Affordances and Product Design to Support Environmentally Conscious Behavior

Jayesh Srivastava
e-mail: j.srivastava@mail.utoronto.ca

L. H. Shu[1]
e-mail: shu@mie.utoronto.ca

Department of Mechanical and Industrial Engineering,
University of Toronto,
5 King's College Road,
Toronto, ON M5S 3G8, Canada

We developed an affordance-based methodology to support environmentally conscious behavior (ECB) that conserves resources such as materials, energy, etc. While studying concepts that aim to support ECB, we noted that characteristics of products that enable ECB tend to be more accurately described as affordances than functions. Therefore, we became interested in affordances, and specifically how affordances can be used to design products that support ECB. Affordances have been described as possible ways of interacting with products, or context-dependent relations between artifacts and users. Other researchers have explored affordances in lieu of functions as a basis for design, and developed detailed deductive methods of discovering affordances in products. We abstracted desired affordances from patterns and principles we observed to support ECB, and generated concepts based on those affordances. As a possible shortcut to identifying and implementing relevant affordances, we introduced the affordance-transfer method. This method involves altering a product's affordances to add desired features from related products. Promising sources of affordances include lead-user and other products that support resource conservation. We performed initial validation of the affordance-transfer method and observed that it can improve the usefulness of the concepts that novice designers generate to support ECB. [DOI: 10.1115/1.4025288]

Keywords: affordance-based design, affordance transfer, environmentally conscious behavior

1 Environmentally Conscious Behavior (ECB)

1.1 Introduction. A great deal of engineering effort has been expended in designing more efficient products. However, the availability of more technically efficient products can actually cause users to be more complacent about the use of those products, such that the overall consumption continues to rise after an initial decline. This is referred to as the rebound effect. Sorrell et al. [1] suggest that as efficiency increases, the perceived worth of a resource declines, making people more inclined to use more of it. As one example, one could argue a number of ways in which flat-panel televisions are more efficient than their cathode ray tube (CRT) predecessors. However, flat-panel televisions now come in screen sizes that CRTs never approached, and are appearing in ever more locations where CRT televisions were uncommon or not used at all. Flat-panel televisions may thus use more energy overall than CRTs did. As another example, with energy-saving modes implemented on many electronics, fewer people fully power down such electronics, even when significant idle periods are anticipated. Similarly, while light-emitting diodes and compact fluorescent lights are more efficient than their incandescent predecessors, there is at least anecdotal evidence that people are less conscientious about turning such lights off when they are not required. Such behavior offsets at least part of the anticipated gains in resource efficiency intended by energy-saving modes and technologies. Therefore, in addition to creating more efficient products, designers should also make products that encourage and enable users to behave in more resource-efficient ways, i.e., by using resource-consuming products less and for shorter durations.

[1]Corresponding author.

Contributed by the Design Theory and Methodology Committee of ASME for publication in the Journal of Mechanical Design. Manuscript received July 31, 2012; final manuscript received August 2, 2013; published online September 5, 2013. Assoc. Editor: Janet K. Allen.

In his environmentally significant behavior framework, Stern [2] categorized people's behavior that has an effect on the material and energy flows of the environment. These behaviors may be active (joining an environmentalist group) or passive (accepting a retailer's bag-free policy), intentional (using public transportation) or unintentional (purchasing an environmentally better product for other reasons) and public (participating in a demonstration) or private (sorting and recycling household waste). We use the term ECB to be roughly synonymous with Stern's Environmentally Significant and others', e.g., Abrahamse et al.'s [3] Pro-Environmental Behavior.

1.2 Approaches to Reduce Wasteful Behavior. The concept of encouraging or enabling humans to behave in less wasteful manners is not new. However, there are limitations to existing behavior-change approaches.

