Encouraging Resource-Conscious Behavior Through Product Design: The Principle of Discretization

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Lead-user methods were applied to develop product design principles that encourage resource-conscious behavior in individuals. Old Order Mennonites (OOMs) were chosen as lead users because of their low-resource consumption lifestyles. Ethnographic analysis revealed that discretizing resource consumption facilitates and encourages conservation behaviors in OOMs. An experimental study demonstrated the effectiveness of discretization in reducing water consumption by non-OOMs. We then generated concepts for products that applied discretization and tested them with users. Concepts were revised and a prototype for saving water was created. [DOI: 10.1115/1.4024225]

1 Introduction

1.1 Encouraging Resource-Conscious Behaviors. The costs of energy, water, and other resources are expected to increase significantly as sources become depleted while global demand continues to rise [1,2]. It is therefore important to find ways of reducing resource consumption. One strategy has been to develop products that use resources more efficiently. While many products, including home appliances, automobiles, and electronic devices, have become more resource efficient, their increased adoption has not led to the expected reductions in resource consumption. In fact, per-capita resource consumption has even increased in many cases [3]. This can in part be ascribed to the *rebound effect*, where the availability of more efficient products can cause users to become more complacent about their usage habits. In cases that document the rebound effect, when a more efficient product is introduced, overall resource consumption first declines slightly but then continues to increase [4–6]. As another approach to reduce resource consumption, we aim to design products that change user behavior. Products should not only be more resource efficient, they should also encourage users to conserve and engage in other resource-conscious behaviors.

Resource-conscious behaviors are described by Stern's [7] environmentally significant behavior framework to include activities that intend to, or actually do, reduce the impact of human activities on the biosphere. While much work aims to understand the factors involved in behavior change and the success or failure of interventions [8–14], the determinants for lasting resource-conscious behavior change still remain unclear. In this paper, we describe how we applied *lead-user methods* to find new approaches to encourage users to behave in resource-conscious ways.

1.2 Lead-User Methods. Lead-user theory was initially articulated by von Hippel [15] as a way for product manufacturers to predict the needs of their future users. von Hippel defined lead users as those who experienced needs well in advance of the mainstream population, and could range from single individuals to entire corporations. For example, in the semiconductor industry, niche firms that used leading edge manufacturing processes and required extreme levels of precision were lead users. Individuals who used technologies well before their mainstream adoption, e.g., networked bulletin boards in the 1980s, could also be called lead users. von Hippel's theory posits that studying lead users is useful for forecasting the needs of mainstream users. In addition, solutions that lead users themselves devised yielded valuable insights.

Expanding the traditional definition of lead users, Hannukainen and Hölttä-Otto explained how users who perform tasks in a more limited capacity than the mainstream, i.e., disabled persons, also exhibit lead-user characteristics [16]. Blind and deaf users of electronics were lead users for mainstream users who are *situationally disabled*. Specifically, operating in a dark environment is akin to visual impairment, and a loud environment presents challenges similar to those faced by the hearing impaired. Disabled users precipitated the development of many product features that were later useful for the mainstream. For example, the hearing impaired used text messaging in mobile telephones well before the mainstream. Lin and Seepersad [17] demonstrated that designers could become *empathic lead users*, gaining unique product insights when they temporarily limited their vision, dexterity or range of motion when interacting with a product.

Noting the utility of lead-user methods, we decided to apply them to identify ways to encourage users to engage in resource-conscious behaviors. We therefore sought to identify users who already engaged in resource-conscious behaviors. The old order Mennonites were identified as one such group.

2 Ethnographic Study: Old Order Mennonites (OOMs)

2.1 Background. The Mennonites are an Anabaptist sect that emerged during the Protestant Reformation in 16th century Europe. To escape persecution for their beliefs, Mennonites travelled around Europe and to other parts of the world, including North America. Mennonite groups are united by shared beliefs in baptism in adulthood, pacifism, and a strict separation of church and state [18]. There are significant differences in the resource-conscious behaviors of Mennonite groups [19]. At one extreme are groups with lifestyles very similar to the mainstream: they live in cities, drive cars, and use electrical appliances and electronic devices [20]. Groups at the other extreme have no electricity in their homes, grow almost all of their food, and only travel by horse and carriage [20].

We interviewed members of the OOMs from Waterloo County, Ontario, Canada. The OOMs do not have running water, travel by

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horse and carriage and have limited use of electricity. Johnson et al. [21] and Craumer [22] studied a similar group and found that Amish farmers in the American Midwest use much less energy relative to their agricultural output than non-Amish farmers. No studies on the domestic energy usage of OOMs or other such groups appear to exist, but the OOMs practice many resource-conscious behaviors that interest us. By studying their lifestyle, the problems they encountered and the solutions they developed, we hoped to find transferrable strategies for encouraging resource-conscious behaviors in mainstream populations.

