizations of point-of-consumption energy use feedback. Data are collected through interviews, questionnaires, in-study observations and system logs (Rodgers & Bartram, 2011). Open-ended interviews are helpful in collecting users’ insight about data patterns or features they find pertinent (Pousman, Stasko, & Mateas, 2007). However, Sprague specifically stated that such qualitative data collection and analysis methods must be implemented cautiously in order to avoid influencing results or biasing participant self-reports (Sprague & Tory, 2009). We are informed and inspired by these evaluation mechanisms and will deploy mixed methods to evaluate our design of residential water consumption visualizations.

2.4. The Approach of Gamification for Sustainable Resource Strategy

As we discussed previously, one of the biggest challenges in promoting sustainable resource conservation is motivation. The core of gamification -- fun and engaging, has made gamification as an effective approach to attracting residents and
driving them taking sustainable behaviours. This part of literature review mainly explores the definition of gamification with its core elements, the psychological supports to gamification in raising motivation, and various applications of gamification in the area of sustainable resource conservation, particularly the water conservation.

2.4.1. What is Gamification?

The term ‘gamification’ originated in the digital media industry as early as 2002, and its definition was changing since it began to gain widespread usage from late 2010. Deterding et al. (2011) defined ‘gamification’ as “the use of game design elements in non-gaming contexts”. They specifically addressed that, different from the serious game, gamified applications only implement some design elements that are found in most games, instead of full ‘game proper’. Alternatively, as Huotari et al. (2012) described ‘gamification’ from a service marketing perspective, gameful experience should aim at supporting user’s overall value creation rather than employing methods from games. Although the above two definitions address on different aspects, Kapp (2012) concluded that they remain the same as “gamification uses game-based mechanics, aesthetics and game thinking to engage people, motivate action, promote learning, and solve problems”.

Gamification is about extracting the mechanics which make game attracting and entertaining and grafting them into other domains. The most characteristic game elements include Points, Badges, Leaderboards, Levels and Competition/ Cooperation. Points can be directly related to user activities and produce strong incentive effects on users’ behaviours. In addition, new ideas may be generated from the mechanic of points (Witt, Scheiner, & Bissantz, 2011). Badges also described as a “visual points system” (Zichermann & Cunningham, 2011) perform the similar function as Points. Moreover, badges present the prominent advantage in encouraging student participation in online learning tool (Denny, 2013). A leaderboard shows a list of players’ scores where users can see their ranking relative to others. Even it simulates people with high ranking effectively on working harder towards the desired behaviour, it may also demotivate lower ranking participants to have fewer interests in the application (Massung, Coyle, Cater, Jay, & Preist, 2013). Primarily levels in games can break down into three different type. The game level means the user can play in different positions in a game, the playing level is the degree of difficulty that players choose when they first start the
game, and the experience level indicates player’s mastery of the game (Kapp, 2012). For example, Power Agent, a game to promote residential energy conservation among teenagers and their families, uses the game level to represent different energy consumption scenarios (Gustafsson, Katzeff, & Bang, 2009). Competition/cooperation are usually found in the gamified application involving social practice, in which competition can optimize users’ own performance, whereas cooperation will motivate them to gain mutual benefits (Gustafsson, Katzeff, & Bang, 2009).

2.4.2. Why Gamification?

The goals of gamification are to induce innovation, increase engagement and change users’ behaviours, what makes gamification to achieve these goals will be unveiled with the theoretical support from motivational theory and behaviour model.

Gamification in Motivating Behaviour Changes

Gamification is “75% to 25%, psychology to technology” (Carr, 2011). Thus, to figure out why gamification technique is effective, the essential step is to understand the psychological theory especially human motivation behind it (Maritz, 2012). As Table 2-6 shows, six principal perspectives on motivation can be applied to gamification, which are the trait perspective, the behaviorist learning perspective, the cognitive perspective, the perspective of self-determination, the perspective of interest and the perspective of emotion (Sailer, Hense, Mandl, & Klevers, 2013). These perspectives can provide design inspiration and guidelines for gamified systems.

Behaviour change is the ultimate goal of fostering motivation. We will discuss how models of behaviour change mentioned in Chapter 2.2.2 relates to gamification. The first model can be related to gamification is the Fogg Behaviour Model (Fogg, 2009). Game mechanics own the power to turn boring chores into desirable activities through affecting the factors of motivation, ability, and triggers accordingly. Game mechanics use positive feedback such as points and badges to build up the users’ motivation. By training/practice or lowering the activation threshold of the target behaviour in the game, the perceived ability of users is increased. Game dynamics place triggers to bring about the occurrence of motivation, ability, and trigger all at the same moment (Wu, 2011). The transtheoretical model is another important behaviour model that can give hints to
gamification design (He, Greenberg, & Huang, 2010). The model suggested that user tasks should be specifically designed to follow each behaviour change stage. Thus, behaviour change could be achieved in long-term.

Table 2-6 Six principal perspectives on motivation that are relevant to gamification (Sailer, Hense, Mandl, & Klevers, 2013).

<table>
<thead>
<tr>
<th>Motivational Perspective</th>
<th>Concept</th>
<th>Relation to Gamification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trait perspective</td>
<td>Individual characteristics have a strong influence on behaviour.</td>
<td>Emphasize on achievement, success, progress, control, competition and so on.</td>
</tr>
<tr>
<td>Behaviorist learning perspective</td>
<td>The probability of future behaviour can be influenced by past negative or positive reinforcements.</td>
<td>Provide immediate feedback in form of positive and negative reinforcement and rewards.</td>
</tr>
<tr>
<td>Cognitive perspective</td>
<td>Goals, expectancies, values of consequences should be considered for motivation.</td>
<td>Provide a clear and achievable goal, highlight consequences of it, and emphasize the importance of an action within a given situation.</td>
</tr>
<tr>
<td>Self-determination</td>
<td>Fulfillment of competence, autonomy, and social relatedness brings motivation.</td>
<td>Let people experience related feelings for self-determination</td>
</tr>
<tr>
<td>Perspective of interest</td>
<td>Motivation is the result of individual preferences for the given task.</td>
<td>Meet the players’ interests and sparks contextual interest.</td>
</tr>
<tr>
<td>Perspective of emotion</td>
<td>Emotions affect motivation.</td>
<td>Increase positive feelings like pleasure and decrease negative ones.</td>
</tr>
</tbody>
</table>

Gamification as a Persuasive Technology

As interactive products to change attitudes and behaviours in a specific content domain, gamification can be treated as an effective persuasive technology. Of seven common elements in persuasive technologies identified by Fogg (2002), tunneling, self-monitoring, surveillance and conditioning present important overlaps in gamification systems (Llagostera, 2012).

Tunneling is important to gamification because users need the guidance through the step by step process. “Gamified systems often operate through very specific courses of action in their connection to the non-game activity being gamified: the
performing of an action is only meaningful to the system if it complies with the milestones set by it” (Llagostera, 2012).

Self-monitoring is widely used in gamified systems to drive users understanding themselves better. Services and companies employ the data metrics as beneficial features to gamify their applications, and such data could usually indicate the engagement and enjoyment of players reliably (Bunch Inc., 2010). An example is the Nike+ Fuelband, a popular gamified sport, which would track personal physical activity data to actively fosters lifestyle changes. Another example is Yun’s web-based application which uses persuasive technology to promote awareness and encourage energy conservation in the workplace. It applied self-monitoring to track real-time and historical energy use for the individual device.

Based on the premise of surveillance, leaderboards are commonly implemented in gamified systems, which persuade people to behave better through social pressure. However, to the users with poor performance, this design takes the risk of discourage them to keep up with others and simply give up (Massung, Coyle, Cater, Jay, & Preist, 2013). Taking the same example of Nike+ Fuelband, it relies on the gamification of fitness activities turning all tracked movement into NikeFuel points, which can be used to engage others in the competition.

Finally, gamified systems are common to provide reward structures such as points and badges to motivate users to take the targeted actions, which refer to conditioning in the persuasive technology (Llagostera, 2012). The PowerHouse, a persuasive game that models energy use in a home, aimed at raising players’ awareness of domestic energy use and changing their behaviours. Players can get direct feedback on their actions through praise and getting bonus points (Bang, Torstensson, & Katzeff, 2006).

2.4.3. Application of Gamification

In essence, gamification is about grafting elements what makes games effective and fun onto other domains (Werbach & Hunter, 2012). We will explore the application of gamification in various industries including marketing, education, health and fitness in
this section. Especially, gamification application within the context of environmental sustainability will be stated.

**Marketing**

Gamification can help marketing organizations achieve their goals by building “stickier user experiences” for their customers (Soonkwan & Wang, 2011). Reward/badge is one of the strategies to gamify marketing plan. For example, Facebook offers reward points or badges to users who promote on their personal Facebook pages for completing activities. Gamification can break down complex tasks into various small objectives, and completion of challenges can be tied to unlocking higher levels. MySalesGame by Callidus Cloud is a perfect example of this feature (Lehdonvirta, 2009; Lockton et al., 2010).

**Health and Fitness**

The reward structure of gamification is able to encourage users to reach their individual health and fitness goals continuously. One example is Fitocracy, one of the world’s largest exercise-related gamification services, which use gamified elements such as points, levels, and achievements. The study from Fitocracy discovered that attitude towards the use of gamification is indicated by social motivations which also encourage users to continue using a gamified service (Hamari & Koivisto, 2013). Besides, apps that targeted at weight-loss (e.g., Lost It!), smoking cessation (e.g., QuitNow!) and mental health (e.g., MeYou Health) also use gamification to bridge the gap between intention and behaviour.

**Education**

Gamification also drew attentions of the educators due to the possibility of making learning more motivating and engaging with reward systems and competitive social mechanisms. According to the review of the literature on gamification in education, Juho addressed that gamification did yield positive results in the majority of the studies and these effects exist mainly in part of the considered relationships between the gamification elements and studied outcomes (Hamari, Koivisto & Sarsa, 2014). Points, badges, and leaderboards are confirmed as the most popular game mechanisms in education (Dicheva et al., 2015). Badges play a key role in challenge achievements
and participation achievements (Dominguez et al., 2013) and in learning time management, and carefulness (Hakulinen & Auvinen, 2014).

