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ECO-FEEDBACK DESIGNS: A BALANCE BETWEEN THE QUANTITATIVE AND THE EMOTIONAL

Qifang Bao
Department of Mechanical Engineering
Massachusetts Institute of Technology
Cambridge, MA

Mian Mobeen Shaukat
Department of Mechanical Engineering
King Fahd University of Petroleum and Minerals
Dhahran Saudi Arabia

Asmaa Elantary
Interior Design Department
Jubail University College
Jubail Saudi Arabia

Maria C. Yang
Department of Mechanical Engineering
Massachusetts Institute of Technology
Cambridge, MA

ABSTRACT

Eco-feedback design is a strategy for encouraging sustainable behavior by making users aware of the resources they consume. Reminding users of their resource usage can help them understand the environmental impacts of their actions and evoke feelings such as sympathy or responsibility for the environment. This study investigated two aspects of presenting resource usage information in eco-feedback designs: the quantitative clarity of the information, and the strength of emotion evoked by the designs. This paper examines how these two aspects of eco-feedback influence users' perception and preference for the designs. Four design prompts with different levels of quantitative clarity and emotion were used to generate 16 designs. An online survey with these designs was distributed among students at four universities in two countries. Results from 216 valid responses showed evidence that both the quantitative and emotional aspects are important to the eco-feedback designs. The survey also gathered data about respondents' knowledge about resource consumption. Results suggested that students in technical majors were generally better at estimating resource consumption, and tended to prefer designs with more quantitative data. In contrast, students in non-technical majors generally made less accurate estimates and tended to prefer designs that evoke stronger emotions. These findings could inform designers on how to make more effective eco-feedback designs to promote sustainable behaviors.

INTRODUCTION

Eco-feedback has been widely used as a design method to encourage pro-environmental behaviors by informing the users of their impact on the environment with relevant information [1]. Its roots are in environmental psychology which includes many models that posit *knowledge* to be one of the most important tools for influencing people to behave in an environmentally friendly way [2–5]. Feedback has been proven effective in promoting pro-environmental behaviors such as reducing household electricity usage [6]. Providing clear and rich data meets the user need of obtaining knowledge to inform their behaviors, thus is a prevailing strategy of eco-feedback designs. However, behavioral economics research has demonstrated that knowledge alone does not always cause people to behave in a predictable way [7]. Kollmuss and Agyeman point out that, even with knowledge of the environment, people sometimes fail to behave pro-environmentally [5]. On the other hand, some relatively qualitative factors can be powerful in promoting sustainable behavior, such as the peer effect in the adoption of green technologies [8].

Multiple dimensions of eco-feedback design have been identified. Froehlich et al. presented *data granularity*, *time granularity*, *comparison*, and *measurement unit* as dimensions of eco-feedback displays [9]. Fang and Hsu suggested *ambient*, *aesthetic*, *emotionally engaged*, and *metaphorical* as four dimensions of feedback systems [10]. Froehlich's dimensions all relate to the quantitative data presented in designs, while Fang and Hsu's emphasize the visual effect and users' emotional reaction to designs.

A typical eco-feedback design strategy is tracking quantitative resource usage information and presenting it to the user [1]. At the same time, sympathy for the environment and altruism are strong motivations for pro-environmental behavior [11]. Thus we believe that both these two aspects of design, the *quantitative clarity of information*, and the *strength of emotion* that a design evokes, are important to the success of eco-feedback designs. However, little existing literature compares these two directly or considers them at the same time.

To fill in this gap, our study investigated eco-feedback designs with an emphasis on both the above aspects. We looked into the effectiveness of designs encouraging sustainable user behaviors as well as their influence on user preferences. We examined potential links between users' preference for eco-feedback designs to their knowledge of resource consumption. Two questions were explored in the study:

1. *In eco-feedback designs, is clearer, more quantitative information preferred over more qualitative, emotionally evocative information?*

By quantitative information we mean the use of numbers or charts to convey resource usage data. Emotionally evocative information is intended to elicit visceral feelings such as sympathy from users.

2. *Does a user's quantitative knowledge about resource consumption influence his or her preference for the two attributes above of eco-feedback designs?*

The expectation for question 2 is that individuals who have more quantitative, technical knowledge about sustainability will prefer designs that feature more quantitative information.

To address these questions, a series of eco-feedback designs that encouraged users to conserve either electricity or water were generated or collected from the literature. Evaluations of these designs were gathered via survey from students at four universities in two different countries. Students were also asked about their knowledge about electricity and water consumption.

RELATED WORK

Design for sustainable behavior bridges sustainable product design and human behavior intervention. Traditional design for sustainability focuses on the products themselves and considers material usage and waste produced during the manufacturing process as well as a product retirement. Techniques and methods include life cycle assessment and environmental impact assessment, among others [12]. Another strategy from social psychology and environmental psychology is to approach the problems from the perspectives of the end user or other stakeholder, for example to study the mechanisms behind human decision-making in pro-environmental behaviors [13–15].

Design for sustainable behavior considers the motivations and barriers for adopting sustainable behaviors, and use products as a mechanism to promote these behaviors. MacDonald and She summarized seven cognitive concepts for successful sustainable design, including *Responsibility*, *Complex decision making*, *Decision heuristics*, *Altruism-sacrifice link*, *Trust*, *Cognitive dissonance*, and *Motivation*, in an effort to build the connection between the behavior and design [16]. Oehlberg et al. collected user research from a graduate-level design course to identify what sustainability means to users and explored how to align user needs with product sustainability [17]. Lilley developed three categories of strategies for designing for sustainable behavior: *eco-feedback*, which guides behavior changes by informing users of resource use; *behavior steering*, which encourages users to behave in ways embedded in the design itself; and *persuasive technology*, which employs persuasive methods to change what people do without their knowledge or consent [18].

Researchers have explored methods and techniques to facilitate idea generation for sustainable products. Srivastava and Shu developed an affordance-based methodology to support environmentally conscious behaviors [19]. The method was tested with graduate student designers and was shown to be capable of improving design concept quality. She and MacDonald developed a psychological priming technique to help designers generate product features that can communicate notions of sustainability [20]. The technique was shown to increase both the quantity and novelty of design ideas. DuPont and Wisthoff developed an online questionnaire (GREEn Quiz) to teach engineering students the principles of sustainable design [21]. This tool was shown to be effective in facilitating students to make more sustainable design decisions.

In addition, a rich literature lies in evaluating how users respond to existing designs. MacDonald and She conducted an in lab experiment mimicking a realistic purchasing scenario to reveal user preferences for the sustainable trigger features of toasters [22]. Cor and Zwolinski tested the effectiveness of four coffee maker designs in encouraging energy and water conservation behaviors as well as acceptance by users [23]. Sohn et al. tested the immediate user reaction to design attributes of products that promote pro-environmental behaviors [24]. Wever et al. studied the household usage of an energy meter and applied a user-centered design strategy to improve its usability [25]. Montazeri et al. used a metaphor strategy in the design of a napkin dispenser and evaluated its use in a cafeteria, finding that it successfully reduced napkin consumption [26]. In another study, they used both an online survey and in-lab experiment to show that the colors of the recycling bins play important role in the effectiveness of encouraging recycling behaviors [27]. The studies described above either only test the design of a single product, or test a variety of designs with distinct strategies to encourage pro-environmental behaviors. In this paper, we focus on a single strategy and explore its effectiveness across several different scenarios. Specifically, our study systematically compares two different flavors of eco-feedback design for four different products.

