Designing Products to Encourage Conservation: Applying the Discretization Principle

Jayesh Srivastava and L.H. Shu

Dept. of Mechanical and Industrial Engineering, University of Toronto, Canada

Abstract

We applied lead-user methods to identify product design principles that encourage environmentally significant behavior (ESB) in individuals. Previous work studied Mennonites as lead users due to their low consumption lifestyles, and found that resources in discrete units instead of continuous flows facilitated resource conservation. This paper describes our efforts to apply the discretization principle to product design. We identified how discretization is evident in current products, and discovered challenges in applying discretization while considering user and facilitator needs. Revised concepts were produced to combine various needs, and preliminary tests on one prototype appear promising for encouraging water conservation.

Keywords:

Design for environment; Environmentally significant behavior; Discretization

1 INTRODUCTION

1.1 Motivation

The costs of energy and fresh water are expected to increase greatly in the future because of both the rise in demand for resources and stricter regulation of emissions and pollution [1]. Therefore, over the past few decades, a great deal of effort has been devoted to designing more efficient products that help users perform the same tasks with less energy and/or other resources. Nevertheless, national energy consumption in all industrialized countries has risen unabated for the last 25 years. One reason for this continual increase is the phenomenon termed by researchers as the **rebound effect**. Studies into this effect have found that improving energy or resource efficiency lowers the implicit price of energy or the resource and hence makes its use more affordable, motivating people to use it more [2]. Therefore, to be effective over the long term, products must not only be more efficient in their use of energy and resources, as has been the goal of traditional life cycle engineering [3], but must also encourage users to reduce their consumption of energy and other resources. The purpose of our work is to design products that encourage or facilitate conservation.

1.2 Environmentally Significant Behavior

We used the **Environmentally Significant Behavior** framework to formulate our design problem [4]. The term environmentally significant behavior broadly describes any human behavior that aims to affect and/or actually affects the balance of matter or energy in the natural environment. These behaviors can be: active (participation in environmental causes) or passive (acceptance of environmental regulation), intentional (use of public transportation) or unintentional (purchasing a fuel efficient vehicle to save money, when it also reduces emissions) and public (contacting elected officials to enact environmental regulations) or private (using a less environmentally harmful laundry detergent).

The focus of our work is household energy and resource use behaviors. Cumulative domestic energy and water use contributes significantly to a country's overall energy and resource expenditure. For example, American households were responsible for 1,220 million metric tons of carbon dioxide emissions in 2008, which accounted for roughly 21% of total U.S. emissions that year [5].

1.3 Lead-User Theory

To look for solutions to the problem of household energy and resource use, we employed the lead-user method. Lead-user theory was originally outlined by von Hippel [6] who studied people and companies that adopted and experimented with technologies and products well in advance of the mainstream. These **lead users** had needs that would be faced by mainstream users in the future and often created their own novel solutions to problems they encountered. Studying their needs served as an effective way of predicting the needs of the mainstream. Examining their make-do solutions also provided a fertile basis for concept generation.

More recently, Hannukainen and Hölttä-Otto [7] demonstrated that users who experienced needs in more extreme ways than the mainstream could also be suitable lead users. Building on this, we studied the Old Order Mennonites, who were extreme in their usage of energy and water due to their partly pre-industrial lifestyle [8].

1.4 Discretization

An ethnographic study was performed in two Old Order Mennonite households [9]. When examining how Old Order Mennonite families met their needs, a pattern emerged. Old Order Mennonite solutions for meeting needs often involved a resource that existed in discrete units, e.g., firewood for generating heat, cans of kerosene for lighting lamps, buckets of water for washing dishes. Conversely, in more modern mainstream settings, these same needs are met by using continuous sources of water and energy.