**Energy Conservation**

In the field of behavioural sustainability, although the potential dimensions are broad including behaviour such as driving, recycling and water, and consumer behaviour) gamification has primarily focused on energy conservation (Morford, Witts, Killingsworth, & Alavosius, 2014), and gamified techniques play the prominent role in energy conservation applications. PowerHouse (Figure 2-10) consists of a number of mini-games that simulate real-world scenarios (e.g., turning on lights and watching TV), where users can play virtually as they consume energy at home. A dashboard graphically depicts the last 24h of real energy usage in their homes, users' in-game statistics, and competition scores with other players. The researchers also considered to balance the tradeoff between gamified mechanics and the overall gaming experience by avoiding explicit information such as pop-up boxes (Bang et al. 2006). Greenify (Lee et al. 2013) is an online social platform that aims to foster sustainability of energy, food, consumption, and transportation. It motivates users with rewards of points, badges and character upgrades for successful mission achievements. Gamification has also been applied in promoting energy efficiency by companies partnering with electricity providers, who are under pressure from governments to meet particular conservation requirements (Redmon 2012). Opower has developed an energy solution that provides customers with detailed home energy usage reports and allows utility company customers to compare their home energy usage against all other users, compete against others individually or on teams, and to join challenges and win prizes based on their performances. Significant reductions of electricity are achieved by Opwer users collectively (Redmon 2012).
Water Conservation

Currently, research on applying gamification in the domain of domestic water conservation is still rare to see, but increased attention is being paid. Several publications (Fraternali et al., 2015; Garlli et al., 2015; Micheel et al., 2015; Novak et al., 2016) describe a research project in European Institute for Participatory Media called SmartH2O project (Figure 2-11) -- an innovative behavioural change and incentive model for residential water, which combining smart meter data with consumption visualization and gamified incentive mechanisms to stimulate water conservation. Actionable water saving tips with gamified mechanisms (rewards, customized feedback, goals, and achievements) were deployed in the project. It proved that gamification incentives are effective in reducing water consumption. It also perceived that changing water consumption behaviour is a multistage process, and different incentives and different stages should be designed to different typologies of customers (Novak et al., 2016).
2.5. Discussion

From the above literature review, we conclude that it is essential to design a feedback tool to promote residential water conservation in raising residents’ awareness that motivating informed decision-making, and both aesthetic visualization and gamification technology are promising approaches to the provision of such feedback. However, the review in this section also revealed that, in the domain of sustainable resource conservation, much more research and applications of using either or both of these approaches are focused on energy compared with water. This situation presents opportunities for us to carry out the research within the context of water. We are interested in questions including how well aesthetic visualizations with gamification skills can support comprehensibility and informed decision-making about water consumption,
whether they are more effective than pragmatic visualizations, and how people like this kind of feedback system in real use. This research space will be explored through our prototype design of feedback tool and evaluation in the following chapters.
3. Research Design

To reduce the residential water consumption, the water industry has mostly focused on regulatory and financial incentives. Water meters are installed mainly in houses in BC, and water bills are sent out by their utility company every four months. Residents can hardly receive timely feedback and get immediate reflection upon their water consumption from such long billing cycles. And, most people don’t have a firm understanding of water usage amounts to identify anomalous or excessive usage on water bills, unless extraordinary excess occurs. Moreover, the cost of water is often much cheaper compared with the cost of electricity, which gives rise to questions about motives for conservation. What’s worse is that most apartments are not designed for individual metering and households are charged a fixed flat rate. Large amounts of home occupants have little-to-no knowledge about water usage and limited methods to find out. This makes people insensitive towards water wastage in their homes. The major problem with it is that the lack of awareness and understanding about water leads to inadequate activities such as using a full load of the dishwasher when washing only a few dishes, cleaning the car with the hose even the car is not very dirty or irrigating garden during mid-day.

Although in HCI research, a great deal of attention has been paid to energy usage and some viable feedback systems have been explored (Rodgers, 2011 & Sun 2014), the eco-feedback of water usage may require new forms or methods because of its different needs, concerns, and motivations. For example, unlike electricity where some automated appliances (e.g., electric heating, central air conditioning systems, and refrigerators) tends to consume the majority of the energy at home, most of the water use often involves some sort of manual human activities (e.g., taking bath, flushing toilet, cleaning car and watering garden). Thus, from enriching residents’ awareness and knowledge of water use at home, to ultimately motivating them to control actions for water conservation, the essential intermediate step is connecting their daily practices and behaviours with the actual water usage amount.
Even the bill most often remains a major household’s feedback on water consumption, and there are a number of commercial products can give feedback to customers. Smart Meter (e.g., Lotik™ and WaterOn™) is now available and being deployed. As Figure 3-1 shows, smart meters are installed at every inlet point such as the hose connection points of toilets, kitchen sinks or bathroom sinks. It records each consumption and sends it to the user and billing engine. Customers benefit from direct and prompt data about when water is used, where it is used, and advanced notification of water leak which is the fifth most water-consuming source in the home. Additionally, to assist the users to be informed of the collected data, web-based applications are developed together to provide more comprehensive information. Both of Lotik™ (Figure 1-3) and WaterOn™ (Figure 1-2) use pragmatic charts to visualize the precise and detailed data through an interactive dashboard. They track the real-time and historical water usage situation, enable the comparison between different time periods and appliances and also alert the excessive usage and leaks. The charts could present the data precisely and comprehensively. However, especially considering the target users as children, these charts are not interesting and engaging to them. Also, they do not support at-a-glance awareness of the data and demand much attention of people to interpret the charts. Besides, purchasing sensors for each appliance, cutting the pipe to install the smart meter system and connecting the hard device with the visualizations expend extra money and efforts. In summary, current water sensing and feedback systems still have some drawbacks to identify and solve the problem of positively motivating people to make sustainable decisions.

Figure 3-1  Smart meters of Lotik™ (left two) and WaterOn™ (right).
3.1. Motivation

Two main challenges can be concerned in finding proper approaches in fostering residents to adopt more sustainable living: how to present consumption information and convey its meaning to users to increase awareness, and how to motivate informed decision-making and sustain behaviour change of residents. Besides, the features, outlined by Fischer, including breakdown, presentation, the inclusion of comparisons, and combination with additional information and other instruments need be taken into account for the design of successful feedback (Fischer, 2008).

Consumption information visualization often addresses the first challenge. To be effective, consumption information can be broken down, e.g., by appliances, by category of consumption or temporally. Compared with pragmatic visualizations, the aesthetic visualization takes the advantage of its flexibility and superiority in the mode of presentation. Employing the metaphorical representations makes the aesthetic visualization more visually compelling and attractive. Before the information becomes effective, it needs to capture attention (Fischer, 2008). Additionally, it is possible to maintain its comprehensibility with various appealing graphic components. Also, in contrast to above discussed digital tools using standard charts (LotikTM and WaterOnTM), at-a-glance awareness is available instead of exploring charts to read numbers. The display that remains peripheral to one’s attention could sustain interest over time. From the review and analysis of the related research, the ambient and aesthetic visualization is a viable approach to convey the information of domestic resource use, mostly in the energy use. We are encouraged to study the effectiveness and feasibility of this approach in the context of water to an extent. More specifically, we aimed to investigate whether it had support for informed decision-making and learning through real practice, what made them effective and in which way.

Gamification succeeds in addressing the second challenge of engaging residents in saving water actively, with the implementation of some methods, such as actionable tips, points, and badges. Action-oriented tips are needed for consumption reduction (De Luca, 2014 & Froehlich, 2011), as the visualization alone usually fails to provide practical hints on how to achieve it (Rist, 2014). Additionally, consumption comparison is also essential for stimulating behaviour change, and Points element enables goal-comparison,
self-comparison, and social-comparison. Compared with benchmarks, users are able to judge whether their consumption is “normal”, excessive, or economical. Furthermore, the game itself functioned as a simulation environment driving the visualizations, and it can provide immediate feedback in real-time when an action is taken rather than waiting for the long billing cycle. As Fischer states “quick feedback would improve the link between action and effect, and therefore, increase consciousness about the action’s consequences (Fischer, 2008)”. Moreover, consumption behaviour tips can specifically adapted to the behaviour of the player in the game. Personalized tips can be more effective than general ones. The game mimics real life water appliances with which users can interact. Getting rid of the drawbacks of current water sensing system, people don’t need to purchase and install any hard devices but still can gain strong knowledge of residential water consumption.

A number of resource conservation (mostly energy) applications for residential consumer employ visualized consumption feedback and gamification techniques to motivate people to conserve natural resources, with various level of success (Rist, 2014 & Froehlich, 2011). Inspired by these existing feedback technologies and theories, we aimed to empirically validate the potential application of this approach with our aesthetic visualization designs integrated into the game environment. This approach would attract people more with its engaging gamified elements and appealing representations. Additionally, during the process, we would also like to gain valuable design experience and provide the insight and recommendations for future design.

3.2. Goals

A design-oriented research perspective was taken to reveal the knowledge that comes from studying the user behaviour and user experience of a design (Fallman, 2007). In this context, we conduct exploratory studies to explore the potential of narrative-related aesthetic visualization as an approach for positive decision-making towards water conservation. Specifically, we would like to see if the flower representation of positive actions applied in the aesthetic visualization can encourage water conservation and how users like this reward component in the feedback. Also,
users’ comprehensibility and preference to the feedback system, the ambience of the display and aesthetic appeal of the visualizations is elicited.

A secondary goal of this study is to explore the usefulness of the simulation game itself. The game itself is more than a simulation environment driving the visualizations but also serve as an experiment. We aim to understand where peoples’ comprehension and actions are weak regarding water conservation at home, and also whether they gain more information through the game experience. Meanwhile, we are intended to collect feedback on the gamification techniques such as evaluation panel and scores to explore the insight provided by gamification in environmental sustainability.

Finally, these designs are studied as means rather than end products as effective feedback for residential water use, and detailed analysis on the design components could help us to find out what worked and what didn’t. User opinions are crucial in this research. We believe that the reaction of users that it provokes and the design inspirations that emerge either can provide more profound insight for future research.

3.3. Research Design

3.3.1. Research Questions

A water game is developed with dollhouse interface as the realistically representative home environment. Both pragmatic visualization in the format of the standard bar chart and the aesthetic visualization with flowers as rewards are designed for data representation. In the simulation game, we mimic different real-life settings in the game, users can act with various options in the way they normally consume water in everyday life, and the consumption situation would be reflected on the visualizations in real-time. The gamification elements such as the scores, badges, and conservation tips are added to make the game compelling to participants, especially children. Details of the game are described in the Chapter 4.1. We categorize our above research goals into the following three research questions to examine the effectiveness of implementing gamification techniques with the different visualizations as the water use feedback tool, with special attention to the aesthetic visualization approach.
Research Question 1: Can both pragmatic and non-pragmatic visualizations assist children in understanding water use and decision making toward water conservation?

Following this question, we wish to know how participants describe their impressions of the visualizations: Are they able to understand these visualizations? Is aesthetic visualization helpful in presenting information or more attractive and aesthetically appealing than the other? Additionally, we are also interested in exploring: can participants understand the representation of positive actions? How do they like the reward mechanism in the visualization? Does it help them to realize what is good for water conservation and affect their decision-making?

Research Question 2: Can this simulation game help children learn about water use?

Sub-questions following this one are: Does the game suggest about what children understand, don’t understand or “forget” about how to use water efficiently in their homes? How do participants like the gamification techniques such as the actionable tips, points, and badges? Do these techniques help them to gain new knowledge about water conservation actions and affect their decision-making? How is their general game experience in learning about water?

Research Question 3: What insight this water feedback which combines visualizations and gamification techniques can provide for the future design of such game for children?

To answer this question, we derived a set of design implications for the future improvement of the current design. We are also in hopes of providing sustainable HCI designers and researchers with the insight into investigating and designing richer and more effective eco-feedback system.

3.3.2. Approaches

To answer above questions, we designed a water conservation game prototype with both a bar chart design as the pragmatic visualization and a flower chart design as
the non-pragmatic visualization (Chapter 4). We also conducted two user studies, including user study A as a pilot study (Chapter 5), and user study B which consists of two workshops (Chapter 6). Both studies have the emphasis on different aspects of the research goals but also has intersections on answering some common research questions.

Due to the privacy concern, we conducted the user study A with nine individuals in the public space such as the public library and the researcher’s lab. In this study, we focused on exploring whether there is any difference between participants’ impressions of the pragmatic visualization and the non-pragmatic visualization. We allowed the participants to see only one type of the visualizations for the first two game stories. And after they completed two game stories, they had to switch to the other one. Through analyzing their impressions on different visualizations, we found that participants prefer to see both visualizations in the water game.