Heterogeneity exists among users, thus preferences for designs are always diverse. Limited literature has made the connection between a user's background and his or her sustainable product preferences. Srivastava and Shu identified different motivations for sustainable behaviors, including *social-cultural*, *egocentric* and *altruistic* [11]. Cor and Zwolinski identified two types of users: eco-sensitive users, who are more environmentally aware and have more environmental knowledge; and non eco-sensitive users, who are less aware and have less knowledge. They found that written information is an effective eco-feedback prompt with the eco-sensitive users. However, it was not as effective with non eco-sensitive users. Persuasive technology was shown to have a high level of acceptance with non eco-sensitive users, though it was not well accepted by eco-sensitive users [28]. In our study, we also attempt to connect user preferences to user profiles.

METHODS

Overview: We first generated designs of four eco-feedback products using multiple design prompts. A survey was chosen to test these designs in order to enable a large amount of data collection within a relatively short period of time. Before completing the survey design, a set of pilot, in-person interviews and draft surveys were conducted with four design graduate students to shape the overall the survey and to refine the survey questions. The survey itself gathered information including:

1. Evaluation of the designs with different types of eco-feedback prompts, from quantitative to emotionally evocative.
2. Sustainability knowledge – respondents' ability to estimate resources used in common daily activities

1. Eco-feedback Prompts

Two sets of similar surveys were created, one focused on electricity usage and one on water usage. Respondents were randomly assigned to one or the other. Each survey included two types of products that encourage electricity or water conservation. These products were specifically chosen after the confirmation that student respondents would be familiar with them and could respond with some level of confidence:

The electricity-focused designs included:

- **Electricity Meter** that monitors home electricity usage.
- **Light Switch** that reminds people to turn off the lights when leaving a room.

The water-focused designs were:

- **Water Tap** that monitors the day's cumulative water usage.
- **Washing Machine** with a water-saving mode that can be selected as an alternative to a normal washing mode.

Four versions of each of the products above were designed to include each of the following eco-feedback prompts:

- **Text or Chart**, with clear, quantitative information about resource usage.
- **Color Emphasis**, incorporates bright colors to attract users' attention.
- **Metaphor Using Objects**, includes objects related to the environment or resource consumption.
- **Metaphor Using Living Creatures**, involves animals or plants as reminders of the environment.

These design prompts were chosen based on existing eco-feedback design literature cited in this paper [23,24,26]. They were created with the intention of displaying different levels of data quantitativeness and emotion evocation. Fig. 1 shows the continuum of these design prompts. It was anticipated that designs that included prompts from the left end of the spectrum would present clearer information, while designs generated with prompts on the right would evoke stronger emotion.

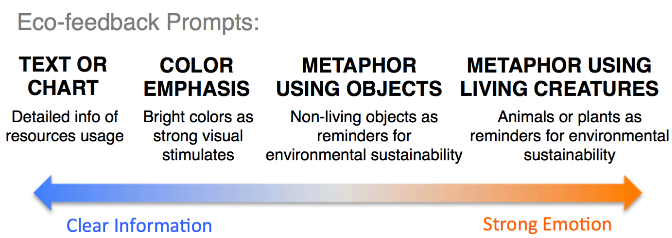


Fig. 1 Design Prompts and Their Expected Effects

The resulting sixteen designs are presented in Table 1. Several of these designs took their inspiration from eco-feedback designs in the literature and from industrial design examples [24,29]. These designs were intentionally hand-sketched rather than rendered or modelled digitally by a professional industrial designer to maintain a consistent visual style. Research suggests that representing designs at different fidelities can unduly influence user response [30]. In this way, potential evaluation bias could be minimized, an effect that has been observed in [30] and mitigated in a similar fashion in [31].

2. Design Evaluation

Each respondent was randomly assigned either an electricity or a water-focused survey, and was asked to evaluate in total eight designs of two different products. The order in which designs were presented was randomized. Respondents evaluated designs with 1~5 likert scales on four criteria:

- **Clarity**: How clearly did the design show resource usage? How clearly did the design communicate the idea of encouraging sustainable behavior?
- **Emotion**: How strong an emotional response did the design evoke?
- **Effectiveness**: How effective would the design be in encouraging the respondent to behave in a more environmentally friendly way?
- **Preference**: How much did the respondent like the design?

Clarity and *Emotion* directly evaluate the two aspects of eco-feedback designs that we were interested in. *Effectiveness* evaluates the designs' potential influence on the long-term user-product interaction behaviors, while *Preference* estimates the users' potential purchasing beahviors. Optional comment areas were provided for respondents to explain their ratings. Fig. 2 shows an example of the evaluation questions.