We were interested in knowing whether the use of discrete energy and resource units was somehow related to the Old Order Mennonites' extraordinary ability to conserve these resources. We performed a repeated measures experiment where participants were given a task of washing paint off a table tennis ball. Water was provided to participants in three forms: continuous (using a tap), discrete (using water from provided containers) and discrete with added work (using water from containers, each of which were to be earned by performing exercise). Participants used significantly less water when it was provided in containers, while the effect of adding work to the conditions was statistically insignificant. We concluded that breaking down resources into discrete units promoted and facilitated conservation behavior. We then hypothesized that discretization may encourage conservation by allowing the user to track the rate of resource use as well as how much of the resource is "remaining", thus enabling one to set goals for conservation [9].

In this paper, we describe the process of developing product concepts by applying the principle of discretization.

2 DISCRETIZATION IN EXISTING PRODUCTS

In our preliminary work, we noticed that the function of many existing resource-conserving products could be described using discretization. The first step of the design process involved a review of such products. Following is a list of characteristic examples.

2.1 Discretization by Proxy

2.1.1 Tokens

Many existing products designed to help conserve water or energy break up the flow of energy or water into discrete units. Some such products are token operated. Entering a token gives a user a certain amount of time to use the product. Many budget hotels make use of token-operated shower systems. Lodgers are given a fixed number of tokens, each of which provides a set amount of shower time. Having to enter tokens provides users with instant feedback on their usage and encourages them to conserve. Our interviews with people who have used such devices reveal that even when they are given a large number of tokens, the discretization of their showering time still encourages them to take shorter showers overall.

Figure 1: Token operated shower controller. (www.franke.com)

2.1.2 Timed Buttons

Some products utilize a more direct connection with the control of the resource flow. For example, public showering facilities often use push button shower valves. Users push the valve in to start the shower, after which the valve slowly returns back to its closed position over a fixed time interval. As with tokens, each push of the valve breaks down the usage time into smaller, discrete units. Although users have the option of pushing the valve repeatedly in order to extend showering time, each push presents an opportunity to end the shower and also tracks overall elapsed time.

Figure 2: Timed shower valve. (http://www.archiexpo.com)

2.1.3 Timed Switches with Precise Feedback

Spring-loaded switch timers such as the product shown in Figure 3 are available in retail stores. They typically replace regular lighting switches inside homes. Users rotate a dial on the front of the device to set the time it should remain on. Many timers also emit ticking sounds as the dial returns to the start position. Part of the effectiveness of such timers comes from reminding the user the passing of time through the audible ticking. Each tick signals a fixed amount of time passing. These products provide the user with precise information about how much time remains until the flow is turned off.

Figure 3: Spring loaded electrical timer. (http://www.canadiantire.ca)

2.2 Discretization by Requiring Additional Physical Action

Figure 4: Instant off tap attachment. (http://www.instant-off.com)

The product shown in Figure 4 is a tap attachment consisting of a rod and a valve. In its neutral position, the valve blocks water from flowing out of the tap. When the rod is moved, the valve opens and water flows out. This helps users to minimize water use as no water flows when the user does not activate the valve, e.g., when applying soap to the hands, or brushing teeth. The flow is therefore discretized through the increased need for physical intervention.

2.3 Discretization by Physical Compartmentalization

Another discretization strategy is to physically break down products into smaller compartments. The multi-drawer dishwasher shown in Figure 5 has two compartments that can operate independently. When one compartment can accommodate the load of dishes, running this compartment uses less water and energy than running a full dishwasher.

Figure 5: A compartmentalized dishwasher. (http://www.fisherpaykel.ca)

2.4 Discretization by Metered Dosing

Another manifestation of discretization is represented in dosing mechanisms used in chemical containers. Through specifications of the interior geometry, the designs of the products ensure that only a prescribed amount of the chemical inside can come out at a time. An example of such a design is presented in Figure 6. The discretization of the flow results in increased precision and a minimization of waste.

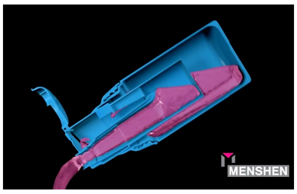

Figure 6: Dosing container. (http://www.menshen.com)

Similar mechanisms are also used in medical and drug delivery applications where precision is required. While designed to prevent dosing errors, such mechanisms, when used to deliver water for example, could help users better control their water usage.

