Energy Conservation Game: Exploring Alternative Visualizations for Residential Energy Use

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ABSTRACT
Residents' awareness of energy use and their actions in energy conservation are inextricably linked because the former enables informed decision-making and can motivate behavior change. While various feedback techniques have been developed to increase resident knowledge, traditional screen-based interfaces, typically require significant effort and attention from residents; do not support at-a-glance awareness of real-time resource use; nor are designed to integrate cohesively with the home [7]. In particular, families and children often do not engage with the kinds of numeric and utilitarian feedback devices currently available. We propose that alternative, aesthetically-inspired visualization approach may be more useful for engaging families in awareness of their energy use. To explore the effectiveness and utility of this approach, we evaluated various forms of depictive and narrative-related aesthetic visualizations via a game that simulates real-life usage. The results indicate that aesthetic visualization is a promising approach in supporting learning, enabling informed decision-making and integrating gracefully with the environment. Our experience also shows that the game not only offers ecologically valid simulations as a testing environment, is also a useful tool to tease out what people do or do not understand about energy conservation at home.

Keywords
Aesthetic visualization, energy conservation, simulation game, design research.

1. INTRODUCTION
Providing effective feedback on energy use helps raise people's awareness of the link between their daily activities and results of energy consumption, and ultimately lets them better control their consumption to improve energy conservation [1][2]. To address this problem, we explore feedback tools that are currently available from paper bills to more recent web-based applications (Google PowerMeter™ and Microsoft® Hohm™). We point out that the problem with the former is that the information provided is inadequate for decision-making, lacking details of how energy is consumed relating to consumer activities. Billing cycles are too long for consumers to receive timely feedback. In-home commercially available digital displays, although precise and prompt, are typically unattractive and unengaging; anecdotally, people report that they put them "out of the way" after a short period of use. Our research explores alternative and aesthetic visualizations for residential energy use feedback.

We adopt Kosara's definition of *aesthetic* visualization defined as opposed to *pragmatic* visualization. It treats aesthetics as an important value and takes the advantage of applying various depictive and narrative-related forms of representation to communicate a concern of the underlying information [4]. Besides aesthetics, another primary property of this approach is that the visualization remains peripheral to people's attention while sustaining interest over time [5]. We argue that this approach to residential energy use feedback offers promise over pragmatic visualization for the following reasons. First, we can explore more engaging representations to make it more attractive, especially to children. Enhanced engagement adds potential to make it an educational tool to inform people of energy use and conservation. Second, it supports at-a-glance awareness. This requires less effort for people to notice and interpret the data. Finally, considering the aesthetics of both the visualization and the home as an explicit factor makes the display part of daily life and activities, and better integrate into the home.

Previous research suggests that ambient and artistic visualization is a viable way to provide resource use feedback at domestic environment [7]. These findings encourage us to study the feasibility of this approach to a greater extent. However, we need to ensure that such approach does not compromise the effectiveness and utility offered by traditionally validated visualizations. More specifically, we want to draw out what makes them effective and in which way and discover whether and how they might make a difference in real practice.

To explore the effectiveness of using different aesthetic visualizations as feedback for residential energy use, we studied several of them with ambient displays and a simulation game. The game is chosen as a testing context because it offers more ecologically valid simulations and is more attractive to our test participants. We chose families with school-age children as our primary participants for two reasons. First, we knew that children had an influence on family awareness of ecological issues. Second, energy formed part of the BC middle school curriculum [6]. We hoped to find out if this feedback helped enhance their learning of energy and conservation. We were also interested in understanding where people were weak in their knowledge and awareness of home energy use at both conceptual and operational levels.

In this paper, the planning and the details of the research study are described; the design and the implementation of the study installations are introduced; the study results are presented with mixed data analysis techniques; and implications of the results are addressed.