Based on the interesting finding of user study A, we modified the particular research questions in the user study B, and we would like to especially explore how the participants use the combination of both visualizations in a real learning context. To answer this question, we modified the details of study process for the user study B without fundamentally varying the feedback design itself. The user study B was conducted with participants in Science Alive! Workshops which were actual learning situations, where children were accompanied by their teachers. The most important difference between user study A and B is that, in study B, participants could switch between different visualizations freely at any stages of the user study. Users in the first workshop of Study B played the game in “play” mode and those in the second workshop played the “explore” mode separately. Another different point between two workshops is that we set learning goals to the participants in the second workshop before they played the game, while in the first workshop, we did not set any goals. We collected the participants’ perceived and actual game scores in the first workshop through the system logs. Comparing the difference between their perceived and actual scores is essential for us to understand how well the participants master the knowledge of water consumption and conservation and whether their decision making is consistent with their knowledge.
4. **Water Conservation Game Design**

Games have proved to be powerful in leveraging participants’ both motivation and engagement (Lawley, 2012). Gamification is treated as an important and useful approach with its implementation of simulation, hands-on experience, and explicit rewards techniques for education purpose (Schifer, 2013). Specifically, it has succeeded in engaging students in exploring large-scale ecological outcomes (Antle, Tanenbaum, & Macaranas, 2013), but it is still rare to apply gamification in enhancing water conservation awareness and engagement of actual residential consumption.

Sitting on opposite ends of the “sublimity” scale, the pragmatic visualization and aesthetic visualization have their own advantages and disadvantages. The former one is designed to aid in data analysis, but is less appealing and interesting for people to explore the underlying problem the data implies. The latter one takes the advantage of applying various narrative-related forms of representation to communicate a concern of the information, but is less readable and recognizable for the data (Kosara, 2007). This leads us to the question of how to balance the aesthetic interest and the readability.

Within the context of residential water consumption, we designed both aesthetic and pragmatic visualizations to provide information of residential water use and integrated them with ambient displays and a simulated water conservation game. Some basic game techniques are employed, such as game Points, Levels, and Competition. The game is chosen as a testing context for visualizations because it offers more realistically representative simulations so as to enable users to connect their actions with water data in the visualizations more directly. Particularly, school-age children are considered as our primary participants, and gamification elements attract children to engage in the activity of “using water” in this research.

Our system is structured and designed based on Froehlich defined design space for the eco-feedback system, which is broken down into eight high-level design dimensions (Froehlich, 2011). These dimensions include what the display medium is
and how the data is represented, how the data is accessed and interacted with, how actionable the presented data is, and what motivational factors are implemented. Based on the research purpose, some of them are integrated not entirely orthogonal, indeed intersected into our design space of game and visualization. In this chapter, the details of the game and visualization design frame and factors will be illustrated.

4.1. Game Design

In the game, a dollhouse UI (Figure 4-1, left) is used to simulate the home environment, which is loosely borrowed from the popular SIMSTM game model. User’s interactions in the dollhouse can drive the information update of both pragmatic and aesthetic visualizations (Figure 4-1, right). The cartoon icon design can attract children and improve their acceptance. The dollhouse has five rooms: Garden, Garage, Kitchen, Bathroom, and Laundry, each of which contains some household water appliances. The settings of rooms follow our survey about the residential water consumption appliances and activities (Table 4-1). Users are allowed to interact with the appliances to simulate their daily water consuming activities such as making a choice on watering garden with hose or sprinkler and at daytime or night. Information of how much water is consumed and how much water is saved if water saved actions are taken interactively will be reflected on the embedded visualizations efficiently in real-time. For example, when washing fruit, if people choose to use flow water from the faucet, 10L will be consumed, while when they use the static water in bowl, only 3L water will be consumed. The data is collected from the website of Home Water Works (link: http://www.home-water-works.org/calculator).
### Table 4-1 Residential water consumption appliances and activities.

<table>
<thead>
<tr>
<th>Room Name</th>
<th>Appliances</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Garden</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Swimming pool</td>
<td>Cover the swimming pool</td>
</tr>
<tr>
<td></td>
<td>Hose</td>
<td>Water the garden at day/ night, with half/ full flow, for 20/ 15 minutes</td>
</tr>
<tr>
<td></td>
<td>Sprinkler</td>
<td>Water garden at day/ night, with half/ full flow, for 20/ 15 minutes</td>
</tr>
<tr>
<td></td>
<td>Water butt</td>
<td>Water garden with the collected rain water in the butt at day/ night</td>
</tr>
<tr>
<td><strong>2. Garage</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Car</td>
<td>Leave car dirty</td>
</tr>
<tr>
<td></td>
<td>Hose</td>
<td>Wash the car with half/ full flow, for 20/ 15 minutes</td>
</tr>
<tr>
<td></td>
<td>Water bucket</td>
<td>Wash the car with half/ full bucket, for 20/ 15 minutes</td>
</tr>
<tr>
<td><strong>3. Kitchen</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Faucet</td>
<td>Turn on/ off faucet</td>
</tr>
<tr>
<td></td>
<td>Dish washer</td>
<td>Wash dishes with full/ half load</td>
</tr>
<tr>
<td></td>
<td>Dirty dishes</td>
<td>Wash dirty dishes in the sink or with flow water</td>
</tr>
<tr>
<td></td>
<td>Vegetables/fruits</td>
<td>Wash vegetables in the bowl or with flow water</td>
</tr>
<tr>
<td><strong>4. Bathroom</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Faucet</td>
<td>Turn on/ off faucet</td>
</tr>
<tr>
<td></td>
<td>Toilet</td>
<td>Flush toilet with half/ full flush</td>
</tr>
<tr>
<td></td>
<td>Bathtub</td>
<td>Take bath in bathtub</td>
</tr>
<tr>
<td></td>
<td>Shower head</td>
<td>Take shower for 5/ 10 minutes</td>
</tr>
<tr>
<td><strong>5. Laundry</strong></td>
<td>Washing machine</td>
<td>Wash small pile of clothes right now; Leave small pile of clothes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dirty and wait for full load</td>
</tr>
</tbody>
</table>

The game is composed of two modes: “play” mode where players can complete tasks accordingly and get the evaluation of their performance; “explore” mode where they are encouraged to practice the game repetitively without task limits.
Task Design

The game consists of four stories -- Outside, Personal Hygiene, Meals and Maintenance (Table 4-2) that mimic people’s ordinary life. In each story, participants are asked to imagine themselves in the given scenario description and complete game tasks (Figure 4-2). The tasks are designed to have special focus on activities that people may do to save water in their home, for example, covering the swimming pool when not using it, checking the leaking water at home, turning off the faucet when brushing teeth, and using dishwasher with a full load of dishes. Instead of explicitly giving them a list of water-related tasks to carry out ahead (for example, they are not told to take care of the garden without a list of tasks such as covering the swimming pool after swimming or watering the garden with sprinkler), we only instruct them to do things as “saving more water as possible”, and make choices depending on their own experience at home accordingly.
Table 4-2  Game Stories.

<table>
<thead>
<tr>
<th>Game Story</th>
<th>Description</th>
<th>Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Outside</td>
<td>On a hot summer afternoon, you invite your friends to your yard. You need to help your parents to take care of the garden.</td>
<td>Water the Garden with the Water-wise Appliance Water the Garden at the Proper Time Water the Garden in Short Time Period Water the Garden with Proper Water Flow Covering the Swimming Pool</td>
</tr>
<tr>
<td>2. Personal Hygiene</td>
<td>On a Sunday morning, before you get ready to go out, wash yourself completely. You should flush the toilet after using it. Moreover, check whether you need to wash your dirty clothes in the laundry.</td>
<td>Wash Your Face Brush Your Teeth Wash Your Body Flush the Toilet Check the Dirty Clothes</td>
</tr>
<tr>
<td>3. Meals</td>
<td>It is a Friday night. You can help your mom to prepare the food for the dinner. After dinner is ready, clean up the dishes.</td>
<td>Wash Your Hands before Preparing Food Wash Vegetables Wash Dishes</td>
</tr>
<tr>
<td>4. Maintenance</td>
<td>Keep the car clean. Check every appliance running smoothly.</td>
<td>Check whether the Car Needs Cleaned Wash the Car with Water-wise Appliance Check Leak Water</td>
</tr>
</tbody>
</table>

Figure 4-2  Game Story Example.
Appliance Types

All the interactions of participants with water appliances are categorized into three types according to how people use them in daily life (Figure 4-3). The first one is the type of multiple options on how to use the appliance in detail. For example, with the sprinkler at the garden (Figure 4-3, left), the player can select when to water the garden, how long the water flow lasts and whether with half or full flow. Appliances like the bathtub and swimming pool are defined as the second type, which participants only need to click once to complete the task. As the middle of Figure 4-3 shows, when the swimming pool is clicked, the players have completed the task of covering the swimming pool to avoid water from evaporation. The last type includes only the faucet. Compared with the second type, when the faucet is on, users have to remember to turn off the faucet in time to avoid wasting water (Figure 4-3, right). Besides these common appliances, a specific usage issue about water leaks is also addressed. Past studies have shown that leak water actually accounts for 13.7% of residential use (Mayer et al., 1999) as the fifth most water-consuming source in the home. Much of this is from leaky toilets as the City of Vancouver stated on their website. A wrench icon is added at the right down corner of each room and can be picked up to find out and fix water leaks.

Figure 4-3   Three types of interactions with water appliances (left three) and wrench for water leaks (right).

Evaluation Panel

After finishing the tasks of each scenario, participants will be asked to evaluate their actions in terms of whether they think they have done things saving water. And two
aspects of the feedback regarding their activities are implemented: the first part is adding face badge feedback, where the smiling face represents they have done well for this task while the crying one means they need improvement. The playful element usually sparks enthusiastic responses among school-age students. In addition, to increase the educational value, actionable water saving tips will be provided when over-consumption is likely or has occurred. It enables users to change their behaviour accordingly, like “You would better to water the garden with the half water flow instead of the full water load” (Figure 4-4). It assists users to translate the information on the display into an action that appropriately reduces environmental impact, besides merely telling them how much water is used and saved. Additionally, we adopted the extrinsic game element of points (2 per task) for providing data for the researcher to evaluate users’ performance, thus their intrinsic motivation could be dynamically triggered. Participants may compare their current scores with past ones, or have social comparisons with their friends and family whom they feel connected to in relevant social context.

![Figure 4-4 Self-evaluation Panel Example.](image)

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4.2. Visualization Design

Two different types of visualizations were designed and studied in our research. The pragmatic one was a set of standard bar charts, and the non-pragmatic one was the design of abstract flower representation as an example. Both visualizations are for mapping abstract residential water use data, such as the current usage, cumulative usage, and cumulative conservation, into a form understandable for users. To create and enhance connections between raising consciousness and action of individual activities, it is essential to providing information at the room-level and appliance-level (Fischer, 2008). Taking such theoretical background into consideration, in both visualizations, we group the data by rooms and consider the appliance-level as the finest data granularity.

4.2.1. Abstract Flower Pot

Inspired by the design considerations and formative insight from Chapter 2, we employ the metaphorical flower representation as the example of the non-pragmatic visualization. It was thought to be visually appealing and easy to draw more attention from the younger generation. Besides, choosing the flower is also about presenting a potential in arousing users' particular motivation in environmental sustainability. Water is essential to the bloom of flowers, and we take that analogy to indicate people that they have contributed to raising flowers by saving water.

Starting from the original version (Appendix C), for the general considerations of aesthetic appearance, ambient quality and space limitation, we modified the design for several iterations. Graphic styles (abstract or realistic), layouts, color palettes, data mappings, and degrees of animation and interactivity are explored. The ideas were fleshed out with sketches on paper and software prototypes.