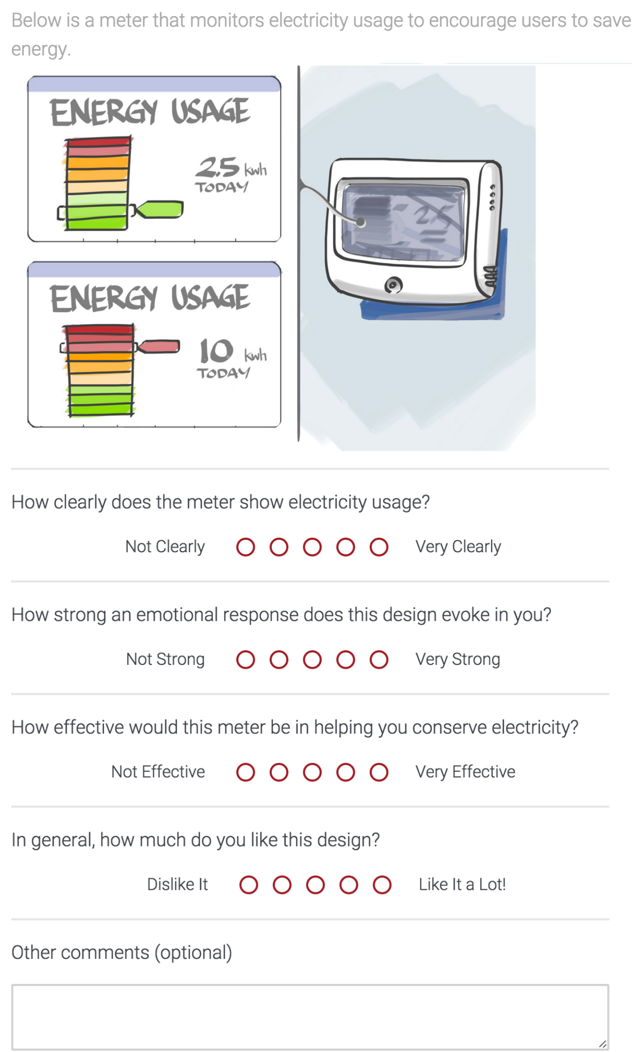
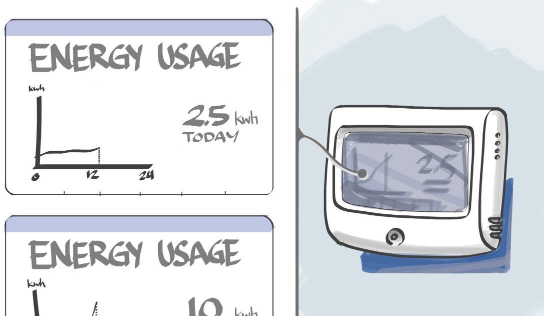
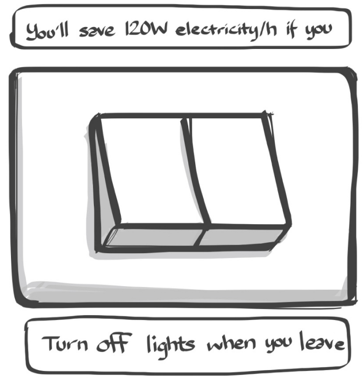
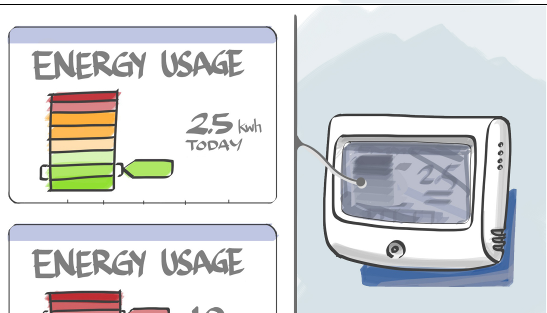
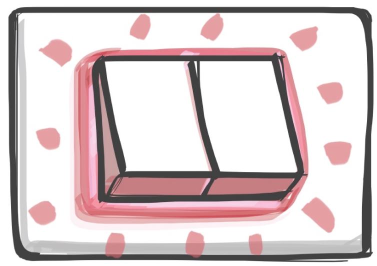
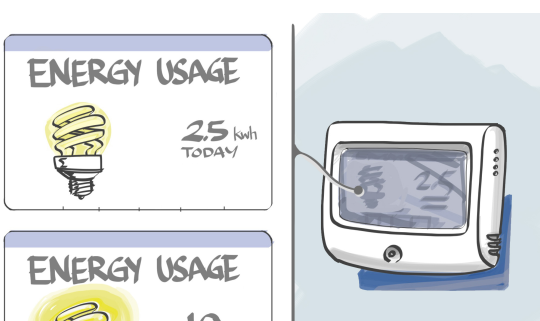
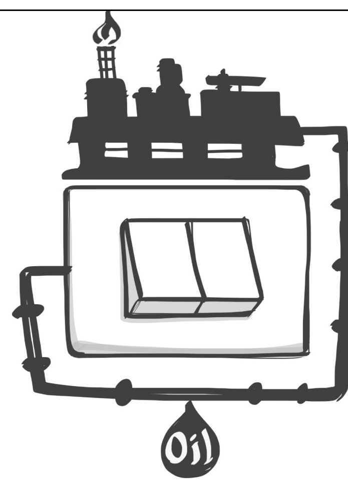
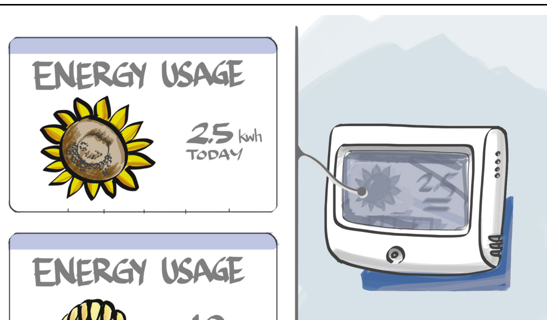
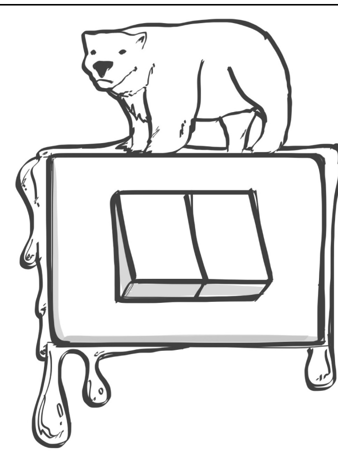
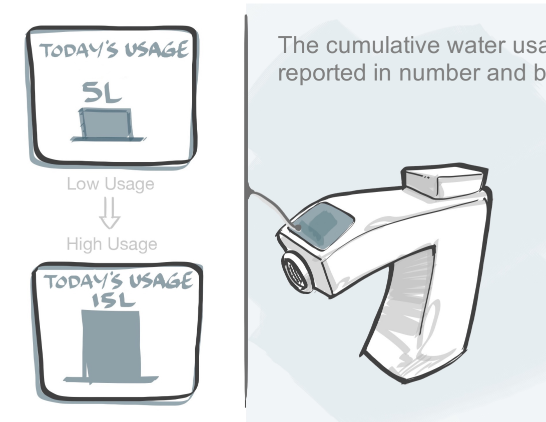
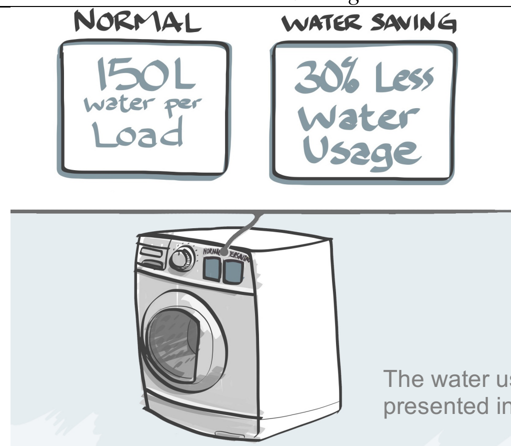
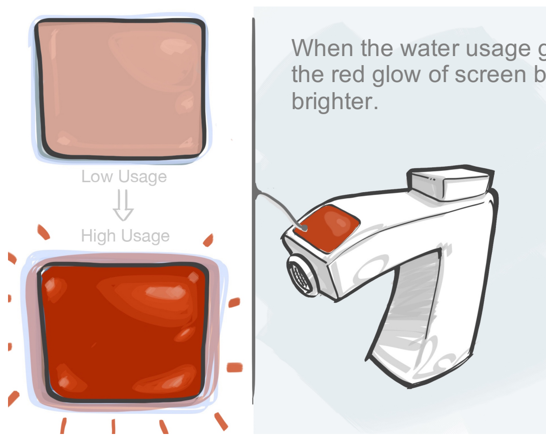
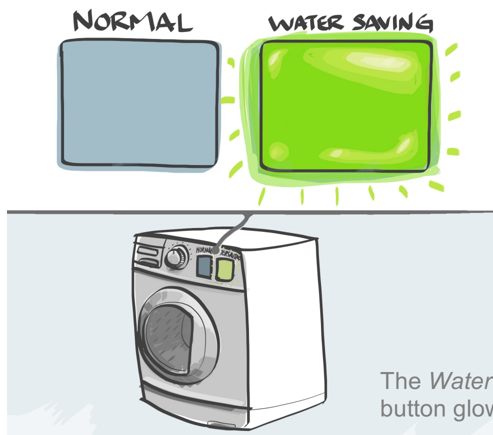
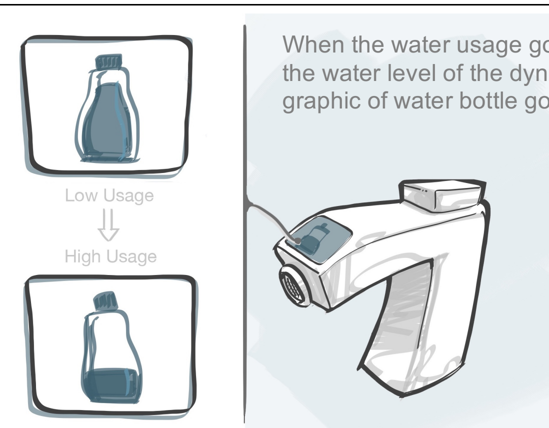
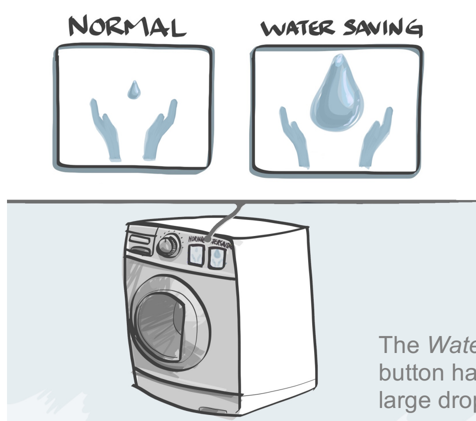
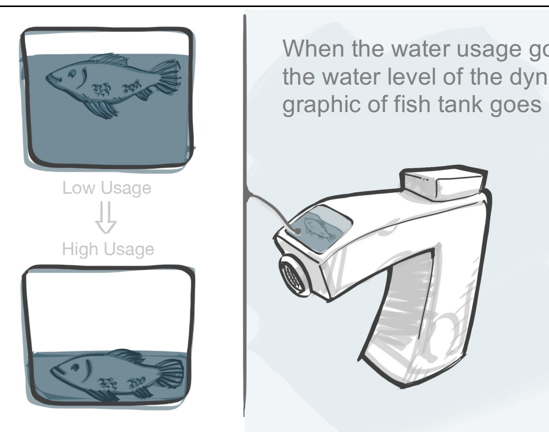
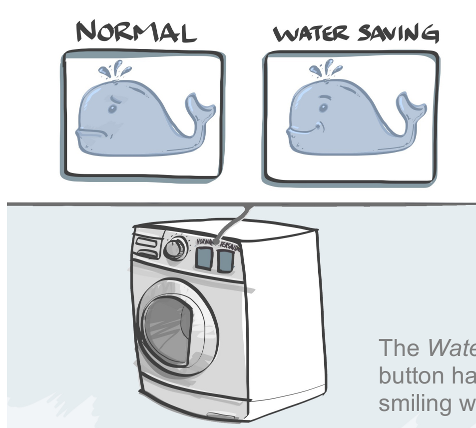