Figure 1 Dollhouse UI

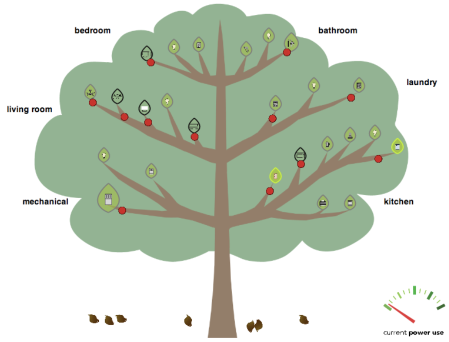

Figure 2 TreeVisWithBerries

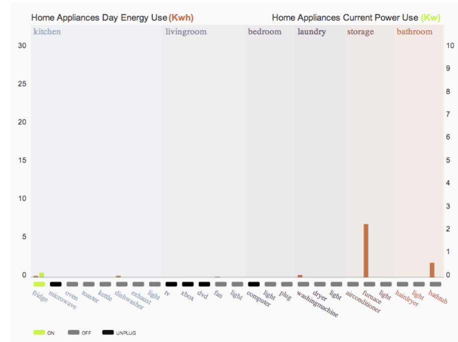

Figure 3 Bar Chart

2. ENERGY CONSERVATION GAME

We created an energy conservation game as a testing environment. The game was intended to make the study session a more interesting process to engage children in the activity of "using energy". Additionally, the game offered the opportunity to explore what people understood and didn't understand about energy conservation in their homes.

2.1 Game Design

A dollhouse UI (Figure 1) simulated the home environment and drove the three visualizations. The dollhouse had six rooms: mechanics, kitchen, living room, laundry, bedroom and washroom, each of which contained household appliances that users might turn on/off/unplug to simulate their daily activities. The game consisted of four scenarios (entertainment, laundry, cooking and general house efficiency) that mimicked people's everyday lives, each of which included five tasks. The tasks were designed to have special focus on activities that people might do to save energy in their home, for example, unplugging unused appliances to stop "vampire" power. But participants were not explicitly given a list of energy-related tasks to carry out (for example, they were not told to turn off the light when leaving a room). Instead, we instructed them to do things as "energy efficiently as possible". After finishing the tasks, participants were asked to evaluate their own actions on whether they thought they had done things efficiently. This was then scored (out of 10, 2 per task) and feedback on their actions was provided ("You could have hung your clothes to dry").

2.2 Visualization Design

Three different visualizations were studied. Two were designed with an abstract tree representation (Figure 2) and one was a standard bar chart with embellishment (Figure 3). All three visualizations gave real-time feedback, which included the individual household appliance's status (on/off/unplug), power and energy usage and cumulative house's energy cost. Notably, one of the tree visualizations employed an explicit representation of positive actions shown as berries on the tree. Table 1 summarizes data features of all three visualizations.

Table 1 Summary of data features of all three visualizations Note: "×" for having the specified feature, "-" for not.

Data Feature	TreeWithBerries	TreeWithoutBerries	BarChart
Status of individual appliance	×	×	×
Energy cost of individual appliance	×	×	×
Energy cost of all appliances	×	×	-
Power use of individual appliance	-	-	×
Power use of all appliances	×	×	-
Number of positive actions	-	×	-

3. RESEARCH DESIGN

We took a design-oriented research perspective [3] with mixed evaluation methods. We aimed both to understand the potential benefits and caveats of this aesthetic visualization approach, and to tease out where people's comprehension of energy conservation at home was weak. The study started with a pilot study of 2 participants and followed by a study of 24 participants recruited through personal contact from colleagues and friends of the researchers.

3.1 Research Questions

The following four research questions were explored.

1. What are the implications of using these visualizations in an applied learning context (the game)?
2. What are the affordances, benefits and caveats of providing explicit action representation as motivations?
3. Where might people use these visualizations (if at all) in their homes?
4. What does this simulation game suggest about people's understanding of how to use energy efficiently at home?

3.2 User Study

All participants in this study were school-age children. This age group was chosen because: 1) energy formed a major part of the school curriculum during the middle school years (grade 5-8) [6]; 2) the impact of children's awareness on parental behavior was known to have an influence on the adults in their homes; 3) these represented our future generations: we were interested in understanding how best to enhance and sustain their learning about energy and conservation. Most of the study sessions were done in participants' homes with two exceptions in coffee shops due to privacy concerns of the participants. The participants' homes were chosen as primary study place because they were the intended locations where the visualizations were to be placed.