The final design for the study is a non-photorealistic rendering of flower pots. The flower pot visualization embedded in the home page shows the overview usage of all rooms (Figure 4-5) while the visualization in each room only contains information of the related room (Figure 4-6, Figure 4-7). We will illustrate the home page one primarily and emphasize the differences between those in each room later. Each flower pot
represents different rooms in a house, which is mapped to the dollhouse interface. On each flower pot, there are branches representing household appliances in the room that the flower pot is mapped to. The bloom of flowers on the branches stands for positive actions towards water conservation, for example, watering garden with the collected rainwater in the butt, turning off the faucet after using it and taking a shorter shower instead of the bath. The size of the flower petals is corresponding to the amount of water conserved of the appliance: the larger the flower, the more water is saved. The bars behind the flower pot use different colors to distinguish between the used water and saved water. The blue bar at left indicates the accumulative water usage in the related room: the higher the bar is, the more water is consumed. While the green bar shows how much water is saved totally in the room: the higher the bar is, the more water is saved. Additionally, two abstract water meters are added at the up left corner to reflect the current water use (Liter) and total water use (Liter) accordingly in the house, which is self-explanatory. The choice the meter is based on the idea that people are familiar with reading the water meter to get information of their water consumption at daily life.

Figure 4-5 Abstract Flower Pot Chart at home page.
As Figure 4-6 shows, the flower pot is placed on the right wall of each room uniformly presenting only the information of this room. The layout, size and color style of the flower pot make it integrate gracefully with the room interface and meet the ambient
requirement. By clicking the flower pot, users could see an enlarged visualization with the appliance name mapped to the single branch additionally (Figure 4-7). Also, the wooden frame adds aesthetic value to the visualization.

4.2.2. Bar Chart

The bar chart was included in the design of the pragmatic visualization because people even children were familiar with it in their everyday lives and also it fits for the quick comparison among the data.

As shown in Figure 4-8, the bar chart design consists of two bar charts. The upper one presents the cumulative usage and current usage of water with separated measurement units, while the lower one shows how much water is saved. Except standing for different data sets, both charts are similar in the layout. The x-axis is a list of household appliances grouped by the rooms in the house. The color of the bars matches the attributes of the y-axis, which indicates the dimensions of the corresponding data: blue for total used water, brown for current used water and green for saved water. The color and layout of the bar chart are specially designed for aesthetic reasons. Same as the flower pot one, the bar chart in each room only shows the usage and conservation of the specific room instead of the general one (Figure 4-9).

![Bar Chart at home page.](image)
Figure 4-9  Bar Chart at Garden Page.

Data features of the above two visualizations are summarized in Table 4-3. The goal of both visualizations is to represent users’ water usage in the game but in different ways.

Table 4-3  Summary of data features of both visualizations.

Note:  “×” for having the specified feature, “-” for not.

<table>
<thead>
<tr>
<th>Data Feature</th>
<th>Flower Pot Chart</th>
<th>Bar Chart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status of individual appliance</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Cumulative water usage of individual appliance</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Cumulative water usage of all appliances</td>
<td>×</td>
<td>-</td>
</tr>
<tr>
<td>Current water usage of individual appliance</td>
<td>-</td>
<td>×</td>
</tr>
<tr>
<td>Current water usage of all appliances</td>
<td>×</td>
<td>-</td>
</tr>
<tr>
<td>Number of positive actions</td>
<td>×</td>
<td>-</td>
</tr>
</tbody>
</table>

Through the design process, these two visualizations were decided to be integrated into the game, as a part of the eco-feedback system. Both of them are
considered as research instruments in this research to explore their potential of helping people have the stronger awareness of water usage at home. But, there were issues and conflict ideas around the design which can be an inspiration for future new designs. First, currently, the heights of the bars are scaled with equal proportion, while the large difference between water usages of various appliances may cause that some bars are too low to read. Scaling data with exponential proportion or other alternatives can be explored. Second, the power meters aren’t embedded gracefully with the flower design and looks abrupt in the picture. A better way to present such data needs to be discussed in the future. Moreover, limited by the space, only maximum of three flowers could bloom as a reward for each appliance.

4.3. System Implementation

The system (including the dollhouse and the visualizations) was developed with JavaScript (with the D3js library). (link: http://waterconsumption.iat.sfu.ca/). It is a web application with high flexibility. It can run on different platforms and compatible with most web browsers. The data is kept in a MySQL database secured on the SIAT lab server.

![System Architecture](image)

*Figure 4-10  System Architecture.*
The system is structured as Figure 4-10. The water (Litre) information of how much water is consumed per time and how much water will be saved as potential effects if water saved facilities or actions are taken comes from the website Home Water Works (link: http://www.home-water-works.org/calculator). The data is stored in the MySQL database. The dollhouse interface loads the appliance water data from the database on initiation and uses the information to calculate the appliance’s actual water consumption and conservation. Every 30 seconds in the simulated system is treated as an hour. The dollhouse then sends the water information back to the MySQL database along with the appliance status (on/off) information. For research purpose, every user’s interaction in the game and their evaluation result is logged into the database for further analysis. To reflect the changes of total consumed and conserved water data into visualizations timely, the system pulls the required data from the database every 0.1 seconds.

Figure 4-11  Display Medium.

Figure 4-11 shows the display medium of the system for the user study. Two different sizes of displayed are implemented under specific user study situations. The left one is an 11 inch iPad (running iSO), and the right one is an around 50 inch touchable screen hanging on the wall (running Windows). Users can touch on the appliances to turn them on and off, and visualizations are all displayed in the same frame.
5. **User Study A**

We conducted this pilot user study with individuals in the public space, such as at the public library. In this study, we explored which of the pragmatic and non-pragmatic visualizations is preferred by users through the quantitative analysis of users’ ratings and the cued-recall debrief. Through the thematic analysis, we explored whether users can discover something new from the game experience, whether they can easily understand the charts. In addition, we can assess how their general experience with the charts and game. Moreover, we would like to glean some design insight as a motivation for our next study. There were limitations because we set all the users to complete the game tasks in the same order.

5.1. **Procedures**

In this study, the participants are nine school-age children recruited through posters in public libraries and through the personal contacts of the researchers. Some participated in the study individually, some with their parents, and some with their friends. Due to privacy concerns of the participants, five of the study sessions were done in public libraries and four were done in the researchers’ laboratory.

The study took around 30-45 minutes, which included four major related activities: the pre-game interview, game session, post-game questionnaire, and open-end interview through a cued-recall debrief at the end.

First, a pre-game interview for around 5 minutes was conducted to gain an overview of the participants’ knowledge about water usage in their homes. Five questions were asked regarding the total water usage of the house, the appliance that uses the most water at home, the conservation actions that might be taken at home to save water, and the knowledge of particular consumption activities (Appendix A-1). They all provided demographic information, including gender and grade.
Before starting with the game, a short introduction and tutorial of the dollhouse interface were given, and participants were encouraged to freely explore the game installation until they felt prepared to start the game. Then, they were left alone in the room to play the game, and the length of this section varied from 20 to 30 minutes. The participants were asked to complete all four tasks. They were assigned to one type of visualization for first two game stories (participants with odd participant numbers were assigned the flower chart, and the others were assigned the bar chart), and then switched to another type for the other two stories. Researchers used screen recorder software to record participants’ activities in the game during this process. This video was used for cued-recall debrief at the end of the study.

After the game, the participants were required to complete a questionnaire on their impressions of the visualizations (Appendix A-2). Impression questions included whether the visualization was easy to understand, interesting, and aesthetically appealing and how the participant liked the visualization in general. Participants were asked to rate the statements on a 5-point scale (strongly disagree, disagree, neutral, agree to strongly agree). The location preference question provided a list of four rooms (e.g., bathroom, kitchen, laundry and living room) for the participants to choose.

Finally, at the end of the study session, subjective data were collected through the cued-recall debrief and open-end interview. The researcher replayed the video of their activities to prompt their thoughts, feelings, and experiences retrospectively. The rationale for choosing this approach is that, the players could use contextual factors to explain how the novel feedback design affected their decisions and behaviours in the game. They were also encouraged to voice any opinions and comments toward the game and visualizations. The interviews were audio-recorded and then transcribed and analyzed using NVivo: a qualitative analysis software that helps researchers organize and analyze rich text-based data. As a limitation, only one coder was involved in transcribing this section of data. However, the interview was short, and the questions were structured. Therefore, the coding was very straightforward.
5.2. Methods

5.2.1. Cued-Recall Debrief

Omodei et al. (1994) developed cued-recall debrief (CRD) to elicit thoughts, affect, emotion, and cognitive experiences of the user when they are using a system. Compared with free recall where some individual trends to not reporting what actually occurred, CRD has provided a better representation of the actual thoughts and feelings of an individual. CRD, as an evaluation approach, cannot only evaluate various aspects of the user experience, but also provides the insight regarding what aspects of design are creating user affective experiences and what the affective experience actually is. Such information can then be fed back to the designers for future improvement.

The CRD methodology is straightforward to apply. Firstly, researchers should videotape the activities being performed by participants from their first-person’s point of view. If the activities are static, such as working at a computer, researchers can video the screen or using screen-capture technologies, whereas the activities are dynamic, a head-mounted camera can be used to video whatever the participant is looking at. As soon as possible after the activity has been completed, the researcher and the participant sit down together to watch the video. The participant will become re-immersed in the activity because the video was taken from the first-person’s point of view and the replay is exactly what he/she previously saw (Bentley, Johnston & Baggo, 2005). During this process, he/she can voice his/her thoughts and feelings freely. The researcher should be good at querying the participant what they were thinking or feeling at that time and eliciting responses from participants that could answer research questions. The video replayed can be paused to give participant more time to comment fully on a particular moment.

The next step the researcher should do is to examine the debrief comment critically, construct an overall view of the user experience and identify the key points of what design aspects influenced their activities and how they impacted them in making decisions and performing behaviours.
5.2.2. Thematic Analysis

To analyze qualitative data, thematic analysis is an accessible and theoretically flexible approach. It identifies, analyzes and reports themes within data. Here, we followed the steps suggested by Braun and Clarke (2006) to do thematic analysis on transcripts of cued-recall debrief data and observations notes of workshops (Table 5-1).

Table 5-1 Phase of Thematic Analysis (Braun & Clarke, 2006).

<table>
<thead>
<tr>
<th>Phases</th>
<th>Description of the Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Familiarizing yourself with your data</td>
<td>Transcribing data (if necessary, reading and re-reading the data, noting down initial ideas.</td>
</tr>
<tr>
<td>Generating initial codes</td>
<td>Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.</td>
</tr>
<tr>
<td>Searching for themes</td>
<td>Collating codes into potential themes, gathering all data relevant to each potential theme.</td>
</tr>
<tr>
<td>Reviewing themes</td>
<td>Checking if the themes work in relation to the coded extracts and the entire data set, generating a thematic “map” of the analysis.</td>
</tr>
<tr>
<td>Defining and naming themes</td>
<td>Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme.</td>
</tr>
<tr>
<td>Producing the reports</td>
<td>Selection of compelling extract examples, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis.</td>
</tr>
</tbody>
</table>

5.3. Data collection

Table 5-2 summarized the research questions, the data collected in study A. Through the analysis of system logs, questionnaires and cued-recall debrief open-end interview, we answered research questions.
Table 5-2  
Data Collection of User Study A.