2.5 Discretization by Imposing Container Size Limits

Many examples of discretization can be found in camping equipment. In the example of solar showers, shown in Figure 7, users fill a bag with water, hang it from a high point and use the attached hose as a showerhead to bathe. The fixed capacity of each bag can function as a way of tracking water usage. Users can also see the amount of water remaining and gauge their rate of use.

Figure 7: Solar camping shower. (http://www.mec.ca).

2.6 Discretization by Phase Change

Finally, flows can be discretized by changing the material state of the resource involved. This tactic is easiest to implement in the case of resources in liquid form. Laundry detergent tablets such as those in Figure 8 prevent dosing errors that occur from users overestimating the amount of liquid detergent they require.

Figure 8: Laundry detergent tablets. (http://www.unger.no)

3 APPLYING DISCRETIZATION TO MAKE NEW PRODUCTS – CONCEPT GENERATION

After identifying discretization tactics used in existing products, we proceeded to apply them to the design of new products that would facilitate water and energy conservation. Americans and Canadians are especially poor at conserving water, using more of it per capita than any other country in the developed world [10]. Showering, toilet flushing, clothes washing, and kitchen and bathroom sink use have all been identified as significant contributors to total domestic water use [10]. Similarly, as previously stated, household energy consumption is responsible for 21% of total emissions in the United States [5]. The primary contributors to household energy use are space heating/cooling, water heating, lighting, and electronics. Together they account for 65% of the total [11]. Our concept generation therefore focused on these areas.

3.1 Functional Application of the Principle

Our previous work suggested that discretization could be applied to products in two ways: by making the source of energy or water entering the product discrete, or by making the output of the product discrete. All domestic products we examined provided a benefit to the user, delivering light, heat, water, television programs, etc. Each product also received water or energy from a central supply or mains, as shown in Figure 9. Therefore, our concepts discretized either the energy or water between the mains and the product (discretization at source) or the energy or water as it exited the product (discretization at output). Four concepts are discussed below.

Figure 9: Schematic of relations between user, product and mains.

3.2 Discretization at the Source

For the energy conservation problem, we noted that there already exists a product that discretizes quantities of energy, namely a battery. To motivate people to conserve energy while using electronic devices, we devised the concept of running devices on battery packs. Existing devices would be plugged into the rechargeable battery pack with built-in transformer. There would also be a battery meter on the side of the pack indicating the amount of charge remaining. New battery packs could be swapped in when one is depleted. The quantity of energy in the battery pack would help users mentally track their usage. If they wished to conserve energy, they could then set goals, e.g., using not more than two battery packs a day for lighting purposes. The battery meter would also function as a fuel gauge, potentially encouraging users to place devices into energy saving modes when the meter is running low. A basic representation of the concept is provided in Figure 10.

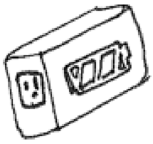

Figure 10: Rechargeable battery pack.

3.3 Discretization at the Output

We then produced three concepts relating to water conservation, each of which applied discretization at the output. The first concept applies to showering/bathing. In our experimental validation of discretization, we demonstrated that providing discrete containers of water for washing tasks resulted in reduced water usage when compared against running taps [9]. The following concept applied a similar proposition to showering. The bathtub divider would be a flat panel with flexible edges. The divider could be slid into any standard bathtub to create a watertight volume on one side. Instead of using a shower to bathe, the user would fill a portion of the tub with warm water and bathe using a water jug on the other side. The concept is illustrated in Figure 11.

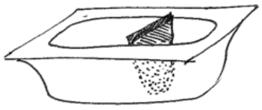

Figure 11: Bathtub divider.