2.2 Methods. We first consulted secondary sources to learn about OOM communities, whose unique nature necessitated significant preparatory work before we could interact with OOM families. We then performed unstructured interviews with three subject-matter experts to determine how best to access OOM families who would be willing to share information about their lifestyles. We finally arranged to visit two OOM families.

The visits involved half-hour semistructured interviews followed by a tour of their homes. A list of guiding questions was constructed beforehand. Semistructured interviews were chosen to ensure that all relevant topics were covered, while still providing flexibility to follow leads based on unexpected responses [23]. As household tasks are rigidly divided by gender in OOM homes, we interviewed both the male and female heads of household to obtain a clear picture of their practices.

We focused on learning about how they met major household needs, specifically, bathing, clothes-washing, dishwashing, heating and cooling, lighting, and food preservation. We noted the domestic appliances (electric and non-electric) that they used to meet their needs and asked about their level of satisfaction with these appliances. We were interested to see if they would have unique insights about common electrical appliances, such as stoves and refrigerators because of their otherwise different lifestyle. As the homes we visited had limited use of electricity, we also asked about their general attitudes toward electricity and energy conservation. Notes were recorded by hand throughout. We were unable to use methods involving photography (such as photo diaries) as OOMs have cultural taboos against photography.

2.3 Observations. We observed many interesting conservation practices in the two OOM homes visited, both of which resembled early 20th century farmhouses. Three generations of family members resided in the same house, with each family having up to eight children. The amount of space available for each member of the household was therefore much smaller than common in the mainstream. The kitchen was the focal point of the house and a wood-burning stove in the kitchen was the central source of heat. Large windows around the house made indoor artificial lighting largely unnecessary during the day. They had almost no electricity-powered devices and primarily used locally sourced renewable fuels, such as firewood. As our visits occurred in autumn, we observed that the indoor temperature in the homes visited was noticeably lower than that in typical mainstream homes. The people we interviewed also wore heavier clothing indoors during the cooler months than is common in mainstream society. Clothes were washed by hand and dried either outside or around the wood stove in the kitchen. A kettle of boiling water on the wood stove was used to humidify the homes in the winter.

Other aspects of the OOM lifestyle also led to reduced resource consumption. Almost all the food in the households interviewed was either grown on their own land or on a nearby farm, greatly reducing the energy required to transport produce. Over a year's worth of canned fruits, vegetables, meats, pickles, and jams were stored in the basement. One home had an uninsulated kitchen pantry separated from the kitchen by a sealed door. In winter, the pantry windows would be opened, allowing it to serve as a cold room for food storage. Potatoes and root vegetables were stored in barrels filled with natural desiccants, e.g., sand, to prevent spoiling from moisture.

The homes visited had few consumer products and reused and repaired items whenever possible, thereby reducing waste. One family had a kitchen table made of parts salvaged from other furniture. Another family used large cisterns to collect rainwater that was then used for washing and to water garden plants. The families were also well attuned to changes in daylight hours over the course of the year and adjusted their work schedules accordingly.

We analyzed our observations to determine environmental significance, what needs were being met and how they compared to mainstream alternatives. There were some needs (such as long-term food storage) OOMs had that do not feature as prominently in modern societies. In addition, many solutions used by OOMs involved both demand reduction, e.g., wearing heavier clothing indoors in winter to reduce need for heating, and a solution on the supply side, e.g., burning firewood in the stove to provide heat. The main observations are listed in Table 1.

2.4 Analysis. There was an unexpected commonality in many of the behaviors the OOMs exhibited. In several cases, the resources used were used in discrete units. For example, the interviewed OOMs could immediately tell us the amount of hot water they used for bathing in terms of buckets. Similarly, they described their heating needs in terms of the number of firewood logs they burned. If additional people were to stay in their home, they knew how many additional buckets of water they would need to obtain. The discrete units also seemed to help OOMs better manage their consumption. If they wished to conserve water, they could set a specific goal of reducing their usage by a particular number of buckets.

Individuals in mainstream society struggle much more in estimating the amount of water or energy they use and understanding its significance. Past work has repeatedly tried to find better ways of explaining usage to users. For example, the design of energy meters has moved toward displaying the amount of energy used as a financial cost, because kilowatt-hour readings are difficult for users to understand [13]. Unlike the discrete units of resources that the OOMs use, mainstream households obtain resources through always-on water and energy connections. Thus, we hypothesized that having resources available in discrete form contributed to OOMs ability to conserve. To test this hypothesis, we designed an experiment that asked participants to conserve water in a washing task.