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Can both pragmatic and non-pragmatic visualizations assist children in understanding water use and decision making towards water conservation?</td>
<td></td>
</tr>
<tr>
<td>1a. Do these visualizations help users perform better or make better self-evaluations in the simulation game?</td>
<td>Pre-Game Interview</td>
</tr>
<tr>
<td></td>
<td>Cued-Recall Debrief</td>
</tr>
<tr>
<td></td>
<td>Open-end Interview</td>
</tr>
<tr>
<td>1b. How do users like the reward mechanism in the visualization?</td>
<td>Cued-Recall Debrief</td>
</tr>
<tr>
<td></td>
<td>Open-end Interview</td>
</tr>
<tr>
<td>2. Can this simulation game help children learn about water use?</td>
<td></td>
</tr>
<tr>
<td>2b. How do participants like the gamification techniques such as the actionable tips, points and badges?</td>
<td>Cued-Recall Debrief</td>
</tr>
<tr>
<td></td>
<td>Open-end interview</td>
</tr>
<tr>
<td>2c. Do these techniques help them to gain new knowledge about water conservation actions and affect their decision-making?</td>
<td>Cued-Recall Debrief</td>
</tr>
<tr>
<td></td>
<td>Open-end interview</td>
</tr>
<tr>
<td>3. What insight this water feedback which combines visualizations and gamification techniques can provide for the future design of such game for children?</td>
<td>Cued-Recall Debrief</td>
</tr>
<tr>
<td></td>
<td>Open-end interview</td>
</tr>
</tbody>
</table>

5.4.  Results

5.4.1.  Participant Demographics

All nine participants were school-age children with the youngest in Grade 5 and the oldest in 10 as Figure 5-1 shows. We have the particular interest with this grade group because children begin to learn knowledge of water resource and conservation from as early as Grade 2 (Abbotsford Mission Water & Sewer Commission, 2013; BC Ministry of Education, 2016). The children at this age group already have some knowledge of water use.
Figure 5-1  Participants’ demographics of User Study A.

All our participants had no idea about their family monthly water use. They were not exposed to any form of water feedback in their house, nor were they ever intended to learn about any current feedback that was available to them. All participants had a sense of which appliance in their homes used the most water and they were able to name several actions that they might save water at home. They gained the knowledge mainly from parents and school. 4 of the 9 participants answered “shower” and 2 mentioned “sink” used the most water. The most commonly answered conservation actions were: “Turning off the faucet when brushing teeth”.

5.4.2.  Thematic Analysis

Through thematic analysis, the audio recordings of Cued-Recall Debrief with individuals were coded and categorized into defined themes (Table 5-3).
Table 5-3  Number of Codes from Cued-Recall Debrief Fall into the Identified Them.

<table>
<thead>
<tr>
<th>Main Category</th>
<th>Theme</th>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information processing</td>
<td>Discover something new</td>
<td>7</td>
</tr>
<tr>
<td>Information processing</td>
<td>Difficult to understand charts</td>
<td>7</td>
</tr>
<tr>
<td>Information processing</td>
<td>Easy to understand charts</td>
<td>18</td>
</tr>
<tr>
<td>Quality of the experience with charts</td>
<td>Negative experience</td>
<td>9</td>
</tr>
<tr>
<td>Quality of the experience with charts</td>
<td>Positive experience</td>
<td>11</td>
</tr>
<tr>
<td>Quality of the experience with the game</td>
<td>Negative experience</td>
<td>2</td>
</tr>
<tr>
<td>Quality of the experience with the game</td>
<td>Positive experience</td>
<td>9</td>
</tr>
<tr>
<td>Preference of visualization designs</td>
<td>Flower pot chart</td>
<td>10</td>
</tr>
<tr>
<td>Preference of visualization designs</td>
<td>Bar chart</td>
<td>8</td>
</tr>
</tbody>
</table>

**Information Processing**

Participants learned new knowledge from the feedback. P3 was confused about the water butt in the garden and why it didn’t use any water. She then discovered that “we can use the collected rainwater in the butt to water the garden.” The feedback also helped them to recall the previous experience. P1 said, “I am curious about the wrench but I don’t know what I can do with it... Oh, this is pretty a good idea. We usually overlook the leaking water. I was told that leak water could waste lots of water, but I don’t know we should check it regularly.”

They could mostly read the pragmatic bar chart to some degree. However, without the introduction of how the aesthetic visualization represents the underlying data, most participants thought the flower was designed to stand for how water is being used rather than being saved. Through several tries on various appliances, most could successfully discover the correct meaning of the representations, with P4 as an exception. Moreover, P5 reflected that the general experience of the game could help in understanding the meaning of the flower.

**Quality of the Experience with Charts**

Generally, participants were satisfied with both visualizations as water information display. Visualizations helped them to know “what you did and how well or bad you did. (P2)” Some of the participants who were familiar with bar chart mentioned
that “I like bar firstly because I can learn from it quickly. But after I know how the flower one works, I like it either.” In addition, P9 repeatedly clicked the mug and the half flush of the toilet with the explanation that “I like flowers, this is why I do this.” All females of the participants favored the flower representation because flowers were thought to be attractive, appealing, and not intrusive to the game environment. Moreover, they understood the conceptual relation between “saving more water” and “raising more flowers.” Both charts were thought to have advantages, as P1 said, “both of them are really good together. “and “Bar chart give actual information and flower give ‘Oh, you should do this, it is good’ immediate information.”

Quality of the Experience with the Game

The gamification techniques proved to be effective in raising users’ awareness of water saving and sustaining their interests. In addition, P1 expressed how he liked the game as “I think the whole game idea is very cool. It helps me to know various ways we may use water at home and which can save water. I also like the idea of setting difference scenarios, so we can roughly know what we should do in the game.” Moreover, we found P3 and P9 replayed some of the stories several times. P3 commented that “after I first evaluated my performance, I am very surprised to see that I didn’t receive full points. I tried to find out where I failed. Then I learned more about tips in saving water. For example, we can use the collected rainwater in the butt to water the garden and leave the car dirty if it is not too dirty.” Further, P9 was excited to see the smiling face and the tick mark to prove his correct actions, yelling "yes" every time.

Participants also gave negative comments on some details of the game design that made them confused. They proposed suggestions on how to improve the game experience. For example, P8 explained why she continuously clicked the dirty dishes as “I don’t know whether I have completed the task yet. The game should give us some reminder if the task is done.” Most participants had no idea that leaking water wastes much more water than expected and that we should check it regularly. Most of them were curious to see the wrench in the game and eager to pay attention to any leaks at home but suggested that hints should be given to guide them to fix the leak with the wrench. Some participants thought they did not learn as much as they expected, because “My parents have taught me most of the tips to save water at home. The game is too easy for me (P2),” and “You can set more difficult levels then I can feel more
exciting. You should not tell what task they should do.” (P7). Moreover, P1 pointed out that the “play” mode should support performance comparison among different stories. Thus, he could have an overview of the total consumption situation.

Preference of Visualization Designs

During the cued-recall debrief, P3 presented her strong preference for the aesthetic visualization, as “the flowers are so cute. I want to see more flowers blossom.” However, P6 had the opposite opinion and said that “the flowers are too girly. I don’t like. I am a boy, and I would like to see more ‘boyish’ designs.” P2 proposed that the preference for visualizations may vary among different age groups, as he said: “It is easier for the younger child to understand the flower chart than the bar chart.”

Figure 5-2 shows the quantitative analysis of how participants rated both visualizations based on four different criteria (interesting, aesthetic, easy to understand and general preference) in the post-game questionnaire (Appendix A-2). They were given a 5-point scale where 1 point represents that they disagree with the related criteria and 5 points represents they agree with it. Generally, participants preferred the aesthetic visualization (flower pot) than the pragmatic visualization (bar chart). Concerning comprehension, the aesthetic visualization was thought to be a bit easier to understand. Both visualizations were thought to be somewhat interesting and aesthetic. Figure 5-3 shows this difference across genders, where females thought the aesthetic visualization was more interesting and aesthetic, whereas the males gave the opposite results.
Figure 5-2  Participants’ impressions on different visualizations.

Figure 5-3  Participants’ impressions on different visualizations by genders.
5.4.3. **Preferences of Location at Home**

To analyze participants’ preference of the locations for the visualization display, we asked them to score the locations on a 5-point scale where 1 point represents the least preferable, and 5 points represents the most preferable option. Figure 5-4 indicates that there is no obvious difference among the four given locations (bathroom, kitchen, laundry, and living room) and that the kitchen and bathroom were a bit more preferred by participants.

This finding was similar to the findings of Rodgers and Bartram (2010) concerning their ambient and artistic visualizations of point-of-consumption energy use feedback. Both showed that people had the desire for some sort of energy use feedback in their homes to keep them informed, regardless of the form. They preferred the feedback in high-traffic places where they spent the most time and used the most energy, especially the living room and kitchen. They would also like to have them in multiple rooms in their homes.

![Figure 5-4 General preferences on location at home.](image)

5.5. **Discussion**

The results of this pilot user study can directly or indirectly answer our research questions to some degree. Participants gave positive feedback on combining
visualizations with the simulated game environment as a promising residential water-feedback system. We obtained participants' preferences on both pragmatic and non-pragmatic visualization designs, their preferences for the locations of the information display at home, their impressions on the gamification techniques, and information on how participants think on the explicit representation as the reward mechanism in motivating positive actions.

We received positive comments from the participants on both visualizations as effective feedback for home water use. In the post-game ratings, both were thought to be similar to the criteria of interesting and aesthetic. This finding is outside of our expectations because we considered the aesthetics to be an important attribute to the design of the flower pot chart, but it did not win over the bar chart design. By reanalyzing the data by gender, we determined that differences exist across genders and females rated the flower pot design as more interesting and aesthetic, while the males presented the opposite results. In addition, P6 stated that the flowers were too 'girly' for boys. In addition, the comprehensibility of both visualizations was proved by the high scores, and the flower design was rated as much easier to understand than the bar chart design.

The current focus of our research is on exploring the effectiveness of the single visualization by asking users to use one specific visualization in each story game. The above results indicated that there was no apparent difference between the users' preference for the two visualizations; rather, it seems that people like the combination of both visualizations. We would like to explore how these visualizations are used together to gain some design insight as a motivation for the next study.

For our second research question, the simulation game proved to be an engaging tool to motivate them to take wise actions. Moreover, the actionable tips, points, and badges turned out to be fun and attractive gamification strategies in arousing participants' awareness of the gap and gain of new knowledge. They can also sustain the users' interest for a long period. For example, they were feeling excited to see the high scores and were motivated to take the informed actions continuously (P9). Meanwhile, when they were given low points, they wanted to read the actionable tips
and replay the game to practice the actions or presented their willingness to follow the tips to save water in the future (P3 and P9).
6. User Study B

User Study A, which explored the effectiveness of the single visualization, indicated that users have no stronger preference for either of the two visualizations. It motivates us to explore how these visualizations could be used together and to gain some more design insight in User Study B. We choose a design study method of observation to determine how and what children could gain from the game and how they would use the visualizations, if they were given the freedom to switch between two visualizations at any time.

First, we compared the participants’ answers on the pre-game questions and post-game debrief to understand their knowledge of residential water, and whether they gained new knowledge from our design. Second, the qualitative analysis of the game logs reflects how much participants know about water conservation or how much interest participants had in the specific activities. Third, we analyzed their game performance, with special attention to the difference between their actual scores and perceived scores, from which we tried to determine whether their awareness and behaviours were consistent. Finally, we conducted a thematic analysis to explore their experience with the game and visualizations and aimed to glean design insight on residential water feedback.

6.1. Procedures

Study B recruited participants from Green Energy workshops organized by PICS at SFU, and they played the game in groups. In each group, there were four to six students, and each study took around 15 minutes. This study consists of two workshops: children from Grades 5 and 6 played the “play” mode of the game and children in Grades 3 or 4 were required to play the “explore” mode.
In the beginning, both workshops conducted the same short pre-game questionnaire, which included three questions to elicit participants’ knowledge about residential water consumption on the total water usage of the house, the appliance that uses the most water at home, and conservation actions that might be taken at home to save water (Appendix B-1).