Fig. 2 Sample Design Rating Questions for an Electricity Meter

Table 1 Designs featured in the Electricity Survey and Water Survey. Designs included four different eco-feedback prompts to encourage resource conservation behaviors

	Products to Encourage Electricity Conservation	
Eco-Feedback Prompts	**Electricity Meter** Monitors and displays cumulative daily electricity usage	**Light Switch** Reminds people to turn off the light when leaving a room
1. Text or Chart	 The electricity usage is reported by curve chart.	 A light switch that has information written above and below it.
2. Color Emphasis	 The electricity usage is reported by colored bar chart.	 A light switch that glows red when on.
3. Metaphor Using Objects	 The dynamic graphic of light bulb becomes bright as the electricity usage goes high.	 A light switch that has a graphic of power plant around it.
4. Metaphor Using Living Creatures	 The dynamic graphic of sunflower withers as the electricity usage goes high.	 A light switch that has a graphic of solar bear standing on top of it.

	Products to Encourage Water Conservation	
Eco-Feedback Prompts	**Water Tap** Monitors the day's cumulative water usage	**Washing Machine** Includes buttons for selecting either *Normal* mode or *Water Saving* mode
1. Text or Chart	 The cumulative water usage is reported in number and bar chart.	 The water usage info is presented in numbers.
2. Color Emphasis	 When the water usage goes up, the red glow of screen becomes brighter.	 The *Water Saving* mode button glows green.
3. Metaphor Using Objects	 When the water usage goes up, the water level of the dynamic graphic of water bottle goes down.	 The *Water Saving* mode button has a graphic of large droplet of water.
4. Metaphor Using Living Creatures	 When the water usage goes up, the water level of the dynamic graphic of fish tank goes down.	 The *Water Saving* mode button has a graphic of smiling whale.

After rating the designs, each respondent was asked which she/he preferred the most. Optional comment areas were provided for respondents to explain their responses. The "most preferred" revealed the users' favorite design, and would be used to check the consistency of each respondent's design ratings.

3. Sustainability Knowledge

Respondents were asked to estimate electricity or water usage of several devices during common daily activities, such as the electricity usage of a laptop computer in an hour [32] or the water usage of a washing machine in one working cycle.

Elements were included in the questions to help respondents make reasonable estimates. Reference points were provided throughout to help with estimation. For example, the energy usage of a single light bulb was given as a reference point for electricity consumption, while a soda can was provided as a reference point for volume of water. The usage estimation questions were presented as logarithmic sliders to emphasize orders of magnitudes rather than a precise value. The absolute values of estimation were shown to the respondents in real time. Sample questions are shown in Fig. 3. Respondents were able to choose to view the survey in either SI or Imperial units.

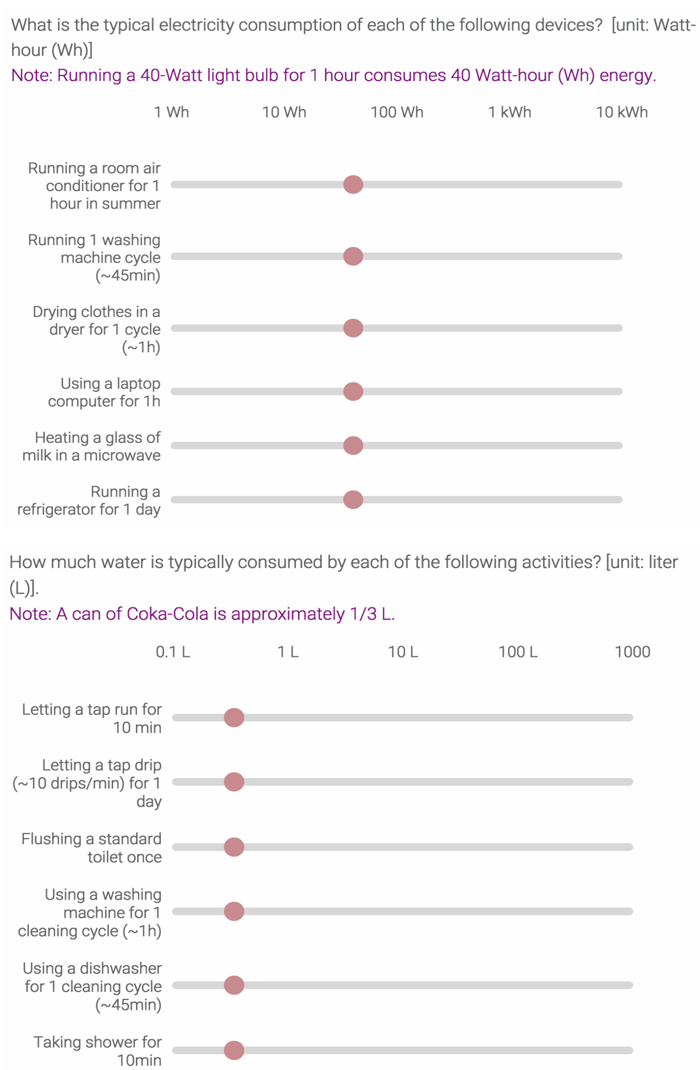


Fig. 3 Electricity (Above) and Water (Below) Usage Estimation Questions

4. Survey Distribution

The survey was distributed among undergraduate and graduate students at one co-educational US university, one all-male Saudi Arabian university, and two all-female Saudi Arabian universities. As an incentive to complete the survey, the US university participants were entered in a lottery for $50, $20 and $10 Amazon gift cards. No incentives were offered to the Saudi Arabian students. The survey was distributed via campus dorm email lists, departmental email lists, course mail lists, and relevant student clubs. Demographic information including age, gender, school and major were collected at the end of the survey.