1.2.1 Socio-Psychological Interventions. Abrahamse et al. [3] thoroughly review socio-psychological interventions aimed to encourage pro-environmental behavior. Steg and Vlek [4] identify two categorizations for such interventions, antecedent versus consequence, and informational versus structural. Antecedent strategies target factors that precede behavior, by increasing problem awareness, giving information about options and positive or negative consequences. Consequence strategies aim to change consequences after behavior and include feedback, rewards, and penalties. While informational strategies that aim to change "prevalent motivations, perceptions, cognitions, and norms," are assumed to change attitudes that affect behavior, information campaigns generally do not result in behavior change. On the other hand, specific prompts, commitment strategies, eliciting implementation intentions, and providing individualized information appear to be more effective. However, Steg and Vlek [4] conclude that informational strategies are effective when the desired behavior does not significantly inconvenience, cost, or constrain individuals.

 Copyright © 2013 by ASME

Downloaded From: http://mechanicaldesign.asmedigitalcollection.asme.org/ on 09/23/2013 Terms of Use: http://asme.org/terms

Structural strategies are more suitable when the desired behaviors are costly or difficult, as they aim to change the circumstances, e.g., costs and benefits, under which behavioral choices are made. Relevant mechanisms to reward good and punish bad behavior include physical, technical, organizational, and legal changes that affect the availability and quality of products and services. For example, changes could take the form of reducing the cost of organic food, closing off areas to motorized vehicles, providing recycling bins and environmentally conscious technology, and banning harmful chemicals. While rewards are observed as more effective than penalties in encouraging pro-environmental behavior, they tend to have short-lasting effects, i.e., only as long as the reward is available. Steg and Vlek [4] conclude that combinations of strategies are most successful in addressing the various barriers to pro-environmental behavior.

1.2.2 Technological Interventions. Duflou et al. [5] propose self-adjusting products using active monitoring, analysis, and control optimization to reduce resource consumption. Under development are methods and algorithms that aim to use automatic, user-demand profiling to achieve resource efficiency without requiring user interaction such as switching off while not in use. While this approach has high potential for effectiveness, we aim for an approach somewhere in between persuading users to behave in desirable manners, and having machines do it for them automatically.

1.3 Motivation. The goal of our work is to discover how products can be designed to encourage and facilitate ECB [6–8]. We studied and developed concepts that aim to support ECB and noted that characteristics of products that enable ECB tend to be more accurately described as affordances than functions. Therefore, we became interested in affordances, and specifically, how affordances can be used to design products that support ECB.

2 Affordances

In simplest terms, an affordance is a possible way of interacting with a product. For example, regardless of designer intent, an object with a low, flat surface affords sitting, as well as the resting of objects. Before we describe a method that aims to apply affordances to influence user behavior, specifically ECB, we first summarize major developments in the field.

2.1 Understanding Affordances. The concept of affordances was formulated by James J. Gibson, a perceptual psychologist, as a way to describe complementary relationships that potentially exist between an animal and its environment [9]. For example, a rock face may afford shelter for one animal or a surface for climbing to another. The nature of these relationships is dependent on features of both the animal and the environment [10].

Norman [11] then explored these relationships as they exist between people and objects. Norman defined affordances as the set of *action opportunities* provided by an object. A knob provides the opportunity for turning. A car provides the opportunity for driving. Norman also developed the notion of *perceived affordances*, and contrasted them with *real affordances*. Perceived affordances are "actions the user perceives to be possible" with a product [12]. Conversely, real affordances are those actions that are actually possible with the product. When discrepancies arise between real and perceived affordances, the user's experience can be compromised. A user may expect to be able to perform an action that is not actually possible, or a user may not recognize that a particular action is possible with a product. Different users can also perceive different affordances in the same object. For example, an analogue clock may afford the telling of time for adults, but not for very young children.

Researchers in the neurosciences have since postulated the physiological mechanisms responsible for the perception of affordances. Tucker and Ellis [13] describe experiments where participants' neural patterns were tracked as they were presented with various stimuli. Their studies suggest that merely observing an object leads to the activation of motor and motor-related areas of the brain, and that observing a manipulable object primes participants to be able to perform actions specifically related to the object more quickly. Buccino et al. [14] suggest that showing participants pictures of common objects with their handles or other affordance-related features removed interrupts the activation of particular motor areas of the brain.