3 Experimental Study

3.1 Method. We designed a repeated-measure experiment where 28 participants were given a washing task. They were provided table-tennis balls with a 15×15 mm dab of acrylic paint applied to them (Fig. 1). The participants were asked to remove the paint using only water and encouraged to use as little water as possible. The amount of water used was then measured. The table-tennis ball was considered clean once there was no more paint residue present on the surface. We first conducted a pilot study with four participants. Water was provided in three conditions (continuous, discrete, and work + discrete). In the first condition (continuous), participants obtained water from a tap. In the second condition (discrete), water was provided in the form of 4 containers, each filled with 100 ml of water. In the third condition (work + discrete), the same containers with 100 ml of water were made available to participants with an additional requirement. Participants were required to step on and off an aerobic step device for 10 s to earn each container, and were only able to earn one container at a time. We had observed with OOMs that the use of discrete resource units (such as buckets of water or bundles of firewood) was often associated with additional effort (i.e., raising buckets from the well, chopping, and carrying firewood). We therefore wanted to investigate whether

Table 1 Old Order Mennonite solutions, environmental significance, and modern solutions to needs

Need	OOM solution	Environmental significance	Modern solution
Space heating	Wood-fired stove in kitchen; people tend to spend time together in one room which increases ambient temperature; heavier clothing is worn during colder months	Unclear—the wood was locally sourced and a renewable resource but its combustion is less efficient than modern power generation	Central furnaces and thermostats
Domestic cooling	Strategic placement of trees outside home to shade parts of house; large windows arranged to enable cross-ventilation	Reduced material and energy use by eliminating air conditioning	Air conditioning
Hot water for bathing	Water collected from cisterns and heated in kettles to fill a bathtub, reused between family members	Reduced amount of fresh water used per person	Running hot water
Drying clothes	Hanging outdoors in summer and around central wood-fired stove in winter	Reduced material and energy usage	Natural gas/electric dryers
Washing clothes	Manual washing machines that use grey water collected in rain cisterns	Electricity and fresh water use eliminated	Washing machines using running water and electricity
Washing dishes	Manual washing using water from hand pump, hydraulic pump, or water carried in from outdoors	Unclear—no electricity is used but more water or detergent may be used as per prior work [24]	Running hot water, electricity-powered dishwashers
Obtaining drinking water	Water collected from well	Fewer processing steps for water	Municipally treated running water
Lighting	Kerosene/propane lamps	—	Electrically connected lighting fixtures
Cold storage of food	Kitchen pantry room with windows to allow cold air to enter during winter months; dark cool cellar below house	Reduced energy and material use, eliminated use of toxic refrigerants	Refrigerators; more rarely, cold rooms in basements
Preparation of fuel before usage	Curing room for stored firewood	—	None needed, fuel is either directly connected or comes prepared
Maintaining indoor humidity in winter	Large vessel filled with water on the wood stove at all times, generating steam for the home	Use of already existing wood stove heat	Electrical humidifiers
Long-term food storage	Cans and jars of preserved food stored in the cellar	Reduced energy required to transport food; encourages food rationing	None required, food can be purchased as needed
Maintenance of home furniture	Done by family members; frequent repair and refurbishment; items designed to last with reparability in mind	Reduced use of virgin materials and energy required for manufacturing new products	Furniture likely to be disposed and replaced when damaged

it was the discretization of these resources or the additional work required that encouraged conservation. In the pilot study, participants used only one container of water in the discrete condition, leading to a floor effect. For the main experiment, we therefore reduced the amount of water provided in the containers to 10 ml (Fig. 2). The order of the conditions was counterbalanced to control for order effects. We recorded observations by hand.

3.2 Results. The quantities of water used in the continuous condition $D(28) = 0.19$, $p < 0.05$, the discrete condition $D(28) = 0.25$, $p < 0.05$, and the work + discrete condition $D(28) = 0.29$, $p < 0.05$, were significantly non-normal. Histograms of the data suggested that significant floor effects still remained in each case. This was likely because in the discrete condition, many participants were able to complete the task using only one container, and in the continuous condition, there was a lower limit for how quickly participants could turn the tap on and

Fig. 1 Table-tennis ball with 15 × 15 mm mark of paint

Fig. 2 Discrete-condition container with 10 ml of water

off. Nevertheless, repeated measures analysis of variance is generally considered to be robust with respect to violations of the normality assumption [25], and was performed on the experimental data shown in Fig. 3.