RESULTS

1. Participant Profile

In total, 145 completed responses were collected from the US university students (referred to as Country A) and 135 completed responses from Saudi Arabia (Country S). These responses were further winnowed according to two rules:

- Respondents had to complete the survey in a minimum of 5 minutes.
- Preferences for designs had to be consistent. If a design was given the highest rating on all four criteria, it should also be ranked as the most preferred. Otherwise, this evaluation was deemed to be inconsistent. Since inconsistency is innate in revealed user preference [33,34], it is not necessarily true that these inconsistent responses were invalid. However, this screening criterion helped to increase the probability that responses were provided in a mindful manner.

After applying these two rules, around 77% responses (216 responses) remained. Table 2 summarizes the distribution of gender and whether the respondent's major was technical (T) or non-technical (NT). Majors in a STEM-related field (Science, Technology, Engineering and Math) were categorized as T, while majors such as art, psychology, and interior design were categorized as NT. In this way, any role that having a technical background might play in respondents' ability to estimate resource usage or preference for designs could be seen.

Table 2 Summary of Responses for the Survey (F – Female, M – Male, T – Technical Major, NT – Non-Technical Major)

	Electricity	Water	Total
Country A	57 (F: 38, M: 19) (T: 55, NT: 2)	61 (F: 39, M: 22) (T: 57, NT: 4)	**118** **(F: 77, M: 41)** **(T: 112, NT: 6)**
Country S	46 (F: 15, M: 31) (T: 32, NT: 14)	52 (F: 17, M: 35) (T: 37, NT: 15)	**98** **(F: 32 M: 66)** **(T: 69, NT: 29)**
Total	**103** **(F: 53, M: 50)** **(T: 87, NT: 16)**	**113** **(F: 56, M: 57)** **(T: 94, NT: 19)**	**216** **(F: 109, M: 107)** **(T: 181, NT: 35)**

2. Design Evaluation

Diverging Stacked Bar Charts plot the results of design evaluations (Fig. 4). This type of chart is recommended for presenting Likert scale results by Robbins et al. [35].

For the Electricity Meter, the design that used Color Emphasis as a prompt was rated highest on all four criteria. The fourth design, which used Metaphor with a Living Creature, had a relatively high *Emotion* score, but also had the lowest *Clarity* score.

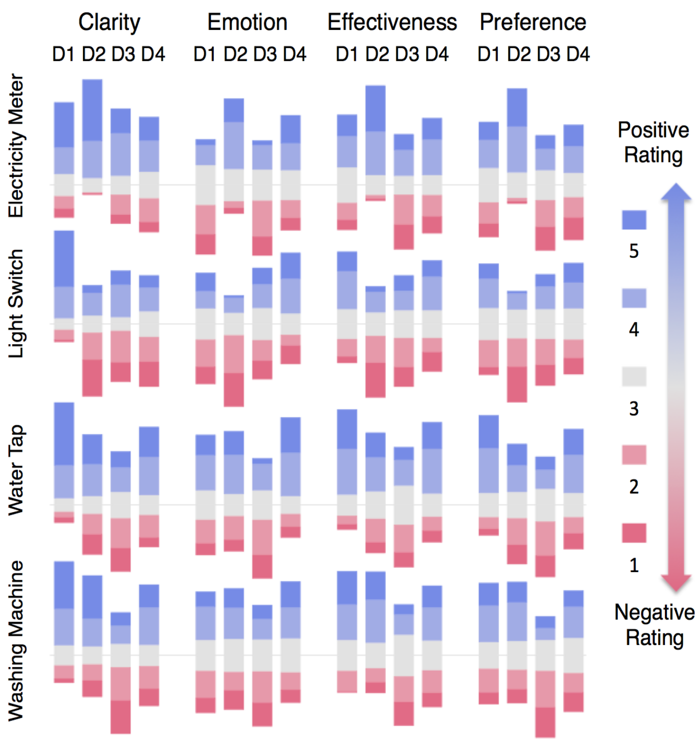


Fig. 4 Design Ratings (on 1~5 Likert Scale). D1=Text/Chart, D2=Color Emphasis, D3=Metaphor Using Objects, D4=Metaphor Using Living Creatures as an Eco-Feedback Prompt.

For Light Switch, Water Tap and Washing Machine, the designs that used Text/Chart as a prompt always had the highest *Clarity* rating and a medium *Emotion* rating. In contrast, designs that employed a Metaphor with a Living Creature had the highest ratings for *Emotion* and medium ratings for *Clarity*. This was consistent with our expectations of the effect of the four design prompts.

Table 3 Pearson Correlations between Design Ratings

		Clarity	Emotion	Effectiveness	Preference
Electricity Meter	**Clarity**	1.000	0.545	0.666	0.677
	Emotion	-	1.000	0.699	0.709
	Effectiveness	-	-	1.000	0.847
	Preference	-	-	-	1.000
Light Switch	**Clarity**	1.000	0.557	0.748	0.626
	Emotion	-	1.000	0.727	0.645
	Effectiveness	-	-	1.000	0.725
	Preference	-	-	-	1.000
Water Tap	**Clarity**	1.000	0.539	0.732	0.730
	Emotion	-	1.000	0.645	0.629
	Effectiveness	-	-	1.000	0.813
	Preference	-	-	-	1.000
Washing Machine	**Clarity**	1.000	0.634	0.710	0.721
	Emotion	-	1.000	0.692	0.723
	Effectiveness	-	-	1.000	0.743
	Preference	-	-	-	1.000

The mean value and standard deviation of all ratings are given in the Appendix. ANOVA was used to compare the ratings between the two groups. Most ratings were consistent, but some significant differences existed between Technical and Non-technical students. The Electricity Meter had the most rating inconsistency, while Light Switch and Washing Machine had fairly consistent ratings.

For all four designs, Technical students rated the *Clarity*, *Effectiveness* and *Preference* of the Text/Chart designs higher than the Non-technical students. This difference was statistically significant with alpha level of 0.05 for *Clarity* and *Preference* for the electricity meters, and *Clarity* for the water tap.

It was expected that ratings for *Clarity* and *Emotion* would be independent from each other. However, there was a significant correlation between these two (Table 3). Correlations between ratings of the four criteria were high in general. *Clarity* and *Emotion* were correlated, with coefficients varying from 0.539 to 0.634. One possible reason for this could be that respondents tended to give high ratings on all criteria for designs that they liked and to give low ratings on all criteria for designs they preferred less. The correlation coefficients between *Effectiveness* and *Preference* were almost always the highest, varying from 0.725 to 0.847.

3. Most Preferred Designs

The distribution of most preferred designs is summarized in Fig. 5. For Electricity Meter, the Color Emphasis design was the most preferred. 66% of Technical students and 38% of Non-technical students chose it to be their favorite. Non-technical students also preferred the sunflower design (Metaphor using living creatures) as much as the second design (Color Emphasis).