2.2 Categorizing Affordances. Past work has also explored ways of describing affordances. Borghi and Riggio [15] categorize affordances as being either temporary (e.g., a retracting knob that becomes unavailable for turning when pushed in) or stable (e.g., gripping surfaces on a knob that are always accessible). Bub et al. [16] categorize affordances as being either functional (i.e., relating to the intended purpose of the object) or volumetric (i.e., property of the size and shape of the object such as grip-ability). Pols [17] categorizes affordances into four groups corresponding to different levels of complexity. The simplest types are *manipulation opportunities* (e.g., a button affords pressing). Next are *effect opportunities* that describe the possible effects of using the product (e.g., a hammer affords breaking a glass pane). Higher still are *use opportunities* that represent the tasks users can imagine completing by using the product (e.g., a drill affords the insertion of screws into a piece of furniture). Highest are *activity opportunities*. These are higher-level outcomes from the use of a product (e.g., a showerhead affords cleanliness).

2.3 Affordance Polarity and Affordance-Based Errors. Jacquet et al. [18] have shown that object affordances influence users' expectations of how an object can or should be used. Therefore, the affordances of a product have a significant impact on the user experience. Affordances have thus been assigned a polarity in earlier work [11,19–21]. Affordances that help the user are *positive* while those that harm the user are *negative*. The notion of polarity is helpful for designers as shorthand for categorizing affordances as either desirable or undesirable. We use a similar definition for affordance polarity with users rather than designers as the final arbiters. Affordances that meet users' needs and enhance their use experience are denoted as positive, whereas affordances that interfere with users' needs and degrade the use experience are termed negative.

Norman [11] catalogued common frustrations that people face when interacting with everyday products. The difficulty in programming a video cassette recorder (VCR), understanding how a shower control works in a foreign country, or even knowing whether to push or pull a door open, can all be described as problems caused by a lack of affordances and/or the presence of misleading affordances. We call such cases affordance-based errors. These errors represent discontinuity between the designers' intentions and the users' perceptions.

2.4 Using Affordances in the Design Process. The benefits of systematizing the design process are well known [22,23]. Maier and Fadel [19–21] have developed a systematic design method based on affordances. Similar to function-based methods, user needs are first collected through surveys, focus groups, etc. The needs are then converted into affordances. Next, ideation techniques are used to generate concepts that provide the necessary affordances. The affordances of the concepts are then analyzed and their design modified as necessary. The concepts are compared against the user needs and a final concept developed. This method is structurally similar to well-known function-based design methods.

The benefit of using affordances is also apparent in, and in our view better suited for, product redesign [24]. A great deal of

Downloaded From: http://mechanicaldesign.asmedigitalcollection.asme.org/ on 09/23/2013 Terms of Use: http://asme.org/terms

product design work has to do with improving or developing the next generation of existing products. Identifying the affordances of existing designs can help improve products. Designers can better understand how users perceive their design, specifically all the potential actions users can envisage performing with their design by listing all its affordances. The design can then be changed to enhance or reduce the salience of particular action opportunities.

2.5 Identifying Affordances. Finding the affordances of a concept or an existing product design can be difficult. Maier and Fadel's method [19] takes advantage of the designer's experience and product knowledge to analyze and identify a concept's affordances. Nevertheless, the difficulty designers encounter when trying to view a design from the user's perspective [25] can lead to missed relevant affordances. To address this concern, other methods rely on the users themselves to provide designers with the affordances in a concept. Galvao and Sato [26] used several interview-style methods to generate a list of affordances for a blender and its component parts. Participants were first asked to speak aloud while using the blender to make a mixed beverage. They were also asked questions about each component of the blender in order to understand the possible tasks for which they could imagine using it. This observation of user interaction with the product while performing a task combined with a thorough review of the architecture of the product produced a large set of affordances. Hsiao et al. [27] built on Galvao and Sato's [26] work by creating an online survey system for determining affordances for products and their components. In each survey, participants were shown one component and asked to select the affordances they felt best matched it. The data were then analyzed and prioritized statistically to produce a master list of affordances associated with the product. While more exhaustive than relying on designers' knowledge alone, these user-based methods are more time- and effort-intensive, especially if they must be repeated for multiple concepts for a single design.