We confirmed that the sample size ($n = 28$) was sufficient for a high observed statistical power $(1 - \beta) > 0.99$. As sphericity had been violated, $\chi^2(2) = 0.02$, $p < 0.05$, we corrected the degrees of freedom using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.51$). The results show a large significant effect of the condition $F(1.01, 27.30) = 22.39$, $p < 0.01$, $\eta_p{}^2 = 0.45$. This confirmed that the way water was made available had a substantial effect on participants' ability to conserve it. Posthoc comparisons using a Šidák correction confirmed that the mean value for the continuous condition ($M = 198.7$ ml, SD = 211.5) was significantly different from the discrete condition ($M = 22.3$ ml, SD = 27.0) with $p < 0.01$ and the work + discrete condition ($M = 16.0$ ml, SD = 16.0) with $p < 0.01$. While the discrete condition was not found to be significantly different from the work + discrete condition ($p = 0.19$), the data supported our hypothesis that discretization enabled conservation.

3.3 Qualitative Observations. We observed some interesting behaviors in our study. Participants who were given one of the discrete conditions first seemed more creative in their washing techniques when they performed the task in the continuous condition. For example, such participants turned the tap on and off quickly, just long enough to wet their hands, and then manually scrubbed the paint off the ball. In contrast, participants who were given the continuous condition first washed the ball under a running tap and changed techniques for the discrete conditions.

The quality of the washing remained the same across the three conditions. The amount of time spent washing also did not differ noticeably in the three conditions. Likely, due to the small size of the paint dab, its removal did not take very much time, regardless of the source of water.

4 Discretization and the Determinants of Behavior Change

We reviewed and found several areas of prior research that may explain how discretization works and is correlated with effecting resource-conscious behavior change.

4.1 Feedback. Feedback has been found to be an important component of successful behavior change in past interventions [8,26–28]. When users are provided with appropriate information about their actions, they are better able to modify their behavior. When users consume resources in discrete units, they benefit from instant feedback about their rate of use. For example, the OOMs were able to track their use of heating fuel by counting the number of firewood logs they put into a wood stove in a day. In mainstream settings, users may need to install additional meters to get the same type of feedback about their usage rates. Moreover, the type of information devices like energy meters provide can be too general and abstract to be effective [29]. Unless each device is metered, users may have difficulty ascertaining which of their activities requires a change in usage to reduce their consumption rate. Discrete resources, on the other hand, are closely tied to particular activities or appliances and make it easier for the user to take action. In the OOM setting, for example, the usage rate of kerosene is clearly tied to hurricane lamps, buckets of water to bathing, and so forth. If the rate of consumption of one resource increases more than desired, the OOMs immediately know which of their activities to adjust to correct the problem.

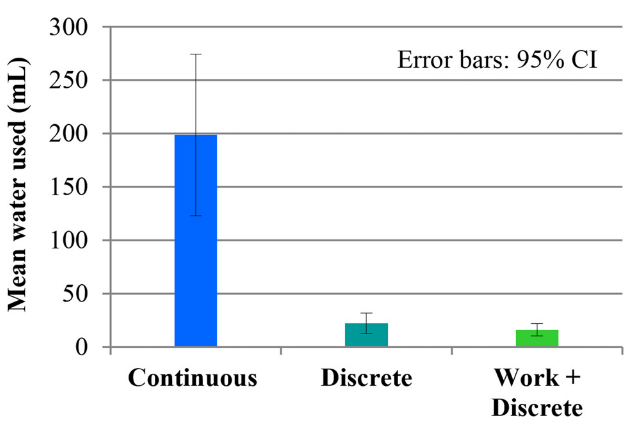


Fig. 3 Mean water used in three conditions ($n = 28$)

Another aspect of the experiment, the distorting effect of volume, can also be related to past work. Our pilot-study participants were provided with larger quantities of water in containers, and they used more water in the discrete condition than participants in our experiment. This relates to the portion-size effect observed in other studies. Wansink et al. [30] presented participants with soup in two types of bowls, a regular bowl and, unbeknownst to the participants, a bowl that would refill slowly by itself. The participants presented with self-refilling bowls did not see the soup in their bowl diminishing significantly, continued eating and consumed more soup than those with regular bowls. In our study, the containers were fuller when they had more water in them, and water may appear more plentiful when presented in larger volumes, possibly prompting participants to use more water in their task. This effect could also explain why, in some cases, discretization does not lead to conservation. For example, fuel tanks in cars are discrete but North Americans continue to drive more every year [3]. This lack of conservation may be due to the relatively large fuel tank and low price of fuel. The larger the discrete volume of resource, the more it approximates a continuous supply and the less it may benefit from discretization effects.