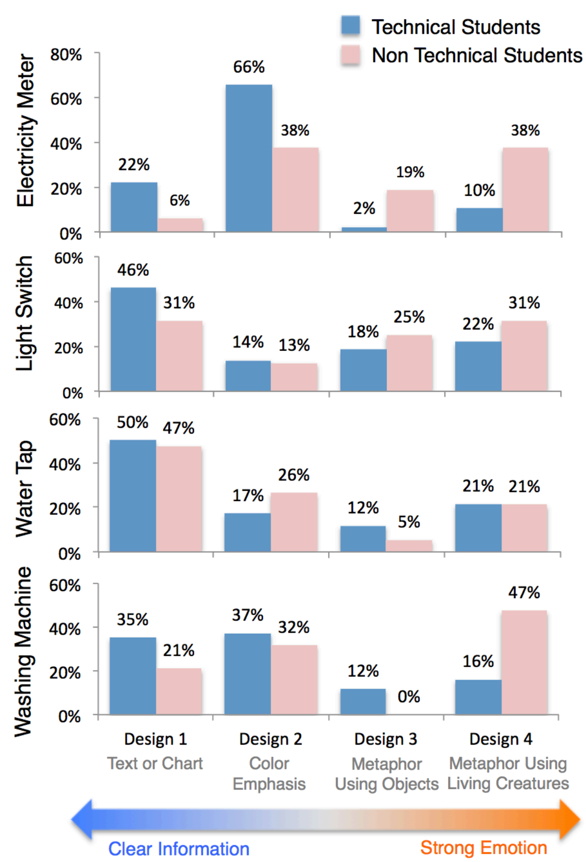


Fig. 5 Most Preferred Designs

For Light Switch, the Text/Chart design that quantified how much electricity could be saved was the most preferred in general. Almost half of Technical students (46%) and 31% of Non-Technical students chose it as their favorite. Again, Non-Technical students also preferred the polar bear design (Metaphor with living creature) as much as the Text/Chart design.

For Water Tap, the Text/Chart design that quantified how much water was consumed was most preferred by both Technical and Non-Technical students, at 50% and 47% respectively. The rest of the designs were much less preferred, especially the water bottle design (Metaphor using objects).

For Washing Machine, almost the same percentage of Technical students (35% and 37%) preferred the Text/Chart design that quantified how much water could be saved and the Color Emphasis design. They preferred the third and fourth designs much less. However Non-technical students preferred the whale (Metaphor using living creature) the most.

Pearson Chi-squared analysis was conducted to compare the differences of the preference between Tech and Non-tech students (Table 4). The differences between the two groups were significant for the Electricity Meter and the Washing Machine.

Table 4 Chi Square Test for Most Preferred Designs (* means statistically significant)

	Electricity Meter	Light Switch	Water Tap	Washing Machine
Chi-square	**17.804**	1.505	1.374	**10.658**
p-value	**0.0005***	0.6811	0.7116	**0.0137***

This shows statistically significant evidences that, for the designs of these two products, the Technical students in general preferred those presenting clearer information much more than the Non-tech students; while the Non-tech students preferred the emotion-evoking designs more.

4. Resource Usage Knowledge

The following equation was used to calculate the score for each respondent's knowledge level of electricity or water usage.

$$Knowledge\ Score_i = 10 - \sum_{k=1}^{6} [\log(E_{ik}) - \log(S_k)] \qquad (1)$$

E_{ik} was respondent i's estimation for questions k. S_k was the standard answer for questions k. The difference between the logarithms of these two values was calculated. Logarithms were used here because the respondents made estimations on logarithmic scales. This measured the difference in magnitude between the two values rather than an exact number: as long as they are of the same magnitude, the difference of the log values would be small. Then the log differences for the six questions were summed together and subtracted from 10. This provided a knowledge score that represented the resource usage estimation accuracy: the larger the accumulated differences between estimations and standard answers, the lower the knowledge score; the closer the estimations to the standard answers, the higher the knowledge scores.

After this transformation, the knowledge scores formed a distribution between 0~10. ANOVA showed no significant difference between the knowledge scores with different units, proving that different units didn't induce significant estimation bias.

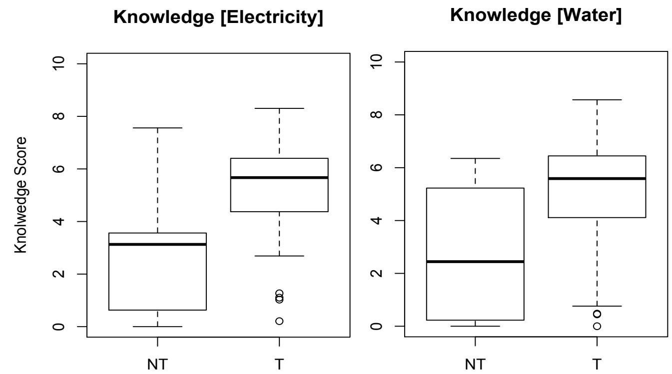


Fig. 6 Box Plot of Knowledge Scores (Left: Electricity Usage Knowledge; Right: Water Usage Knowledge; NT - Non-Technical Students; T - Technical Students)

Fig. 6 shows the boxplots of knowledge scores of the Technical students and the Non-technical students. Not surprisingly, Technical students made much accurate estimates of usage for both electricity and water. The differences between Technical and Non-technical students were statistically significant, shown by the ANOVA p-value presented in Table 5.

Table 5 Means, Standard Deviations and ANOVA Results of Knowledge Scores (* means statistically significant)

	Mean (StDev)		ANOVA
	Technical Students	**Non-Technical Students**	**F Ratio** (p-value)
Electricity	5.32 (1.61)	2.73 (2.19)	**31.01 (< 0.001*)**
Water	5.13 (1.88)	2.88 (2.46)	**20.23 (<0.001*)**

Since the data collected were asymmetric by gender and country, the technical or non-technical background was confounded with these two factors. To evaluate the importance of gender and country, the female and male students in country A (the majority of both had technical education backgrounds) were compared and no significant difference between their knowledge scores or preference for designs was found. Male students in country A and the male students in country S (majority of both groups were in technical majors) were also compared. There was no significant difference in their design preference or their electricity knowledge scores as well. Though there was statistically significant difference between their knowledge scores in water, the difference was much smaller compared to the difference between technical and non-technical students. These analyses suggested that we could eliminate the effects of country and gender in the scope of our study.

5. Qualitative Feedback on Designs

About half of the respondents provided at least one qualitative comment in their design evaluations and/or their choice of most preferred designs. These qualitative responses to the survey were carefully examined and are discussed here to add richer context to the quantitative findings above.

5.1 Reflections on Eco-Feedback Design Prompts

Many respondents commented on the effectiveness of Text/Chart designs for encouraging resource conservation behavior, noting that it gave the most detailed and clearest information:

"It is interesting to see how electricity consumption accumulates in a whole day." "I personally like the time trace because it is more informative." [Electricity Meter]

However, some respondents disliked Text/Chart because it offered too much information and would take too much time to read and interpret:

"Probably wouldn't read as I turn off a light switch." [Light Switch]

"Too many words." [Washing Machine]

The cited advantage of the Color Emphasis design was that it was "*simple and visual"* and *"quickly draws attention"*. However, Color Emphasis was not as highly rated for the Light Switch and Water Tap:

"If I saw it without knowing what it talks about I would not understand." " People might think the glow is so you can find the light in the dark." [Light Switch]

"Needs to be more quantitative"; "Can be confusing with hot or cold water". [Water Tap]

Thus attracting users' attention along may not be enough. More information may need to be provided. When Color Emphasis was combined with Text/Chart it became very powerful. The Color Emphasis design for Electricity (the one with colored bar) used bright color to indicate electricity usage level, and at the same time showed the amount of electricity consumed in numerical format. It received the highest rating on both *Clarity* and *Emotion* and was chosen as the most preferred design by the majority of participants.

Compared to Text/Chart designs, Metaphor related designs were appreciated for their vividness and concision:

"Having a visual connection to the environment would promote the strongest emotion while being aesthetically appealing."