The study took around 30~45 minutes, which included three major related activities. Study data were collected and analyzed with several methods. First, a short pre-session interview elicited participants' knowledge of their home energy use. Three questions were asked, including total energy cost of the house, energy use of a particular household appliance and conservation actions that might be taken at home to save energy. The interviews were audio-recorded and then transcribed and analyzed.

Second, a game session varying in length from 20 to 30 minutes was performed. The game included four stories (scenarios) and participants were asked to complete all of them in the same order. The game data were digitally logged by the system itself, which contained basic information of the participant (user name and

Figure 4 Participants' actual score(grey), self-assessed score (orange) and difference (green) by task and display

school grade), game scores for each story task (actual score and self-evaluated score) and a log of all interactions participants made during the game. The data were analyzed using descriptive statistics.

Finally after the game, a post-session questionnaire collected participants' impression of the visualization they saw and if and where they would like to have the visualization in their homes. Questions included a rating of the visualization's attractiveness and appeal, whether they thought they would use such a tool, and location preferences. The location preference question provided a list of seven rooms (e.g. living room, bedroom and etc.) for the participants to choose. Participants were also allowed to specify rooms that were not on the list or choose "would not like it in their house". The questionnaire concluded with an open question that allowed participants to leave any comments they had about the visualization. Questionnaire data was collected electronically via a web interface and analyzed quantitatively to make comparisons among all three visualizations.

4. RESULTS

4.1 Participants' Energy Understanding

All 24 participants admitted they had no idea about their family monthly energy cost. They didn't care about their family electricity bills and they never thought about discussing the issue with their parents. All participants had a sense of which appliance in their homes used the most energy, though a few of them were unsure about their guesses. And all participants were able to name 2-3 actions that they might take at home to save energy.

4.2 Game Performance

Scores (both actual and perceived) varied greatly for each game task. Figure 4 showed that participants did best with "lighting" "turn off unused appliances" and "wash yourself" and they also perceived themselves to have done best in those tasks too. This result indicated that participants had firm knowledge of saving energy with those actions. Participants' actual scores were low in "unplug unused appliances" (including "Heat milk", "play games" and "watch movies") and "fridge setting". However, they didn't seem to realize their poor performance in those tasks as they rated themselves to be much higher. In general, participants were able to correctly complete most of the game tasks and they always considered themselves to have done better than they actually did. The gap here offered a great opportunity for the participants to learn what was the right thing to do from the game feedback.

The actual score for each game story showed that participants did better as they progressed through the stories except the last one, for which a few of them had difficulty understanding the story descriptions. Similarly, although for all stories, participants perceived themselves to have done better than they actually did, the differences got smaller as they progressed through the stories except the last one. This trend suggested that participants tend to have better understanding of the game as they progressed through and think more about energy conservation while completing the tasks.

One of our major interests in this research was to find out if there existed any differences among participant groups. Unexpectedly, the results were relatively even. Participants who saw the "TreeWithoutBerry" display scored highest in most game stories, but the difference was small across all three visualizations.

4.3 Impressions on Visualization Design

The aesthetic visualizations ("TreeWithBerry" and "TreeWithoutBerry") were thought to be more appealing, interesting and attractive than the pragmatic one (Bar Chart) (Figure 5). Particularly, the berry made the tree visualization even more interesting and appealing. In terms of comprehension, all three visualizations were thought to be easy to understand with a similar score between Neutral and Agree.

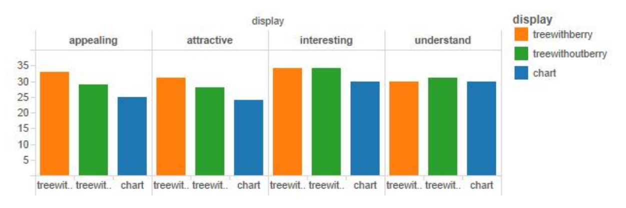

Figure 5 Participants' impressions on different visualizations

4.4 Preferences of Locations at Home

All participants would like to have the visualization in their homes as all of them selected at least one room as their preferred location to place the visualization (Figure 6). The most common rooms indicated as locations for the visualization were the living room

(16 of 24) and the kitchen (12 of 24). This indicated that people preferred to have them in high-traffic places where they spent the most time and used the most energy. Interestingly, all rooms provided on the questionnaire were chosen by at least one participant and many participants were willing to place the visualization in multiple rooms at home (9 of 24 selected more than one room).