4.2 Scripting and Behavior Steering. Scripting has also been identified as a strategy for behavior change. In scripting, the product is embedded with design cues that persuade the user to behave in a particular way [13,27,28,31]. One approach to scripting is to make an undesirable behavior more difficult [13,28,31]. Discrete resources employ scripting by providing a deterrent to starting new units. For example, if a washing task required slightly more water than could be carried in two buckets, the OOMs were motivated to find a way to make do with two buckets to avoid having to obtain another bucket. Similarly, in our experiment, participants appeared to not want to open another container if they were close to completing the task. The work involved in opening another container was minimal, yet they still appeared deterred.

This aspect of discretization also fits with behavior-change frameworks developed by Fogg [32] and Lockton et al. [33,34]. Using Fogg's terminology, discretization works by adding *demotivators* to wasteful behaviors and increasing the user's *ability* to control the behavior. Using Lockton's *design with intent* framework, discretization creates deterrents as *roadblocks* to wasteful behaviors.

4.3 Paying Before Use. Prepayment is another successful behavior-change strategy used in past interventions. Völink and Meertens [35] found that installing prepayment gas meters reduced gas consumption by 4% in the groups they studied. Working with discrete resource units often requires individuals to pay for resources before use. For OOMs, heating fuels, such as propane and kerosene must be purchased beforehand, firewood must be chopped and collected during previous months, and potable water must be extracted from wells before it can be used. This requirement motivates the conservation of resources as individuals seek to minimize their costs in money, effort, or otherwise. In contrast, the continuous flows that provide mainstream society with energy and water do not feature this inhibitory mechanism.

Consumers typically pay for water, electricity, and other resources, often much later after use.

5 Application to Product Design

Having better understood the mechanisms behind discretization, we then looked for applications of the principle. Lilley et al. [27] have described how products can function as catalysts to effect pro-environmental behavior change in users. We therefore sought to design products that would enable resource-conscious behaviors via discretization. Below, we first review existing methods for applying behavioral insights in the product design process.

5.1 Applying Behavioral Insights Like Discretization. Design tools that help designers apply behavioral insights [8,26] tend to fall along a spectrum defined by Lockton et al. [36,37] that ranges from *inspirational* to *prescriptive*. At the *inspirational* end are tools, such as catalogues [38] that list successful resource-conscious behavior-change interventions. The product designer is expected to be inspired by the examples and apply some aspect of them to the design problem. At the *prescriptive* end are systematic [39] methods that guide designers more explicitly. There are benefits to both types of methods: inspirational methods take advantage of designers' past experience while prescriptive methods reduce the designers' learning curve. Traditional ecodesign tools on the other hand have been found to be largely Life-Cycle Analysis (LCA), checklist or Quality-Function Deployment (QFD)-based and therefore systematic and prescriptive [40]. Using a combination of approaches, we first built a catalogue and list of implementation strategies to support inspiration, and then applied discretization prescriptively using a source/output framework.

5.2 The Inspirational Approach—Extant Examples of Discretization. First, we aimed to create a catalogue of existing products that successfully applied discretization to enable conservation behaviors. Although none of these products explicitly mentioned discretization, it was apparent from their operation that they enabled conservation behavior by either discretizing continuous flows of resources, or providing smaller portions of already discrete volumes. Products were found from online shopping databases, resource-conscious internet forums and visits to local retailers. We categorized the products reviewed by *themes* or the particular ways in which they employed discretization. Table 2 lists the common themes extracted from existing products and characteristic examples for each theme.

5.3 Generating New Product Concepts. Using our inspirational design repository, we generated new concepts for discretization-employing behavior-changing products. We focused on products that helped users conserve energy and water, as the consumption of both is extremely high in North America [41,42]. We also aimed to develop concepts that could be easily retrofitted with existing products that are already being used.