Then, after a short tutorial of the dollhouse interface, students in the first workshop were asked to complete given tasks directly without being provided questions in the post-game debrief (Appendix B-2). They could not complete the questionnaire until they finished the game session. In the second workshop, children were given a set of questions about the water use situation at home first, and they could play in the game freely to find the answers in the “explore” mode. All groups were randomly assigned to see one of the two visualizations as the initial display, and they could switch between them without limitations. The game data were digitally logged by the system itself, which contained basic information of the participant (user gender and school grade), the game scores for each story task (actual score and self-evaluated score), and the log of all interactions that participants made during the game. The data were analyzed using descriptive statistics and visualized using Tableau. The researcher took observation notes during the game session on how they performed in the game, and what they discussed regarding the game and visualizations. These notes then were transcribed and analyzed using NVivo. The external coder was also involved in transcribing the data to verify that we would reach an agreement.

6.2. Data collection

Table 6-1 listed the research questions, the data collected in the User Study B, and how to measure and analyze these questions with such data. Conducting mixed-method user studies proved to be viable for grasping valuable insight into the information visualization design (Ellis & Dix, 2006; Pousman, Stasko, & Mateas, 2007; Sprague & Tory, 2009). We collected the data of the detailed analysis of system logs, questionnaires, and observation notes in both workshops. We sought to explore how non-pragmatic visualizations can affect children to enhance awareness of water use with or in place of pragmatic visualizations, whether a simulated game is valid in helping
them learn about water use, and what insight can be provided by this water-feedback design that combines visualizations and gamification techniques.

**Table 6-1  Data Collection of User Study B.**

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Can both pragmatic and non-pragmatic visualizations assist children in understanding water use and decision making towards water conservation?</td>
<td>Pre-Game Questions</td>
</tr>
<tr>
<td>1a. Do these visualizations help users perform better or make better self-evaluations in the simulation game?</td>
<td>Post-Game Debrief</td>
</tr>
<tr>
<td>1b. How do users like the reward mechanism in the visualization?</td>
<td>Observation notes</td>
</tr>
<tr>
<td>2. Can this simulation game help children learn about water use?</td>
<td></td>
</tr>
<tr>
<td>2a. What does this simulation game suggest about people’s understanding of how to conserve water at home?</td>
<td>Log files of user interactions</td>
</tr>
<tr>
<td></td>
<td>Log files of game scores</td>
</tr>
<tr>
<td>2b. How do participants like the gamification techniques such as the actionable tips, points and badges?</td>
<td>Observation notes</td>
</tr>
<tr>
<td>2c. Do these techniques help them to gain new knowledge about water conservation actions and affect their decision-making?</td>
<td>Post-Game Debrief</td>
</tr>
<tr>
<td>3. What insight this water feedback which combines visualizations and gamification techniques can provide for the future design of such game for children?</td>
<td>Observation notes</td>
</tr>
</tbody>
</table>

6.3. Results

6.3.1. Participant Demographics

User Study B consists of two workshops (Figure 6-1). In both workshops, all 56 participants were school-age children. In Workshop 1, there were 36 participants, including 20 participants from Grade 5 and from Grade 6. In Workshop 2, five of the 20 participants were from Grade 3 and 15 participants were from Grade 4.
6.3.2. Participants’ Understanding of Residential Water

In this section, to understand where participants understood, not understood or “forgot” residential water, and determine whether they gained new knowledge from our feedback system, we collected the participants’ answers in both pre-game questions and post-game debrief, and compared those under the same question.

Most of the participants admitted that they had no idea of how much water they or their family use every month (Figure 6-2). Few of them ever thought about discussing about this issue with their parents. Only seven of them gave the right answers that were around the average consumption amount in BC which is 3000-8700 liters depending on the family size. And six of them thought they know the answer, but their numbers were much smaller than the average amount. It indicated that the gap still exists between their awareness of water consumption and the actual situation. More participants in Grade 5 gave the right answers than other Grades, and even more than Grade 6. They
had such particular performance because these participants just attended the water conservation lecture held by the city of Surrey two weeks ago.

Most participants had a sense of which appliance in their homes used the most water. Before participants played the game (Figure 6-3), out of 77 answers, 36 of them indicated that the bathtub, shower, and sink consume the most water at home, and only one answered that it was the hose. Participants thought that appliances they used most or were familiar with usually use the most water. The pro-game chart shows the data quite differently (Figure 6-4), where the number of participants who thought the hose consumed the most water at home increased to six and the number who thought the “sink” decreased to two. In real life, the hose indeed consumes more water than the sink and the faucet, even though the kids use the sink and the faucet much more often. Moreover, eight of them mentioned that swimming pools, washing cars and sprinklers consume the most water at home, which was not selected by anyone before the game. This finding proved that the children gained new knowledge about water use at home from our feedback design.
**Figure 6-3** Pre-Game Questions: Which appliance use most water at home.

**Figure 6-4** Post-Game Debrief: Which appliance use most water at home.
Before playing the game, most participants could name at least one action that they might take at home to save water (Figure 6-5). “taking shorter shower”, “turning off the faucet when brushing teeth” and “not leaving faucet on” were three primary ways to save most water at home. Specifically, six participants in Grade 5 also mentioned: “wait for the full load of laundry” (Figure 6-6).

![Figure 6-5 Pre-Game Question: Name three activities you may do to save water at home.](image1)

![Figure 6-6 Pre-Game Questions of Grade 5: Name three activities you may do to save water at home.](image2)
After the game (Figure 6-7), some positive actions were mentioned more times than previously. For example, the count of “half flushing toilet” increased from one to 11, “covering the swimming pool” increased from zero to seven, and “leaving the car dirty” increased from one to four responses. Participants gained knowledge from the feedback.

The game helped them explore other potential water-wise actions that they may not have been familiar with before, such as car washing and leaking water. Through playing the game, six more participants thought that if the car is not very dirty, just “leaving the car dirty” could save lots of water. Two of them considered stopping the leaking water to save water, which was not mentioned before the game.

In addition, their answers tended to be more specific than previous answers. For example, in saving water in the garden, the answers were more general, such as watering the garden properly and using less water, whereas, after the game, they gave more details, such as watering the garden with collected rainwater in the water butt and watering the garden at night.

![Bar Chart](chart.png)

**Figure 6-7** Post-Game Debrief: Name three activities you may do to save water at home.
6.3.3. Game log

The game log records participant’s interactions with the game interface, i.e., when to water the garden, at night or daytime. The number of the game logs could be an important aspect to be analyzed in this study, because it directly reflects how much participants know about water conservation or how participants are interested with the specific activities. The more records indicate that the participants need more efforts to complete the game tasks or they are more curious about exploring the game.

![Figure 6-8](image)

**Figure 6-8** Number of game logs by individual appliances.

Figure 6-8 showed a significant difference among the number of participant’s interactions on different appliances. The bathtub, faucet, laundry, toilet, swimming pool and water butt had higher clicks. We can conclude two possible reasons to explain this finding. First, the children were familiar with them in daily life, such as the bathtub, faucet, washing machine, and toilet, which were also mentioned with high frequency in the pre-game questions. Second, interactions with these appliances, such as the swimming pool and water butt, can result in more obvious changing effects in visualizations, for example, larger flowers or higher bars. These changes tended to raise the interest and curiosity of the participants and engage them more in conservation actions.
Figure 6-9  Number of game logs by individual selections in the garden.

Figure 6-10  Number of game logs by individual selections of (a) washing dishes; (b) washing clothes; (c) faucet.
Figure 6-9 and Figure 6-10 take a more detailed look at the number of game logs on individual selections by different appliances or tasks. Notably, for the task of watering the garden (Figure 6-9), most participants clicked “half flow” and “15 mins” to save water with both the hose and sprinkler. However, most of them thought that watering the garden during the daytime could save water, which is false. More informed decisions were made on the task of washing dishes (Figure 6-10(a)) and washing clothes (Figure 6-10(b)), which participants were familiar with. The numbers of records on “turn off the faucet” was smaller than “turn on the faucet” in both the bathroom and kitchen (Figure 6-10(c)). Even “turning off the faucet when brushing teeth” was mentioned as a primary way to save water in the pre-game questions; yet, some of them still forgot to do so in the game. This finding indicated that a gap existed between their knowledge and actions.

6.3.4. Game Performance

In our user study, the participants in Workshop 2 played the game in “play” mode, and the system logged their game performance, including the actual game scores and user-perceived game scores. The difference between their actual scores and perceived scores reflected whether their actual behaviours were consistent with their knowledge and awareness of water conservation.

By tasks

Scores, both actual (Figure 6-11) and perceived (Figure 6-12) varied greatly for each game task. Participants did best with “wash dishes” and “water the garden with the proper water flow” and they also perceived themselves to have done well in those tasks too. These results indicated that participants had the firm knowledge of saving water with those actions. Their actual scores were low in some tasks, including “water the garden with the water-wise appliance”, “water the garden at the proper time”, “brush teeth” and “wash your body”. However, they didn’t seem to realize their poor performance in those tasks as they rated themselves much higher than the actual scores. In other words, large negative delta values (negative delta values are represented in red color, positive values in green color and zeros in blue color) in Figure 6-13 showed that a gap existed between their knowledge and actual behaviours. Relating to our third question in the pre-game questions, although “turning off the faucet when brushing
"...and "taking a shorter shower" were mentioned by many participants as one method of water conservation, it was not done in practice in this simulation game. As for "check whether the car needed cleaning," some children said that they were unfamiliar with it and that it was not something they would normally consider, but they learned this knowledge from the game and would tell their parents to save water when cleaning the car.

Figure 6-11   User Actual Game Score by Tasks.
Figure 6-12  User Perceived Game Score by Tasks.

Figure 6-13  Delta (actual score – perceived score) by Tasks.
By groups

Figure 6-14, Figure 6-15, Figure 6-16 below illustrate game performance for each game story by groups in terms of the actual game score, user perceived game score and the difference between the two (delta). Generally, most groups didn’t realize their poor performance, and they rated themselves to much higher than the actual scores. Figure 6-16 showed that around half of the total tasks got large negative delta values in red color. All other groups tended to give themselves full scores for most tasks they completed, but only G5 got the actual full scores for all tasks in the story of “Outdoor” and G8 had the same good performance in the story of “Maintenance”.

The average actual scores of G7 were mostly higher than the perceived ones. This resulted from the fact that this group liked to click different options that were not optimal to explore how water was used in various activities. “Click Flow water. No, we have no flower, try the other one (G7)” . They also had an interest in the player scores and replayed the game until they were satisfied with their high scores. “Yes, I have 6 scores!” They discussed it a lot and sometimes gave suggestions to others on how to improve based on the feedback of the game, as “You should turn off the tap after use. You should water garden at night. I see, water butt saves lots of water, I don't use that before. “ Additionally, G2 explained why they received low actual scores on some tasks, as “We don't know what flowers mean when we first noticed them. But then we keep playing the game, try different options to see why we have flowers.” They were asked by the teacher to pay special attention to the charts because they rarely enlarged the charts and focused more on the game results.

Among all groups that have fixed the leaking water, except G2, the participants’ perceived performance was the same as the actual performance. In other words, the delta values were zeros (in blue color). We observed that the wrench usually aroused their curiosity about what they could do with it. They would like to pay attention to explore everywhere and discussed how to fix the leak. “Try to click this (wrench), use it to see what will happen... There is leak water! fix it! (G1).” “Oh, we find it. It will not waste water anymore (G2).” “Hey, click this (wrench). What can we do with it? (find out leak water and fix the appliance) oh, so it stops to waste the water (G5).” All groups that completed the task of “covering the swimming pool” also had the same perceived and actual scores. They were impressed by the large amount of water saved by “covering
the swimming pool” and the obvious changes of the bar chart and flower pots. “Wow, the bar is so high! I know, we saved lots of water, because if we cover the swimming pool, we can keep water from evaporation (G3).” In addition, G1 kept clicking the swimming pool to see the bar raising and the flowers blossoming, “We have flowers, click (swimming pool) again. The bar is out of frame, stop keeping click it! (G1).”