The purpose of the affordance-finding methods thus far has been to determine the affordances users desire in products, i.e., positive affordances. The designers/researchers were interested in finding all the positive affordances already present in the design as well as any positive affordances that should be added. As mentioned, there are also many cases where the affordances present in a design are undesirable, or negative. Methods that rely on asking users about their needs may not provide a way to find the negative affordances in a design. Furthermore, existing methods do not provide much guidance with respect to which affordances should be provided, or potential sources of affordances, to support novel patterns of use.

3 Transferring Desirable Affordances to Support ECB

Designers can modify a product's affordances to improve users' experiences by better meeting their needs. In addition, designers can also take a more prescriptive approach with affordances, i.e., they can use the affordances of a product to encourage users to behave in particular ways. Next, we present a possible method whereby designers can modify affordances with the aim of helping users behave in more environmentally conscious ways.

3.1 Patterns and Principles to Support ECB. Past work has highlighted how generalized environmentally conscious design principles can be extracted by studying existing products. Telenko and Seepersad [28] developed a method of studying products, deriving relevant environmentally conscious principles, and finally employing the principles to generate improved product concepts. Our work has similarities with this approach, in that we develop concepts and study existing products to develop concepts with reduced environmental impact. However, we focus on finding behavior-changing affordances in existing products and transferring them to other products that would benefit from them.

We uncovered potential design patterns and principles while observing lead users in resource conservation. Inspired by Hannukainen and Hölttä-Otto's [29] and Lin and Seepersad's [30] expanded definition of lead users originally described by von Hippel [31], we observed people who conserved resources more than the general population and derived design principles. Three design patterns/principles that may work in encouraging and facilitating ECBs are: *discretization, transformation, and localization*. Below, we describe these patterns and principles in more detail and identify the affordances associated with them.

3.1.1 Discretization. After studying how old order mennonite communities conserve resources, we noticed that their resources existed in discrete units (e.g., logs of wood), whereas energy and resources supplied in the modern world tend to be in continuous forms (e.g., electricity). We confirmed that when users were presented with resources in discrete units (e.g., water in cups instead of continuously from a tap), they conserved that resource more effectively [6,8]. Discretization leads to at least two affordances we believe support resource conservation. First, it is easier to track the rate of use of discrete units of resources. Second, discrete units "run out," and the ability to impart both the finite nature and the amount of resource remaining may encourage conserving behaviors.

3.1.2 Transformation. More mainstream (non-Mennonite) lead users in ECB were also interviewed and observed [32]. Of note is that they either already use or could benefit from products that embody the transformation principles identified by Singh et al. [33] (expand/collapse, reveal/conceal, and fuse/divide). The more obvious affordance enabled by transformation is portability. For example, collapsible versions of reusable cups and bottles may reduce reliance on disposable versions by requiring less space to carry. The less obvious consequence of portability is spontaneity in carrying out ECB. Specifically, the more portable an object that supports ECB, the more likely it will be available to support spontaneous use. For example, compact reusable bags that pack into their own pouches are more likely to be available for spontaneous use than the bulkier, possibly wheeled versions of reusable shopping bags.

3.1.3 Localization. Finally, the principle of localization has been shown to be effective in helping users engage in ECB. When Momoh [34] studied how lead users in ECB maintained thermal comfort in an office without air conditioning in the summer months, he discovered that they employed various techniques for local cooling, e.g., using small desktop fans, changing body position to promote greater heat transfer. Momoh [34] proposed and investigated the use of localized cooling gel-packs to reduce overall energy consumption in maintaining thermal comfort. Conversely, one can wear thick clothing layers in a cold office environment, but cannot perform typing and other office work while wearing thick gloves. A commercially available keyboard heater[2] enables one to perform office work in a cold environment. Affordances associated with localization include the ability to focus resources to where they are most needed, and the ability to control individual consumption of resources.