We prescriptively used the schematic in Fig. 4 as a guide for applying discretization. Energy-consuming and water-consuming

Table 2 Themes of how discretization is implemented in existing products

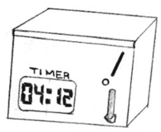
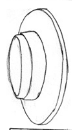
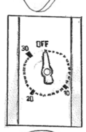
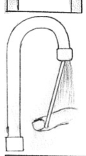
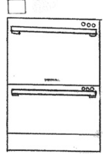
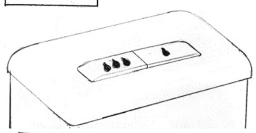
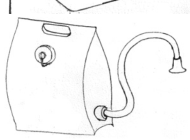
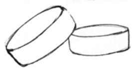
Theme	Example	Description
Tokens		A token-operated shower control provides a preset amount of water/showering time. The showering time and water usage are discretized, and the implicit cost of using the shower is increased
Timed buttons		Push-button shower valve allows water to flow when pushed in. The valve retracts over time, shutting off the water at full retraction. The showering time and water usage are discretized
Interval countdown		Spring-loaded light-switch timer, where the dial is turned to set a time and coil the spring, uncoils and shuts off the lights. The audible clicks emitted by the timer may remind users of time passing. Lighting time and electricity use are discretized
Only on when needed		A rod-and-valve attachment for taps, in the neutral position, prevents water from flowing, when pushed, allows water to flow. The continuous flow of water is discretized into periods when the rod is pushed
Compartmentalization		A dishwasher has multiple drawers that can run independently. Users can run a single drawer when they do not have enough dishes to fill the entire unit and thus reduce water and energy use. The volume of the dishwasher is further discretized into smaller volumes
Metered dosing		A dual-flush toilet mechanism allows users to conserve water by using the low-flush setting when appropriate. The volume of water used for flushing is further discretized into smaller amounts
Packetization		A camp shower enables users to fill the bag with water, hang it from a high point and use the attached hose as a showerhead for bathing. The limited capacity of the bag discretizes the water available and functions as a way of tracking water usage
Phase change		Solid laundry-detergent tablets discretize loose powder and difficult-to-measure liquid detergent into appropriate doses to help reduce the wasting of detergent [27]

Fig. 4 Relationship between user, product, and mains

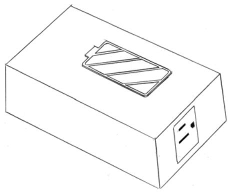


Fig. 5 Rechargeable battery pack

products receive their resources from a source (e.g., the mains) and provide a benefit to the user at their output (e.g., heat, light, water, television programs). We generated concepts that discretized either the resource between the mains and the product (discretization at source) or as it exited the product (discretization at output). Three concepts are discussed below.

5.3.1 Discretization at the Source—Energy. As batteries already exist to store energy in discrete amounts, we extended the concept of a rechargeable plug-in battery pack for use in existing, plugged electronics and appliances. Instead of plugging into an outlet, users would plug their devices into the battery pack shown in Fig. 5, which features a meter to display the amount of charge remaining. When one pack is depleted, a new one can be swapped in. Users can track their energy consumption by monitoring the change in the charge meter over time. For high energy-consuming devices, users can track consumption by counting the number of battery packs they have had to use in a day. If they wish to conserve energy, they can then set their own goals, e.g., using not more than two packs a day for lighting needs. When the charge meter is close to zero, users would also be motivated to modify their usage of the device or appliance or put it into a power-saving mode in order to extend usage time.

5.3.2 Discretization at the Output—Water. Following are two concepts that apply discretization at the output to enable water conservation. The bathtub-divider concept, shown in Fig. 6, is a flat panel with flexible edges that can be slid into any standard bathtub to create a watertight space. Instead of using a shower to bathe, the user fills the created space with warm water and bathes using a water jug on the other side.

The next concept, shown in Fig. 7, facilitates water conservation by modifying a traditional showerhead. Incorporating the instant-off tap attachment described in the inspiration repository, water does not flow out of the shower when the rod is in the neutral position. This reduces the running of water when the user is applying soap or shampoo. The concept provides the benefit of maintaining the water temperature for the user. With most shower fixtures, the user must obtain the desired temperature each time the water is turned off and on.

5.4 Concept Evaluation. After generating the three concepts above, we tested their desirability with users. Short interviews with a handful of users and consulting an industrial designer confirmed significant concerns about the concepts.