Figure 6-14  User Actual Game Score by Groups.
<table>
<thead>
<tr>
<th>Grade</th>
<th>Group</th>
<th>Maintenance</th>
<th>Meals</th>
<th>Outside</th>
<th>Personal Hygiene</th>
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<tbody>
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<tr>
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</tr>
</tbody>
</table>

**Figure 6-15**  User Perceived Game Score by Groups.
6.3.5. **Thematic Analysis**

Table 6-2 presented the number of the workshops’ observation notes per theme related to the three main categories of feedback design.
Table 6-2  Number of Codes from Workshop Observation Notes Fall into the Identified Themes.

<table>
<thead>
<tr>
<th>Main Category</th>
<th>Theme</th>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information processing</td>
<td>Discover something new</td>
<td>31</td>
</tr>
<tr>
<td>Information processing</td>
<td>Difficult to understand charts</td>
<td>11</td>
</tr>
<tr>
<td>Information processing</td>
<td>Easy to understand charts</td>
<td>29</td>
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<tr>
<td>Quality of the experience with charts</td>
<td>Negative experience</td>
<td>11</td>
</tr>
<tr>
<td>Quality of the experience with charts</td>
<td>Positive experience</td>
<td>19</td>
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<tr>
<td>Preference of visualization designs</td>
<td>Bar chart</td>
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</table>

Information Processing

Participants were excited to master new knowledge or recall previous knowledge from the feedback. The knowledge of “fixing the leaking water” was mentioned with the highest frequency (G1, G2, G5, G7, G9, G13, G14). The wrench icon aroused their curiosity, and they tried to explore how it worked. They pointed out that “We learned about leak water waste lots of water. But we didn't have a sense of checking it before. (G14)” and “Try to click this (wrench), use it to see what will happen. There is leak water! Fix it! (G1).” The game offers children various ways of using water, some of which they may have not ever tried in real life before. For example, some groups discussed how and when to water the garden. They concluded that watering garden with collected rainwater could save more water than using the hose, and that watering flowers at night could vaporization. The presence of large flowers motivated them to discuss why covering the swimming pool could save so much water, and one of them explained that “It can keep water from evaporation (G3).”

The meanings of the bars in both visualizations could be understood quickly by the majority of participants, as “I know the bar chart before, I know how to read it. I think it is easier for me to read (G13).” The real-time changes of the bars can affect the participants’ performance in the game immediately-- “Stop clicking the bathtub, the bar is too high. It is out of the frame. (G1)” and “why the bar is keeping growing... Oh, there is leak water (G13).” Groups from different grads had different understanding levels of the
bar chart. The participants from grade 5 and 6 were more familiar with the bar chart than those from grade 3 and 4. However, a few kids easily forgot the exact meaning of each bar during the game and asked several times: “Can you tell us again what do these bars mean? (G14)”

We also noticed that if there is anyone in the team could understand the charts quickly, he or she might lead the team to understand the charts through interactions and communications.

Most groups noted that flowers are a reward for their actions that saved water. G3 discussed, “What is this?… (water butt, you can water garden with collected rainwater) Oh, we can use it. Yes, we didn't use any water, we get a flower.” Some kids misunderstood the meaning of the flower in the game, and once told, they were attracted by the flowers and were eager to see more. For example, G14 mentioned that “I thought the flower should mean how much water we used. But after you ask us about this question, I pay attention to it. Now, I got it. It means how much water we saved. I like flowers.” However, a few groups could relate the size of the flowers with the amount of saved water, except G10, which discovered that “The larger flower, the more we saved.”

Only two groups (G8 and G9) noticed the two meters that measure the cumulative water usage and saving for all rooms, but they both asked, “What is this?” and could not grasp how they worked immediately. Other groups did not even pay any attention to them. G9 suggested that “I think you should have this in each room. So, when I put the bar chart in room, I can know faucet is running water now. “ Additionally, the problem of how to scale the axis properly was raised. “I cannot see how much water I used in the faucet (which is the tiny amount of water compared with other consumption), you can make it clearer (G10).”

**Quality of the Experience with Charts**

Participants’ comments highlighted the ambience attribute of the aesthetic visualization. The graphics flower and flower pots can be integrated into the game environment harmoniously. With the flower visualization, we received lots of positive feedback on its ambience attribute, as “In this small space (small frame on the wall), I can know I saved water, or I wasted water easily (G7).” and “Flower pots can show all
information in this small frame. I needn't enlarge it (G10).” However, some participants complained about the high visual complexity of the bar chart, as “The bars in the small space are not clear, I cannot understand it quickly when I am playing the game (G7).” “There were so many texts and bars in small space, too narrow, I cannot tell what happened unless I enlarge it (G10),” and “I like this flower pot because I cannot understand the bar chart in such a small screen. I prefer to keep the flower pot when I play the game (G11).”

Both visualizations obtained positive comments, and each had its own advantages. The aesthetic visualization was more preferred as a peripheral display when participants were taking actions in the game, while the pragmatic visualization functioned better in providing more accurate measures and comparisons among rooms. In our observation of a girl in G12, when she answered the questions in the post-game debrief, she kept going back to the large screen to enlarge the visualization, and switched between the bar and the flower pots to find answers. The participants in G14 usually went back to the game to check the bar chart. They preferred checking the bar chart on the home page with general information of every room rather than entering each room to see separate charts.

Quality of the Experience with the Game

Between the two workshops with the separate “play” mode and “explore” mode, we found that participants had a different focus on visualizations and gamification strategies as feedback. Participants in the previous workshop preferred to be gaining new water-saving knowledge through points and actionable tips, whereas those who had been set learning goals paid much more attention to exploring different visualizations to find answers. The participants in the “play” group admitted that “I tried to complete tasks, and always forget to see the charts.” They were interested in cooperating with others and looking forward to seeing the scores as the evaluation of performance. The comparison with others was also valued. They often cheered when someone received a green smiley face or tick.

The teachers from Grade 5 commented positively on the design of the game stories: “The whole idea of this game is good because it sets learning goals for children,”
and they treated the game as “a potential education tool in class to help kids to recall and enhance the memory of what they have learned on water conservation.”

**Preference of Visualization Designs**

Generally, participants preferred the non-pragmatic over the pragmatic visualization for several reasons. First, the non-pragmatic visualization has a lower visual complexity than the pragmatic visualizations. “I like to see flower pot at the game. Flower pots can show all information in this small frame. I needn't enlarge it. But the bar there are so many texts and bars in small space, too narrow, I cannot tell what happened unless I enlarge it (G10).” “I like this flower pot because I cannot understand the bar chart on such a small screen. I prefer to keep the flower pot when I play the game (G11).” “I like the flower pot because it puts how much water I used and saved together, it is easier to compare (G7).” Second, the graphical representations look more attractive and appealing. “I like the flower, because it looks cute and I can know I did good actions quickly (G1).” A teacher from Grade 5 also presented her opinion, as “Compared with the bar chart, I prefer the flower pots. Also from my teaching experience, I think the flower pot is more attractive to kids.” Finally, the reward mechanism in the flower visualization can motivate participants to change behaviour in saving water. “We have flowers, click (swimming pool) again (G1).” “Click Flow water. No, we have no flower, try the other one (G7).” “We have lots of flowers, see, leave the car dirty, we have a large one (G12).” They also felt inspired when they took water-wise actions, as they cheered “Yes! We get flowers, good job! (G5)”

Additionally, some participants liked the bar chart more because they thought the bar chart was easier to read and comprehend. “I can read the bar charts, but I cannot understand how much water I used from the flower one quickly (G1).” “I like the bar chart because I can know how much water used and saved in the shower, in tap. The flower one only has sum of them. It doesn’t show everything (G2).” The bar chart also showed more detailed information of each appliance, while “The flower pot does not show everything. We don't know which action save how much water (G6).” Additionally, not all participants arrived at the agreement that the flower visualization is more aesthetic than the bar chart. A girl in G8 said that “it looks more scientific”. Also, a boy in G13 mentioned that “I think two charts show the same information. They also look like the same. I don’t think the flower pot is more beautiful.”
Many participants would like to see both visualizations in the feedback. “I think the flower shows the general knowledge of how much we used and saved, the bar shows more details (G12).” “I think I can understand the bar chart more easily, but the flower looks more interesting. I like both (G10).” “I know bar chart before, I know how to read it. I think it is easier for me to read. But I also like the flower one, I like to see more flowers (G13).”

Participants expressed their preference of visualizations in the post-game debrief (Appendix B-2). They selected among three options: “bar charts”, “flower pots” and “didn’t matter”. In both genders, participants preferred the aesthetic visualization of the “flower pots” than the pragmatic one of the “bar charts”. Among the boys, more of them chose “didn’t matter” than “bar charts”, while among the girls, more chose “bar charts” as the second preference (Figure 6-17). Answers from participants in Grade 6 showed different statistical results. More of them thought that it did not matter which display was used to show the water information (Figure 6-18). They wanted to receive some sort of feedback regardless of its form.

Figure 6-17 Post-Game Debrief: Which display do you prefer? categorized by gender.
Conducting the study in an actual learning situation and restructuring study based on the findings of the pilot study with individuals, we have answered our research questions to further and deeper extents in this chapter. Generally, participants reflected that the water conservation game was quite impressive, engaging, and also informative. It is a promising method to teach home water information to our children, help them to be aware of how water is consumed in their everyday lives, and suggest what they might do to contribute to water conservation. The visualizations, with the reward mechanism and the gamification techniques, such as points and actionable conservation tips, offered them a chance to gain new knowledge or recall the knowledge they have learned from school or family on water conservation, and they were further motivated to practice water-wise actions in the game. However, to fully validate whether the feedback can change people’s behaviour still requires longitudinal studies in real-life settings in future research. Out of the anticipated expectation, this feedback system is very promising to function as a novel educational tool to assist teachers in water conservation curriculum.
Regarding the first research question, the non-pragmatic visualization was proved to provide useful water use feedback with or in place of the pragmatic visualization. Presenting water usage in real time, visualizations allowed users to immediately link their actions and effects directly and obtain feedback on whether they need to change behaviours toward saving more water. Generally, participants preferred the non-pragmatic visualization over the pragmatic visualization, as they thought “growing flowers” was an interesting reward representation for their positive actions. Moreover, the ambience attribute of the flower pot visualization is more obvious than the bar chart visualization. The graphical representation of flower and flower pots were integrated into the game background without being intrusive. It also maintained lower visual complexity to support more immediate understanding of the display; “I gained one larger flower because I covered the swimming pool” or “No flowers show, I should take shower instead of the bath”. For the pragmatic bar chart, some participants complained that the display is much busier and that “we have to enlarge it to see the clarify the information.”

In this user study, participants were allowed to switch between both pragmatic and non-pragmatic visualizations. As the results indicated, users prefer to see the flower pot visualization peripherally when they took actions in the game, while they prefer to check the bar chart during self-evaluation stage. Both the ambience of the non-pragmatic visualization and the accurate measurements of the pragmatic visualization were considered important by the participants. There is no absolute answer to which one can be completely superior to the other. The future design of feedback will expand to explore the possibilities of combining different types of visualizations into the feedback system to serve different goals. How to maximize the advantages of both in the game environment can be another promising research direction.