However, they are effective only if the connection between the metaphoric objects and the environment exists in users' mind. If so, figurative images will act as powerful reminders for environmental sustainability:

"It's the clearest and appeals to an understanding of our energy system's dependence on fossil fuels, which we should be working to diminish." [Light Switch]

If the user didn't see the metaphoric connection, the design could be confusing:

"I wouldn't immediately associate it with energy conservation." [Light Switch]

Metaphor with living creatures was more successful than with non-living objects. It evoked much stronger emotions and was evaluated to be more effective on encouraging resources conservation behaviors than Metaphors with objects. Animals and plants were naturally associated with the environment thus were more accepted as metaphoric figures for sustainability. Also they reminded people of the responsibility they had to protect the environment:

"I would want to keep it (the sunflower) alive, thereby using less energy." "It leads me for deep thoughts about the future and responsibility that we have for the next generations." [Electricity Meter]

"The polar bear triggered my emotions and encouraged me to save this animal." "It's both noticeable and clear and emotionally impactful." "It reminds us that our behaviors might kill other creatures in this planet while we should save them and offer them a clean and safe environment." [Light Switch]

"I like the idea of directly relating water consumption with the environmental effect." [Water Tap]

"Animal figures have more emotional effect for raising awareness." "This design makes you feel like you are saving a life." "It is touchier than the others. The facial emotion plays big rule." [Washing Machine]

5.2 Which Is More Important in Eco-Feedback Designs: Information Clarity or Emotion?

Some participants thought the detailed information about resource consumption would be helpful as reminders to act in an environmentally conscious way:

"It gives me a concrete number to know how much water I'm using every time I wash clothes and would encourage me to be more careful and make sure I have a full load before starting a cycle." [Washing Machine]

However to the others, the numbers might not be as appealing:

"This is not too helpful. It is just more numbers tracking my daily life, and it evokes no response from me." "This number probably doesn't mean anything to anybody." [Electricity Meter]

Whether it is useful to give detailed usage data largely depends on whether the data can be appropriately interpreted, as one respondent pointed out: *"Numbers can be meaningless if people are not educated on energy measurements."* Thus the designs that presented detailed usage information might be attractive only those who already had sufficient knowledge of electricity or water usage. This will be further discussed in the next section.

Another way to help users interpret data is to provide comparison usage data as a reference point. This could take the form of average usage data so users would have a sense of whether they use more or less resources. It could also be a target usage value to give users a goal to achieve. One respondent commented: *"It would be more effective for me if it included a target water usage line. It would become a game!"*

To many respondents, the emotional impact of the designs was more effective in raising environmental awareness and encouraging resource conserving behavior. One commented: *"Feelings are more attracting as compared to graphs"* and "*Though data is important to me, for some reason, the visual is highly appealing and provides incentive on a daily basis."*

One specific emotion mentioned being evoked by the designs is *guilt*, emphasizing its value in promoting pro-environmental behavior:

"By showing an image of a flower withering as the energy consumption increases, makes a person feel guilt." "It shows the negative feeling on the sunflower and that will

remind me to stop using electricity when I don't need it." [Electricity Meter]

"I would feel quite guilty/wasteful if my fish died!" [Water Tap]

"It's cute and would make me feel bad about choosing normal mode." [Washing Machine]

However, it might drive people away because of negative associations:

"It is using guilt to get you to turn off the lights. It might be nice if there was a positive image to get you to turn them off." "Guilt always works! I don't think anybody would buy such a design though." [Light Switch]

DISCUSSION

To address the two questions asked at the beginning of the paper:

1. *In eco-feedback designs, is clearer, more quantitative information preferred over more qualitative, emotionally evocative information?*

We found that both the quantitative and emotional aspects of the designs are key to the success of eco-feedback designs. The *Clarity* and *Emotion* ratings represented the rational and emotional power of the designs respectively. Consistent with our expectation, Text/Chart designs tended to have higher ratings for *Clarity* presumably because they presented more concrete data on resource usage. Designs generated by Metaphor using living creatures usually had higher ratings for *Emotion*, presumably because the images of animals and plants were evocative. The *Effectiveness* and *Preference* ratings were highly correlated with both the *Clarity* and *Emotion* ratings, indicating both *Clarity* and *Emotion* are important to users' evaluation on the designs.

However, which one of these two aspects was more effective in encouraging resource conservation behaviors and was more preferred by the user varied from person to person: some chose their most preferred design because it was *"the most emotionally powerful" "the most evocative, and has the strongest emotional response";* while the others preferred to know more data and detailed information: *"It's a lot clearer than the other", "It is the most informative and straightforward", "Considering resources (consumption) should be rational and practical, not emotional".*

In this study we did not distinguish the user preference for the designs from the designs' effectiveness on encouraging sustainable behaviors. On one hand, users prefer the designs that they believed could help people to better develop environmental-conscious behaviors; on the other hand, designs perceived to be more attractive could motive people to use them more often thus be more effective on encouraging sustainable behaviors. The high correlation between the *Effectiveness* and the *Preference* ratings supports this point of view.

2. *Does a user's quantitative knowledge about resource consumption influence his or her preference for the two attributes above of eco-feedback designs?*

Our study found that respondents with technical background made better estimates of resource usage, and preferred designs that presented numbers and detailed energy or water usage. Non-technical respondents made less accurate estimates of resource usage, and generally preferred more of the metaphor designs, which had stronger emotional appeal.

This finding implies that respondents' environmental knowledge is closely related to their preference for eco-feedback designs. Respondents with technical majors had more training in understanding numbers and working with data. Thus it was not surprising that they tended to make more accurate estimations on resource consumptions and could in general better appreciate devices that provided quantitative resource usage data.

This seemed to be not only true for quantitative data, but also for qualitative data. For example, results suggested that only when a metaphoric figure was familiar to the user and the connection between the figure and the environment was understood, could emotions be triggered to promote sustainable behaviors.

CONCLUSIONS & FUTURE WORK

In this study, we found evidence that both presenting clear information and evoking strong emotional responses are important aspects for the design of eco-feedback products. Which of them is more effective on encouraging sustainable behaviors in users is related to the users' level of knowledge about resource consumption.

These results could be used as guidelines for better developing eco-feedback products. However, the survey method only collected immediate responses to the designs, and was not capable of capturing how users might respond to the designs if they were encountered every day. Would fatigue set in? Field study that tracks the users' long-term behavior changes with prototypes of the designs could potentially solve this problem.

The results of this study were largely governed by the particular population surveyed: there were more female students in country A and more male students in country S. Almost all respondents in country A had a technical education background, while in county S almost all students with technical education background were male and almost all non-technical students were female. This introduced risk that the gender, country and major were all confounding factors in understanding the demographics of the data. Future studies should gather the responses from broader populations to further justify the findings.

In future work, analysis could be conducted at an individual level to better understand the links between environmental knowledge and design preferences. Furthermore, this study did not make specific observations about possible cultural differences in design preferences between respondents from the two different countries, though this would also be a rich area for future research. Finally, a deeper understanding of the specific types of emotions evoked by a design and their effectiveness in encouraging pro-environmental behavior is an area ripe for further study.

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APPENDIX I: Design Ratings

D1=Text/Chart, D2=Color Emphasis, D3=Metaphor Using Objects, D4=Metaphor Using Living Creatures As An Eco-Feedback Prompt.