Alternatively, the second concept facilitated water conservation during bathing while still making use of a showerhead. This concept made use of a modified version of the instant-off tap attachment described earlier. Similar to the tap attachment, water would not flow out of the shower when the rod is in the neutral position. This would reduce the unnecessary running of water when the user is applying soap or shampoo. Figure 12 illustrates the concept. Additionally, many users told us that they do not like turning off the shower when soaping up because when they turn it back on, they may have to readjust the controls to achieve the desired temperature again. Using this device, it is more likely that the water would remain at the right temperature while the flow was stopped.

Figure 12: Shower rod.

The final concept of discretization at the output involves a timer or metronome connected to a tap. When the user turns the tap on, the metronome or timer would emit audible beeps at regular intervals, thereby giving the user information about the amount of time elapsed and the amount of water used. Users wishing to conserve water could then use the number of audible ticks to track water usage, or as a reminder to turn off the water. The concept is illustrated in Figure 13.

Figure 13: Tap feedback device.

4 CONCEPT EVALUATION

The four concepts generated were then compared and evaluated for their potential effectiveness in helping users conserve energy and water. We also consulted an industrial designer and a few potential users on the quality of the concepts. The concerns they identified helped us learn about the challenges of applying discretization tactics.

4.1 User Feedback

Three main problems emerged: the concepts made the task more difficult, added additional steps without removing existing ones and ignored or violated other user needs. As an example of making the task more difficult, the showerhead attachment would make it more challenging for the user to rinse off in the shower, as one hand would always be occupied in operating the switch. Secondly, we were advised that some of the concepts ignored or even violated other basic customer needs. While using a bathtub divider would indeed reduce water usage, users liked the warmth and sound provided by a shower and expected to be uncomfortable bathing with a jug. Such unsuitable design solutions would likely motivate users to revert to their past energy and water use habits and could potentially even sour them on the idea of using environmentally friendly products. Past research has demonstrated that adhering too rigidly to DFE criteria can actually lead to products that perform poorly from an environmental perspective [12]. Similarly, it appears that only focusing on environmental goals can lead to products that perform poorly in terms of user-friendliness.

4.2 Facilitator Feedback

We also thought of implementing these concepts in university dormitories for validation. Examining that particular application brought a new set of challenges to light. In dormitory settings there is another group of people, namely maintenance staff whom we refer to as facilitators, whose needs must be taken into account as well. While students are the final users of any energy or water saving product, the facilitators are responsible for their installation and upkeep. Consultation with a building manager at the University of Toronto provided us with several cases where conservation schemes failed because they overlooked the needs of the facilitators. An organic waste program at a dormitory was unsuccessful because it imposed too many additional irregular garbage pickups to the schedules of the maintenance staff. An energy saving initiative at the same dormitory ran into difficulty, as it required constant monitoring even though maintenance staff was only available for two-thirds of the day. A current on-campus reusable food container program is problematic because the affected employees do not have an easy way of doing all the extra tasks it imposes while also doing their usual work. Similarly, products such as the rechargeable battery pack would add considerable workload to facilitators. Though our original focus was on household energy and water consumption, these identified challenges provided valuable insight. Firstly, in many households, the individuals who would install and maintain these products could be different from the users of the product (e.g., housekeepers as facilitators or parents as facilitators and children as users). More generally, the installation and maintenance concerns raised by the facilitators were actually relevant to all household users.

Our concepts therefore had to be revised with a focus on meeting the users' and facilitators' needs. Rather than add steps to the operation of existing products, we decided to present alternatives to existing products. To begin, we examined the activities users were performing while using these products, and sought opportunities for applying discretization to individual parts of the process.

5 TASK ANALYSIS AND NEEDS ASSESMENT APPROACH

The targeted activities (showering/bathing, hand washing, food and drink preparation, space heating and cooling, using lighting and electronics) were broken down, and needs were assessed from the user's perspective.