Three types of problems emerged: the concepts often (1) made the task more difficult, (2) added additional steps without removing existing ones, and (3) ignored or violated other user needs. As an example of making the task more difficult, the showerhead attachment made it more challenging for the user to rinse off in the shower, as one hand would always be occupied in operating the rod. Even worse, some of the concepts violated other user needs. While using a bathtub divider would, indeed, reduce water consumption, it would not provide users with the warmth of a

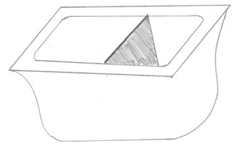


Fig. 6 Bathtub divider

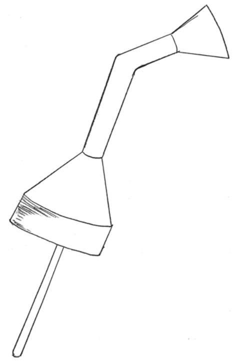


Fig. 7 Shower rod

shower that they desired. Users also expected bathing with a jug to be very uncomfortable. The battery-pack concept was inconvenient and also problematic from a life-cycle perspective. The packs are likely to degrade over time and require replacement. The environmental impact of the manufacturing, use, and disposal of large numbers of battery packs would be significant. Users saw these concepts as annoyances that would encourage them to revert to past wasteful habits and even discourage them from buying resource-conscious products all together. Interestingly, many of the existing product examples we collected in our repository also exhibited such drawbacks. The push-button operated showers, for example would result in a shower experience marked by frequent stops and starts, frustrating users.

We therefore revised the concepts to balance meeting user needs with reducing environmental harm. To begin, we analyzed the activities users were performing while consuming energy and water, and looked for opportunities to apply discretization to individual parts of the process. We also removed our previous constraint of developing concepts that could easily be retrofitted with existing products.

5.5 Revised Concepts

5.5.1 Countdown-Snooze Power Button. Battery-powered electronic devices, e.g., laptops and cell phones, which discretize energy, inspired our original concept that required users to plug electric devices into battery packs. Such devices also help users adjust their behavior when required by displaying the level of battery power remaining. We concluded that it is impractical to change many plug-in devices to run on discretized energy with actual or simulated batteries. Instead, we decided to transfer other energy-conserving features of laptops and cell phones, such as reverting to standby modes or turning off after a set time. We noted that many devices, such as lights and televisions often remain on even when they are not actively being used. Users are typically unaware of the amount of energy these devices consume and often forget/neglect to turn them off. While many televisions have timer functions, they are often neither prominent nor used frequently. Related to timers, in addition to displaying time, alarm clocks also enable users to discretize and more actively track the passage of time through the use of a snooze button.

We therefore developed a concept, shown in Fig. 8, that replaces the power button on a television with a timer/snooze button that powers the device for discrete time periods. When the device is turned on, a timer begins to count down and shuts off the device when the timer reaches zero. The times for each device can be set by the user based on his or her use patterns and energy saving goals. Pressing the snooze button during the countdown extends the device's usage time by a fixed amount, e.g., half an hour. Thus, active use is required for the device to stay on, since the default in the absence of activity is to turn off.

5.5.2 Shower Planner. The feedback for the bathtub-divider concept emphasized that users enjoyed the warmth provided by showers. Using a jug to bathe also required more work than showering. 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, shown in Fig. 9. The concept features a timed shower valve with marked detents, a temperature-control slider and a flow-rate control. The timed valve springs back to closed position once the set time has elapsed. Users can therefore track their shower time in discrete units (number of detents) and set lower time limits if they wish to conserve water. The temperature-control slider allows the user to set the temperature before turning on the water, and use a lower temperature setting if they wished to conserve energy. Finally, the flow control allows users to reduce the flow rate instead of completely shutting off the water, when applying soap, etc. This concept maintains the present benefits of a shower without adding unnecessary steps and would be preferable to current push-in timer valves, as it allows more control over settings. In addition to enabling resource conservation, this concept may also help users stay on schedule by encouraging and keeping track of a short showering time.

5.5.3 Metered-Tap Attachment. The metered-tap attachment concept consists of a self-refilling container that connects to a standard tap. The container is transparent, holds several cups of water, and has markings to indicate the volume of water held (Fig. 10). The container can be opened and closed with one hand and automatically refills after being emptied. To encourage conservation, the clear container provides visual feedback to the user about the amount of water used; the markings help the user only take out as much water as needed, e.g., for a recipe; the number of times the container fills breaks down the flow of water into discrete units. The container can also be bypassed to use the tap directly if larger amounts of water are required, e.g., to fill a bucket.

5.6 Building a Prototype and Preliminary Testing

5.6.1 Prototype. From the revised concepts described above, we proceeded to build a prototype of the metered-tap attachment. The prototype, shown in Fig. 11, consists of a transparent container connected to a tap with a rubber hose. The hose can be quickly attached or removed from the tap. The markings on the container indicate the number of cups of water inside. Cups were used as the unit of measurement as they seemed more relevant for kitchen tasks. The automatic refilling mechanism for the prototype was not complete, so refilling of the container was done manually.