3.2 Concepts that Incorporate Affordances of ECB Enabling Principles. We next describe concepts that incorporate these ECB-enabling patterns and principles.

3.2.1 Discretization Example: Domestic Water Conservation. One of the largest contributors to domestic water use in North America is bathing, and more specifically showering. Reducing the amount of water used while showering would have a significant effect on overall water usage. In addition, many users are unaware of the amount of water they consume while showering. We spoke to the director of facility services of a student dormitory

[2]thanko.com

Downloaded From: http://mechanicaldesign.asmedigitalcollection.asme.org/ on 09/23/2013 Terms of Use: http://asme.org/terms

at the University of Toronto, who is very passionate about, and arguably a lead user in resource conservation [35]. He attempted to convey the volume of water consumed during showers to student residents but found that even when presented with the information, the university students did not have an appreciation for the significance of the quantity.

Existing affordances in products related to showering provide the user with the ability to monitor neither the quantity of water used, nor the flow rate. Most shower controls in North America only allow control of temperature. It is therefore understandable that users can have difficulty moderating their water usage during showering.

In this case, the ECB and related affordances we wanted to incorporate enabled users to track and thus limit their water usage. We found a relevant example in the context of camping. Many camping activities are less resource-intensive versions of daily home activities. We therefore considered some camping products as "lead-user" versions of everyday products. Camping showers in particular allow the conservation and tracking of water usage. They consist of a sealed bag, connected to a tube with a valve. The bag can be hung from a high location and the user opens a valve to allow water out. The amount of water used while operating a camping shower is much lower than that of a typical domestic shower.

Two main affordances of camping showers appear to be instrumental in encouraging users to minimize water usage: *limiting the amount of water available* and *indicating the amount of water remaining*. Figure 1 shows a concept developed by the authors that makes use of these affordances. The concept features a transparent container of fixed capacity connected to a showerhead. Water enters the container from the mains and the user can fill the container to a desired level before showering. The water then flows from the container through the showerhead that allows adjustment of flow rate and orientation. The markings on the container allow the user to track the rate of water usage as well as the amount remaining. Heating only the given quantity of water would further encourage shower completion when the container empties.

3.2.2 Transformation Example: Increasing Use of Environmentally Preferred Transportation. A student group in a final-year undergraduate design course noted that university students comprise lead or extraordinary users with respect to bicycle helmets. While other students and many workers have lockers or desks to store helmets, undergraduate students at University of Toronto generally must carry their helmets from lecture to lecture. Leaving a helmet, even locked, with their bicycles likely results in theft. However, carrying their helmets presents an annoying burden that discourages the use of helmets and thus the environmentally preferred transportation method of bicycling. Helmets take up an unacceptable inner volume of book bags, and attaching helmets externally to book bags while squeezing through crowded rows in a lecture hall is awkward.