5.1 Showering/Bathing

User Tasks	System	User Needs
Turn on water	-	Easy to set temperature
Divert to shower	-	Get wet, feel warm
Apply soap and scrub	-	Be able to apply soap, feel warm
Rinse off	-	Have enough pressure
Turn off water	-	Easy to turn off

5.2 Hand Washing, Food and Drink Preparation (Sink Tasks)

User Tasks	System	User Needs
Turn on water	-	Easy to set temperature and pressure
Wash hands / fill container	-	Be able to apply soap / have sufficient water
Turn off water	-	Easy to turn off

5.3 Space Heating/Cooling

User Tasks	System	User Needs
Turn on		Easy to turn on
Increase/decrease temperature setting	Increase power to heating or cooling system	Easy to adjust settings and achieve personal thermal comfort
	Periodically turn on/off system	
Turn off		Easy to turn off

5.4 Use of Lighting and Electronic Devices

User Tasks	System	User Needs
Turn on	-	Easy to turn on
Receive light /entertainment/other function	-	Easy to change settings, output, function, etc.
Turn off	-	Easy to turn off

6 REVISED CONCEPTS

Four revised concepts based on balancing user needs with conservation efficacy are described below.

6.1 Shower Planner

The feedback for the bathtub divider concept suggested that users very much enjoyed the warmth provided by showers. Using a jug to bathe also required more work as the bathtub divider would have to be put in and the tap turned on to fill up the volume created. To address these concerns while still providing users with a method of tracking their water usage in discrete units, we developed the shower planner concept. The product comprises two parts, a timed shower valve with marked detents and a temperature control knob. On the valve, each detent represents an amount of time that the user can set and the valve springs back to closed position over that time. Users could therefore track their shower time in discrete units (number of detents) and set lower time limits if they wished to conserve water. The temperature control knob would allow the user to set the water temperature before turning on the water. This control would again have multiple discrete settings. Users could then choose to use a lower temperature setting if they wished to conserve energy. This concept maintains the present benefits provided while showering without unnecessarily adding to the process. The concept would also be preferable to current push-in timer valves, as it would afford the user more flexibility for setting time and not restrict usage. Figure 14 shows a basic representation of the concept. In addition to enabling resource conservation, this concept also helps the user to track and manage time during a shower.

(a) Possible configuration with temperature/timer controls on ends

(b) Sketch of possible timer control valve

(image from http://www.keuco.de)

Figure 14: Shower planner.

6.2 Metered Tap Attachment

The metered tap attachment concept consists of a self-refilling container that connects to the tap. The container would be transparent, be able to hold several cups of water, and have markings on the outside indicating the volume of water remaining in the container. The spout of the container could be opened and closed with one hand. The container would employ a float valve to periodically refill with water after being emptied. In terms of encouraging conservation, the clear container would provide visual feedback to the user about the amount of water used; the markings would ensure that the user only took out as much water as necessary; the number of times the container would need to be filled would break down the flow of water into more discrete units. The concept would also be easy to install and remove in cases where more water was required.

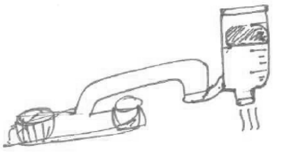

Figure 15: Metered tap attachment.

6.3 Fuel Gauge Thermostat

The third concept, designed to promote and facilitate energy conservation in domestic heating and cooling, involves a modified thermostat. In addition to setting a desired temperature, users can also set an energy quota in discrete artificial units, represented as bars in a battery meter that disappear as energy is used. When the full quota of energy has been used, the system will turn off, subject to a safe minimum/maximum temperature. When first installed, the users could set a very high quota of bars to determine their current usage before setting a goal. Whenever users walk by the thermostat, they would see the bar display. If the bars were declining rapidly, they could then be motivated to raise or lower the temperature setting to conserve energy. The concept is shown in Figure 16.

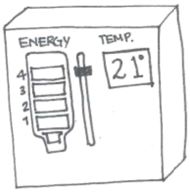

Figure 16: Fuel gauge thermostat.