Electricity Meter

		Mean (StDev)			ANOVA
		All	Technical	Non-Technical	F Ratio (p-value)
D1	Clarity	3.75 (1.29)	3.90 (1.23)	2.94 (1.34)	**7.996 (0.006)**
	Emotion	2.67 (1.11)	2.69 (1.13)	2.56 (0.96)	0.177 (0.675)
	Effectiveness	3.32 (1.19)	3.39 (1.17)	2.94 (1.24)	1.980 (0.162)
	Preference	3.14 (1.23)	3.25 (1.22)	2.50 (1.10)	**5.283 (0.024)**
D2	Clarity	4.36 (0.81)	4.47 (0.66)	3.75 (1.24)	**11.70 (0.001)**
	Emotion	3.66 (1.02)	3.71 (1.02)	3.38 (1.02)	1.474 (0.228)
	Effectiveness	4.11 (0.93)	4.18 (0.84)	3.69 (1.25)	**3.981 (0.049)**
	Preference	3.99 (0.92)	4.10 (0.79)	3.38 (1.31)	9.074 (0.003)
D3	Clarity	3.47 (1.23)	3.44 (1.25)	3.63 (1.15)	0.316 (0.575)
	Emotion	2.65 (1.11)	2.56 (1.11)	3.13 (1.02)	3.556 (0.062)
	Effectiveness	2.81 (1.37)	2.68 (1.36)	3.50 (1.21)	**5.094 (0.026)**
	Preference	2.78 (1.29)	2.72 (1.33)	3.06 (1.06)	0.928 (0.338)
D4	Clarity	3.30 (1.25)	3.21 (1.27)	3.81 (1.05)	3.236 (0.075)
	Emotion	3.35 (1.30)	3.29 (1.35)	3.69 (0.95)	1.291 (0.259)
	Effectiveness	3.20 (1.34)	3.10 (1.36)	3.75 (1.13)	3.222 (0.076)
	Preference	3.04 (1.39)	2.97 (1.42)	3.44 (1.21)	1.561 (0.214)

Light Switch

		Mean (StDev)			ANOVA
		All	Technical	Non-Technical	F Ratio (p-value)
D1	Clarity	4.17 (1.06)	4.22 (1.03)	3.88 (1.20)	1.429 (0.235)
	Emotion	2.93 (1.30)	2.83 (1.30)	3.50 (1.21)	3.709 (0.057)
	Effectiveness	3.42 (1.12)	3.47 (1.12)	3.13 (1.15)	1.284 (0.260)
	Preference	3.16 (1.14)	3.18 (1.13)	3.00 (1.26)	0.347 (0.557)
D2	Clarity	2.44 (1.32)	2.44 (1.40)	2.44 (0.73)	0.000 (0.998)
	Emotion	2.23 (1.09)	2.21 (1.09)	2.38 (1.09)	0.321 (0.572)
	Effectiveness	2.42 (1.24)	2.39 (1.29)	2.56 (0.96)	0.257 (0.613)
	Preference	2.29 (1.13)	2.31 (1.19)	2.19 (0.66)	0.160 (0.690)
D3	Clarity	2.91 (1.34)	2.83 (1.38)	3.38 (0.96)	2.296 (0.133)
	Emotion	2.99 (1.29)	2.95 (1.33)	3.19 (1.05)	0.442 (0.508)
	Effectiveness	2.83 (1.29)	2.74 (1.32)	3.38 (0.96)	3.389 (0.069)
	Preference	2.82 (1.26)	2.79 (1.29)	2.94 (1.12)	0.177 (0.675)
D4	Clarity	2.76 (1.31)	2.76 (1.32)	2.75 (1.29)	0.001 (0.981)
	Emotion	3.35 (1.38)	3.45 (1.34)	2.81 (1.52)	2.935 (0.090)
	Effectiveness	3.12 (1.31)	3.11 (1.32)	3.13 (1.26)	0.001 (0.978)
	Preference	3.13 (1.30)	3.15 (1.30)	3.00 (1.32)	0.178 (0.674)

Water Tap

		Mean (StDev)			ANOVA
		All	Technical	Non-Technical	F Ratio (p-value)
D1	Clarity	4.19 (1.09)	4.36 (0.93)	3.32 (1.42)	**16.57 (<0.001)**
	Emotion	3.24 (1.23)	3.18 (1.20)	3.53 (1.35)	1.256 (0.265)
	Effectiveness	3.88 (1.09)	3.95 (1.08)	3.53 (1.07)	2.396 (0.124)
	Preference	3.72 (1.13)	3.79 (1.11)	3.37 (1.21)	2.195 (0.141)
D2	Clarity	3.26 (1.43)	3.33 (1.41)	2.89 (1.52)	1.466 (0.229)
	Emotion	3.33 (1.26)	3.41 (1.22)	2.89 (1.41)	2.718 (0.102)
	Effectiveness	3.32 (1.25)	3.40 (1.22)	2.89 (1.33)	2.672 (0.105)
	Preference	3.04 (1.34)	3.11 (1.31)	2.68 (1.49)	1.571 (0.213)
D3	Clarity	2.83 (1.32)	2.82 (1.33)	2.89 (1.33)	0.051 (0.821)
	Emotion	2.63 (1.16)	2.56 (1.13)	2.95 (1.27)	1.743 (0.189)
	Effectiveness	2.95 (1.17)	2.93 (1.18)	3.05 (1.13)	0.185 (0.668)
	Preference	2.73 (1.23)	2.71 (1.27)	2.84 (1.07)	0.173 (0.678)
D4	Clarity	3.47 (1.27)	3.54 (1.28)	3.11 (1.15)	1.894 (0.172)
	Emotion	3.66 (1.25)	3.78 (1.19)	3.11 (1.41)	**4.704 (0.032)**
	Effectiveness	3.50 (1.23)	3.56 (1.22)	3.21 (1.27)	1.301 (0.256)
	Preference	3.35 (1.31)	3.40 (1.33)	3.05 (1.22)	1.132 (0.290)

Washing Machine

		Mean (StDev)			ANOVA
		All	Technical	Non-Technical	F Ratio (p-value)
D1	Clarity	3.90 (1.14)	3.98 (1.13)	3.53 (1.17)	2.516 (0.116)
	Emotion	3.05 (1.22)	3.02 (1.24)	3.21 (1.18)	0.376 (0.541)
	Effectiveness	3.65 (1.08)	3.66 (1.10)	3.63 (1.01)	0.010 (0.919)
	Preference	3.28 (1.25)	3.36 (1.20)	2.89 (1.45)	2.231 (0.138)
D2	Clarity	3.54 (1.43)	3.57 (1.42)	3.37 (1.50)	0.328 (0.568)
	Emotion	3.11 (1.30)	3.10 (1.28)	3.16 (1.42)	0.036 (0.850)
	Effectiveness	3.52 (1.22)	3.54 (1.20)	3.42 (1.35)	0.156 (0.694)
	Preference	3.27 (1.25)	3.30 (1.22)	3.11 (1.41)	0.375 (0.541)
D3	Clarity	2.54 (1.32)	2.51 (1.32)	2.68 (1.38)	0.270 (0.604)
	Emotion	2.75 (1.27)	2.74 (1.25)	2.79 (1.40)	0.019 (0.889)
	Effectiveness	2.73 (1.19)	2.72 (1.15)	2.74 (1.41)	0.002 (0.964)
	Preference	2.50 (1.24)	2.44 (1.24)	2.79 (1.23)	1.286 (0.259)
D4	Clarity	3.21 (1.33)	3.24 (1.29)	3.05 (1.54)	0.326 (0.569)
	Emotion	3.33 (1.26)	3.35 (1.25)	3.21 (1.32)	0.196 (0.659)
	Effectiveness	3.21 (1.26)	3.22 (1.26)	3.16 (1.30)	0.042 (0.838)
	Preference	3.04 (1.26)	3.06 (1.24)	2.95 (1.39)	0.133 (0.716)