In terms of our second research question, the simulation game, which mimics real-life settings proved to be a useful testing platform to elicit what children understand, do not understand, or “forget” about how to use water efficiently in their homes. Participants became engaged in the game session and tried hard to explore everything that might cause changes in the game installations, including picking up the wrench to check for leaking water. They liked the game because it set tasks to complete and provided various options to use water. Comparing their actual performance in the game
with their perceived score or self-perception in the pre-game questions, we discovered that a great gap exists between their knowledge and actions. For example, before the game, two primary methods were mentioned by most participants to save water: “taking a shorter shower” and “turning off the faucet when brushing teeth”. They also thought they had performed well in these two actions in the simulation game by marking a smile face in the evaluation section. However, most of the times, they over-rated their performance in the game and received the cross mark and low points as feedback. By presenting such differences between the actual and perceived performance, the game proved to be a helpful tool to assist them in realizing this gap and potentially bridging it in the future practice. Additionally, we received lots of positive comments on the gamification strategies such as the actionable tips, points, and badges. They were thought to add many interesting and engaging elements in the feedback. They can also motivate participants to raise awareness of the gap and gain more knowledge on water conservation. The knowledge they obtained was reflected in the post-game debrief and interview, where they listed other potential water-wise actions that they may not have been familiar with before, such as “Cover the swimming pool” and “Check the leaking water”.

Something unexpected was found between the two workshops that experienced the game in “play” mode and “explore” mode separately. Participants in the previous workshop preferred to gain new water-saving knowledge through the gamification strategies, such as points and actionable tips, whereas those in the latter group paid much more attention to exploring different visualizations to learn about the water use information. The “play” mode brought players more hedonic experience and the “explore” mode with learning goals being set ahead served more as an educational tool.

For the third research question, the user studies around our residential water feedback design inspired us with valuable design insight and implications for future improvements and other designs. The current design is merely conceived as a research instrument rather than a final commercial product. Selecting the graphical representations that have conceptual relations with the underlying data, working environment, and targeted audiences is essential in communicating information. For example, many participants expressed their preference for the flowers as they can easily and directly relate “more flowers are growing” to “more water is being saved.”
Meanwhile, the diversity of user preferences for visualizations among genders, ages, and personal experience should be thoroughly considered when selecting the graphical representations, colours and layout.

Moreover, ambience is a key issue to be considered in affecting decision making in the game environment, where the visualization display is presented in the periphery of the user’s attention. Providing sufficient information to keep people informed of the consumption situation and lowering visual complexity to maintain at-a-glance awareness are needs that should be satisfied in the visualization design. Thus, designers should put particular thoughts on showing specific data to a certain degree. In our research, in each room, only the cumulative use and saved water information of the appliances in this room are presented on the visualizations, and information for other rooms is cut off to lower the visual complexity. Flowers are related to rewarding specific appliances, which can help the users directly connect their activities to the effects.

Furthermore, the observation on how children collaborate with each other during the game process inspired us to expand the social aspects, such as the leadership board and different competitive strategies in the game, to enhance the motivation. The above findings are valuable in the future design practice, as they implicate what the water feedback should address.
7. Contributions and Future Work

In this research, we have discovered the preliminary evidence that the approach of combining the non-pragmatic visualization and gamification is a promising alternative to the provision of residential resource use feedback. It was evidenced by our user studies in which both pragmatic and non-pragmatic visualizations were tested through real usage via a simulation game that mimics a real-life environment. Using a design-oriented research perspective (Fallman, 2007) and mixed methods, we explored the potential of this approach in affecting sustainable decision making. Largely positive reactions to the non-pragmatic visualizations were received regarding the aesthetic attributes, comprehensibility, support for at-a-glance awareness and perceptibility with residential-use contexts. We suggest that ambient and artistic approaches should be considered as one facet of a rich ecosystem of feedback strategies; meanwhile, balance should be addressed between aesthetic interests and pragmatic usefulness. In addition, gamification strategies such as actionable tips and points should be considered an effective method for increasing engagement and encouraging informed decision making in water use.

We situate our work within the broader research area of sustainable HCI (DiSalvo, Sengers, & Brynjarsdóttir, 2010), and particularly into genres of “persuasive technology” and “ambient awareness (DiSalvo, Sengers, & Brynjarsdóttir, 2010).” Our work also draws from the research in eco-visualization (Pierce, Odom, & Blevis, 2008) eco-feedback techniques (Froehlich, 2011). Inspired and motivated by various works within this field, which primarily focus on energy conservation (Sun, 2014; Rodgers, 2011; Bartram, Rodgers, & Muise, 2010; Holmes, 2007), our main purpose of this research is to explore the eco-feedback approach for motivating decision-making on residential water conservation. As a result, our research presented some considerations to be made in the design of this class of feedback and provided the insight that can inspire future design solutions using these techniques, which are not always addressed by traditional techniques or evaluation methods.
7.1. Contributions

This work makes three primary contributions to validating that combining both pragmatic and non-pragmatic visualizations with gamification can be viable a approach in supporting sustainable decision making in residential water conservation.

First, through mixed method user studies, we have arrived a conclusion that non-pragmatic visualization is a promising approach to affect users’ understanding of water use with or in place of the pragmatic visualization. The non-pragmatic visualization can sustain people’s engagement with its more appealing representations and reward mechanism, support at-a-glance awareness, and maintain its comprehensibility. High user preference ratings, positive attitudes, and feedback from participants also support the implementation of the non-pragmatic visualization into the water feedback system. Further, the participants’ interactions in the game indicated that both the ambient attribute of the non-pragmatic visualization and the pragmatic attribute of the pragmatic visualization play an essential role in providing water use information. Neither one is superior to the other. Combining them can bring more possibilities to the eco-feedback design.

Additionally, gamification has shown the potential to better engage people using attracting and entertaining elements. Moreover, the game proved to be an effective strategy in motivating water-wise actions and promoting learning because it drives the visualizations to update the changes of water consumption in real time, so as to relate people’s behaviours with effects immediately. Besides, from the user interactions in the game, we obtained more information about what children understand, do not understand or “forget” about how to use water efficiently in their homes to provide significant hints for future work.

Furthermore, we raised more general design concerns and the insight regarding developing effective water feedback tools from our prototype design and user studies. First, the content of the artistic visualization can be inspired by various artworks. However, designers should seriously consider its conceptual relation with the underlying data (Holstius, Kembel, Hurst, Wan, & Forlizzi, 2004), working environment and targeted audiences when selecting the graphical representation. Graphical representations that
can arouse the audiences’ emotional and affective responses lead to better comprehension and engagement. For example, children are interested in more abstract and cartoon-looking representations, such as our flower design, and they are excited to see the growth of flowers, which is mapped with the amount of saved water.

Second, ambience is a pivotal issue to be considered in affecting decision making in the game environment, where information visualizations should provide users with at-a-glance awareness of water use. A balance is need between providing sufficient information to support people’s perceptions and lowering the visual complexity to maintain instant readability. Thus, designers should put special thoughts on what data should be presented and to which degree. For example, in each room, we showed consumption information of only the related room instead of all rooms and addressed the flowers of each household appliance as a reward for saving water. Such information is closely relevant to residents’ understanding and perception of their activities in the simulation game.

Third, users’ opinions and preferences regarding visualizations are diverse and even conflicting based on gender, ages, personal experience, and which aspect of water consumption information they expect to perceive. Given the flexibility to shift between non-pragmatic and pragmatic visualizations, most users could take advantage of both.

Our work has also peripherally addressed the importance of social influences and collaborative decision making in supporting conservation through observing children’s communication with classmates in workshops. The gamification techniques, such as points, can expand residential resource-use feedback from the individuals to the family or group.

Finally, this research demonstrated the benefits of collecting participants’ comments to understand their experience with the game and visualizations better. The importance of the qualitative or mixed methods was highlighted in understanding not only what participants did but also why they behaved and felt that way. It is useful for future researchers and designers in the field of residential resource-use feedback to know that they can start their works, relying on user-based knowledge.
7.2. Future Work

Our research study under discussion has revealed the promise of non-pragmatic visualization and gamification techniques in promoting water conservation. Numerous opportunities are still available for future work to evolve exploration within this field. These include long-term in-situ evaluation of these techniques, further exploration and development of more general and completed designs, and a variety of questions regarding social implications of designing resource use feedback.

Users’ perception of an informative art display is affected by their habits, attitudes and physical context. Due to the limitations of sample size, study duration, and physical context, the current work is entirely exploratory and preliminary. It is insufficient in proving whether this approach sustains informed decision making and ultimately changes behaviours. Well-controlled experiments are required to prove its feasibility. Therefore, the next avenue of our work is to conduct long-term field deployments to assess these factors over time.

Future work will explore more comprehensive and complete design guidelines for the improvements of the current feedback design or the development of novel approaches. During our design process for the current prototype and interviews with users, we obtained several design implications and hints that will be explored further. We will explore more abstract representations of water use and reward for positive actions, situating these visual representations within a much broader scope of visualization possibilities. In addition, we hope to develop a framework that will help designers uncover proper representations to be mapped with underlying data in such resource use feedback. Besides selections of general graphical styles, more detailed features will be outlined such as contextual relationships, colour choices, and layouts of graphics. In improving the general game experience, we will further polish the details of the game settings to mimic real-life environments more vividly.

We have answered the question regarding whether non-pragmatic visualizations can be effective in affecting decisions with or in place of pragmatic visualizations in our research. We will expand this finding to explore more possibilities of combining different
types of visualizations into the feedback system and find how to maximize the advantages of both in the game environment.

The importance of social influence and collaborative decision making in strategically supporting sustainable conservation is addressed by both the psychological research (Gertner, 2009) and ethnography by HCI researchers (Dillahunt, Mankoff, & Paulos, 2010). A potential implication of our future work is that exploring whether eco-feedback designs with the focus on social groups can be a more effective motivator of pro-environmental behaviour. To date, our work is currently predominantly on individuals and has peripherally addressed this set of considerations through implementing a points mechanism to support comparison with others and conducting user studies in groups. However, this still opens rich opportunities for further study, including how to define strategies for individual vs. group feedback. For example, our feedback shows a potential for application as an educational tool in the class to enhance student awareness of water use. We need to explore how feedback strategies might actively address the consumption situation of individuals in the group rather than just the individual, how feedback technologies can foster or enable social influence, and whether leadership boards and other gamification techniques be helpful with this issue.
References


SmartH2O project. EU FP7, No. 619172, 2014-17. URL: smarth2o-fp7.eu/


Appendices
Appendix A

Study A Documents

1. Pre- Game Questions
2. Post- Game Questionnaire
Pre-Game Questions (Study A)

The purpose of this semi-structured Pre-Game Questionnaire is to elicit information about whether and how each participant is aware of water use in their homes. Topics to cover are:

1. Do you know how much water you or your family use every month?
2. Do you know which water appliance costs most water in your home?
3. Can you name three activities that you may do to save your home water?
4. How do you or your family clean the car?
5. When is the best time to water the garden?
Post-Game Questionnaire (Study A)

Participant NO.: ___________  Gender: _______________  Grade: _______________

Flower Pot Visualization:

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Bar Chart Visualization:

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Where would you like to have those visualizations in your home?

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<td>Bathroom</td>
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Appendix B

Study B Documents

1. Pre- Game Questions
2. Post- Game Debrief
Pre-Game Questions (Study B)

Group: ___________  Gender: ___________  Grade: ___________

Questions:
1. Do you know how much water you or your family use every month?

2. Do you know which water appliances use most water in your home?

3. Name **three** activities that you may do to save your home water.
Post-Game Debrief (Study B)

Questions:

1. What tasks did you play -- check all.

☐ Task1: Outside
☐ Task2: Personal Hygiene
☐ Task3: Meals
☐ Task4: Maintenance

2. What appliances used the most water?

3. Can you name three activities that save your home water?

4. Name two activities that saved the most water?

5. Which water display did you prefer?

☐ Flower Pots
☐ Bar Charts
☐ Didn’t matter
Appendix C

The Original Version of Flower Visualization Design