6.4 Snooze Button for Electronic Devices

For the use of electronic appliances such as computers, televisions, as well as lighting applications, we developed the concept of a versatile snooze button. As in alarm clocks where a snooze button is utilized to postpone an event--the alarm going off, in lighting and electronic products, the snooze button would be used to postpone the shutting off of the devices. In products such as televisions, the snooze counter would begin counting down as soon as the device was turned on. At predetermined intervals, the button would need to be pushed in order to prevent shutdown. This would only be a minor nuisance and gently suggest to the user to manage his or her time with the device better. Similarly, in the case of lighting, networked lights using systems such as Zigbee [13] and Z-wave [14] could be controlled by a single snooze button carried by the user. If not pushed in a predetermined interval, the lights in an area would be turned off. While the settings for a snooze button would be very different for lighting than for electronics, for example, a longer delay period would likely be required for lighting, having to press the snooze button periodically would give the user more tangible feedback about the length of usage. If the user were interested in conserving energy, he or she would then better be able to manage the use of lighting appropriately. The concept is shown in Figure 17**.**

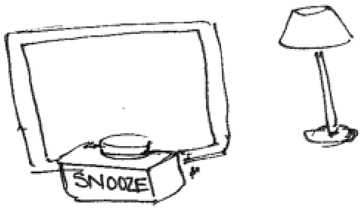

Figure 17: Snooze button concept.

7 PHYSICAL PROTOTYPE AND PRELIMINARY VALIDATION

7.1 Prototype

A basic prototype of the metered tap attachment concept was produced for testing. The prototype is shown in Figure 18. It consists of a transparent container connected to a tap with a rubber hose. The hose can be quickly and easily attached or removed from the tap. The markings on the container indicate the number of cups of water stored in the container. Cups were used as the unit of measurement as they seemed more relevant for the task of making tea or cooking with recipes. The automatic refilling mechanism for the container was not complete and therefore refilling of the container was done manually to simulate the mechanism. The spout of the container employs a snap fit mechanism that can be opened and closed with one hand.

Figure 18: Metered tap attachment prototype.

7.2 Preliminary Test

Three participants performed a typical kitchen sink task; they were asked to fill a hot water kettle to make a serving of tea, first using the tap alone and then using the prototype. The intent of this preliminary test was to refine the concept further through qualitative feedback and basic quantitative comparison.

Participant	Tap	Prototype
1	4 cups	2 cups
2	2 cups	1 cup
3	1.5 cups	1 cup

Table 1: Amount of water used for task in each condition.

In each case, the participants used less water with the prototype than when using the tap alone. In terms of positive reactions, participants appreciated the elimination of measurement uncertainty that the prototype provided. It seemed to be useful in helping them moderate and track their water usage. One participant indicated that such a product would be very useful for preparing recipes that require precise quantities of water. Each participant was also able to operate the opening and closing mechanism with one hand easily. In terms of improvements, participant feedback suggested that the durability of the prototype be increased. Also, storing standing water for long periods in the container was a concern for one participant, who was unsure if the water sitting in container would be safe for drinking.

8 FUTURE WORK

After a promising first test, we plan to produce a higher fidelity prototype for the metered tap attachment and also create physical prototypes of the other concepts. A statistically valid test of the effectiveness of these prototypes in encouraging and facilitating conservation will then be performed. Additionally, we plan to perform a long-term test to determine the persistence of the behaviors encouraged by these products. More generally, our future work will involve further analysis of how to balance environmental goals with other user needs in the design of products to effectively support environmentally significant behavior. As such, we must also consider the needs of product designers, i.e., how to encourage them to design environmentally positive products, in conjunction with the needs of users and facilitators we have identified.

9 SUMMARY

In the context of traditional life cycle engineering, our approach aims to reduce the total environmental cost [15] of products by changing the behavior of the user. In this paper we have highlighted several important parts of our design process. First we identified tactics for applying the principle of discretization by surveying existing products. Then we generated paper concepts and tested them with users and experts. This yielded valuable insights about the necessity of incorporating general user needs and facilitator needs into our design requirements. Our revised concepts aimed to overcome those concerns. Preliminary tests on one prototype appear promising for encouraging water conservation for a particular task. The next step is to build and refine more prototypes and validate them with statistically significant tests.

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