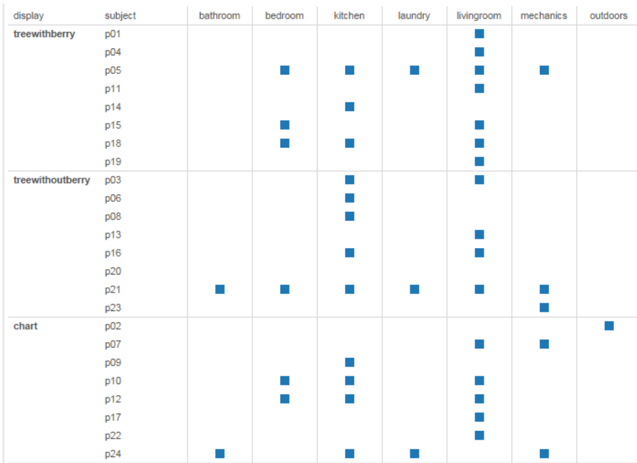

Figure 6 Participants' preferences of locations at home

5. DISCUSSION

Our findings, to various extents, directly or indirectly referred to our research questions. In terms of our first research question, all three visualizations proved to be effective as feedback for home energy use. This was indicated by the game performance results that participants seeing different visualizations were all able to complete the game tasks with moderate scores and there was no significant difference among the three groups. The real-time feedback on the visualizations helped participants immediately link the effects to their actions and let them give a thought on what they should and should not do next to score higher. As a matter of fact, this was what we expected as effects on decision-making. Additionally in the follow-up questionnaire, all three visualizations were rated as easy to understand. Comprehensibility was key to visualization design regardless of its form and was the basis for it to serve its function. However, the aesthetic visualizations were considered to be more appealing, interesting and attractive than the pragmatic one.

Much to our unexpectation, the explicit representation of positive actions (the berries) didn't affect participants' performances in the game. Although, our results showed that the "berry" was preferred by most participants and indeed drew more attention during the game (with more game logs than others), it didn't make a difference in leading to more energy conservation actions.

Our results also indicated the viability of these visualizations, especially those designed using the aesthetic visualization approach, to serve as feedback for residential energy use. All participants were willing to have it somewhere in their homes, and many of them would even like to have them in multiple rooms. Back to our pre-session interview question, all our participants were not exposed to any form of energy feedback in their house, nor were they ever interested in any existing feedback that was available to them. This made our approach to energy feedback a promising method to bring home energy information to our children and help them get a sense of how energy was consumed in their everyday life and what they might do to save energy.

Referring to our last research question, the simulation game proved to be useful both as a testing platform and an experiment itself to help us gain more insightful findings of how people understood energy conservation in their homes. With this ecologically valid simulation, we were able to draw more information than a pure interview and discover the great gap between participants' self-perceived understandings of energy conservation at home and their actual performances. For example, quite a few participants mentioned "unplugging appliances not in use" as one way to save energy, but in the simulation game, few of them actually did that. The game turned out to be a useful tool to help them realize and bridge this gap as we saw apparent improvement as they progressed through the game stories.

6. CONCLUSION

In conclusion, all three visualizations seem to be effective as feedback for residential energy use but the two aesthetic visualizations appear to be more engaging and attractive to children. This suggests that these visualizations may be an interesting tool to help our future generation raise their awareness of home energy use and promote more behaviors towards energy conservation. However, this requires future studies that involve long-term evaluations with real-life settings. Besides, the game itself proves to be a useful experiment to elicit participants' perceived understandings of energy conservation as compared to their actual performances.

7. ACKNOWLEDGMENTS

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