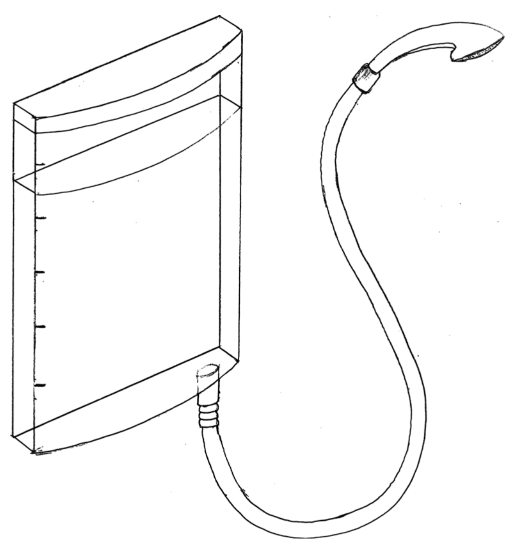

Fig. 1 Water-conservation-enabling shower concept

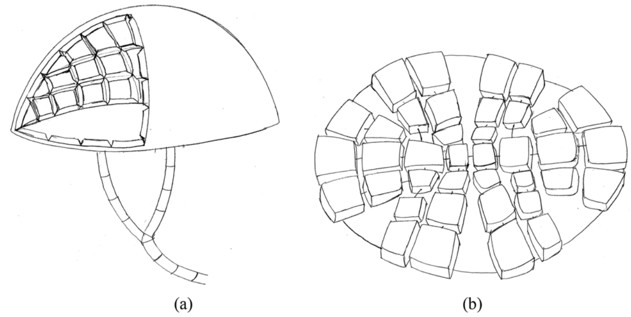

Fig. 2 Collapsible helmet with segmented internal plates, adapted from Anderson et al. [36]

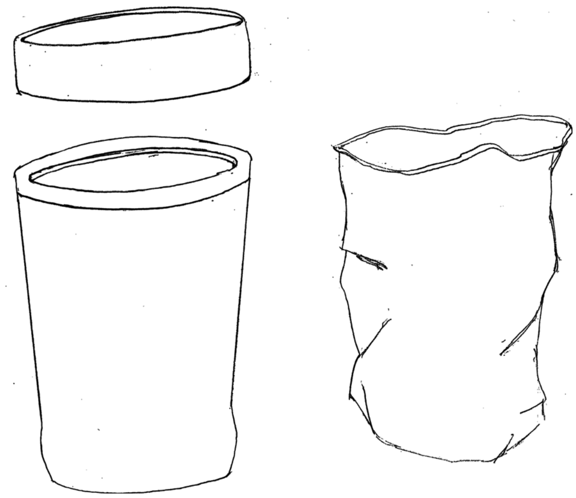

Fig. 3 Reusable coffee cup with removable liner, adapted from Pienkow et al. [37]

Transferring the portability affordance of the expand/collapse transformation principle, the student group devised a collapsible helmet, shown in Fig. 2, as a solution. This helmet collapses to flat when not in use, taking up much less volume in a book bag, and through drawstrings, takes the form of a helmet when needed [36].

3.2.3 Localization Example: Reducing Use of Disposable Products and Cleaning Needs. Another team of students in a 4th year design course tasked with developing a product to enable ECB focused on improving reusable coffee cups [37]. Selecting as lead users those who already carry reusable coffee cups, the team decided the key impediment to using such cups is that cleaning them is inconvenient, particularly for students who must carry their cups with them all day. The team developed a concept that incorporates a disposable (potentially biodegradable) liner that aims to localize the effect of dirt to a less energy-intensive item than an entire disposable cup, shown in Fig. 3. One can argue that this concept also makes use of the fuse/divide transformation principle. As is the case with the transformation principles, our ECB-enabling principles are not necessarily mutually exclusive.

4 Affordance-Transfer Validation

In addition to using the above and other principles directly to generate concepts, such concepts could also result from transferring affordances that support the desired resource-conserving

Downloaded From: http://mechanicaldesign.asmedigitalcollection.asme.org/ on 09/23/2013 Terms of Use: http://asme.org/terms

behavior (e.g., portability and convenience) and affordances from lead-user products (e.g., camping shower). We were interested in how repeatable these strategies are for other designers, and had an opportunity to study their use by novice designers, i.e., 4th year engineering students and graduate students from a variety of fields.

4.1 Affordance Transfer From Compatible Products. We performed a pilot study with novice designers to learn how the affordance-transfer method could be applied to transfer affordances from behaviorally compatible products.