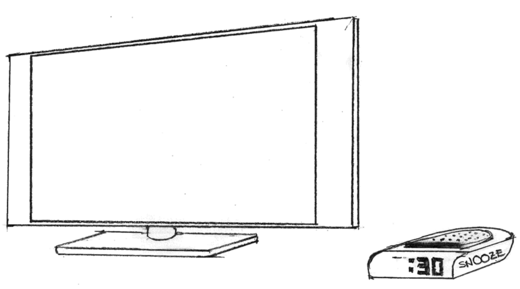


Fig. 8 Countdown-snooze power-button concept

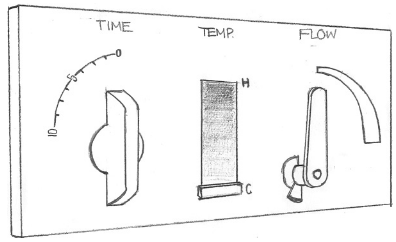


Fig. 9 Shower planner

The spout of the container can be pulled to open and pushed to close using one hand.

5.6.2 Preliminary Prototype Testing. 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 user feedback.

Table 3 shows that each participant used less water with the prototype than when using the tap alone. Participants' impressions of the prototype were generally positive as they appreciated the elimination of measurement uncertainty. The device seemed to be useful in helping them moderate and track their water usage. One participant remarked that such a product would be useful for recipes that require precise quantities of water. Each participant was able to operate the opening and closing mechanism with one hand. In terms of improvements, participants suggested that the durability of the prototype be increased. Storing standing water for long periods in the container was a concern for one participant, who was unsure if the water would remain safe for drinking. Although the same water may have remained standing in the plumbing system, the visibility of the stored water seemed to trigger concerns.

5.7 Discretization and the Rebound Effect. Concepts that apply discretization should not be as susceptible to the rebound effect as products that are simply more resource efficient. In the rebound effect, when a product becomes more efficient, its cost of usage declines in the user's mind, which can motivate him/her to increase its usage over time. Discretization has the opposite effect, in that the mental cost of using the product increases compared with before discretization, and remains constant unless discretization is bypassed. As it is aimed at modifying user behavior and not simply changing the resource efficiency of a product, discretization should not be prone to the rebound effect.

6 Conclusions and Future Work

Our work first demonstrates the effectiveness of applying lead-user methods to the problem of designing products to enable resource-conscious behaviors. We have shown how communities living a less modern lifestyle, such as the OOMs, can be a useful source of novel insights. Our ethnographic study of the OOMs revealed the principle of discretization. We then tested the effect of using discrete resources empirically. As the results were promising, we built a repository of products that employed

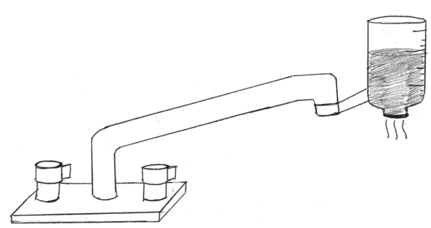


Fig. 10 Metered-tap attachment

Fig. 11 Metered-tap-attachment prototype

Table 3 Amount of water used for task in each condition

Participant	Tap	Tap + prototype
1	4 cups	2 cups
2	2 cups	1 cup
3	1.5 cups	1 cup

discretization and then prescriptively applied the principle to generate product concepts. We discussed the concepts with potential users who highlighted many concerns, leading us to revise the concepts. The revised concepts aimed to respect user needs in addition to encouraging resource conservation. We then built and performed preliminary testing on a water-conserving prototype.

There were limitations in this work that we identify below. First, as is the case with many resource-conscious behavior-change studies, the generalizability of the discretization principle requires more validation. The experiment to test the discretization principle took place in a laboratory and involved an artificial washing task. It would be useful to examine the effect of discretization in a domestic setting and to test whether the effect persists over time. Second, the experimental design did not allow us to fully investigate the effect of adding effort to the task. Further testing should include a fourth condition that adds work to the continuous flow case to determine the main effects and interactions of the work condition.

Our work supports the notion that discretization enables conservation behaviors. With future work, we aim to confirm the effects of discretization in more robust environments and find more ways to apply it to product design. The product concepts and prototype generated for discretization were tested with a small number of people due to time constraints. Future concepts and prototypes would benefit from more thorough testing with a larger number and range of users. We also require more feedback from designers to see whether they find the methods developed in this work useful and easy to apply. We plan to share our findings with professional designers and work with them to develop more product concepts. We will also consult designers on how to make resource-conscious design principles easier to incorporate into their usual work processes.

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