4.1.1 Method. Twenty-two 4th-year engineering undergraduates were taken to a Canadian Tire retail store. Canadian Tire is a mass-retailer similar to Kmart in the U.S., but with more emphasis on tools and hardware than clothing and personal products. Participants were asked to develop concepts that encourage the conservation of either household electricity or household water. The method of affordance transfer was explained to the participants, who were then asked to first find and list the affordances of an *obstructing* product pertaining to one of the two conserving behaviors. Next they were asked to find a *behaviorally compatible* product, list its affordances and then attempt to transfer relevant affordances from the compatible to the obstructing product. The affordances and product concepts generated during the 45 min were collected and analyzed.

4.1.2 Results. All but one of the participants were able to follow the procedure correctly. Most students selected the task of encouraging water conservation. Based on a mop bucket, one participant thought of adding a strainer and bucket under a kitchen sink to collect used water for secondary applications, e.g., watering plants, flushing toilets, etc. Based on the nozzle configuration of a showerhead, another participant wanted to enable water saving by redesigning an inflatable pool so that its bottom surface would have a pyramid-like wedge in the middle. The participant reasoned that many users sit at the edges of inflatable pools, so raising the middle section would reduce the water required to fill the pool.

4.1.3 Discussion. While the affordance-transfer method appears easy to understand, as even our novice participants were able to follow the steps without making errors, there were shortcomings in the quality of the concepts generated.

Most concepts tended to be either novel or feasible, but rarely both. For example, many concepts sought to "aerate" or otherwise "optimize" the water flow, thereby reducing the actual volume of water required. Although these were useful and feasible concepts, they had already been implemented in closely related, if not identical products. Concepts that were more original tended to be unappealing to consumers, or were unlikely to continue to be used if purchased.

In addition, some participants likely had a conservation strategy in mind, and then "found" behaviorally compatible products to support this pre-existing strategy, rather than identify and transfer novel and useful affordances from behaviorally compatible products as intended. For example, the large push button on top of a hot water thermos/dispenser was identified as a source product for push-button valves that retract, and discontinue flow when fully retracted.

These challenges could be attributed to two possibilities:

(1) The participants had a difficult time identifying behaviorally compatible products, detecting and transferring salient affordances that result in novel and useful products, possibly due to their lack of design experience, or
(2) The selected retailer did not have novel and useful examples of behaviorally compatible products.

The participants also had difficulty abstracting particular affordances of the products so they could be transferred in a different, more practical embodiment in their redesign. For example, one participant, when trying to change the affordances of a showerhead to be more like a water meter, suggested that the indicator lights and digital readout of the meter be added directly to the showerhead. Instead of a direct transfer of features, the participant could have instead taken the idea of water usage feedback from the water meter and then thought of a broader set of ways (affordances) to provide that same feedback in a showerhead.

As a result of such observations, we were interested to learn whether the type of behaviorally compatible product chosen had any effect on the quality of ideas generated. Therefore, we first devised a method to compute the difference between the obstructing product and the behaviorally compatible product. Semantic distance has long been used as a measure for quantifying the difference (in meaning) between words [38]. Many approaches have been developed by computer scientists to calculate semantic distance, most employing WordNet, a lexical database of English words. We first attempted such an approach for calculating semantic distance between the obstructing and behaviorally compatible products, but the WordNet database proved unsuitable for analyzing the names of products. The specific product type often did not exist in the database (e.g., water cooler) and WordNet did not have a way to link words together functionally (e.g., the words "mop" and "bucket" were found to have no semantic relatedness).

Therefore, we developed another method for measuring semantic distance, one that considered how products were categorized in a retail store database. Retailers have extensively studied how best to organize products in stores in ways that are sensible for customers [39]. We quantified the distance between two products in a retail database based on the number of levels one had to traverse before two products shared a superordinate category. The distance ratings fell on a three-point scale. If two products were already in the same category, the distance rating was 1; if they shared a category one or two levels up, the rating was 3; if they shared a category three or more levels up, the rating was 9. The database used belonged to Canadian Tire Corporation, where the study was conducted.

Two raters evaluated concepts for novelty and feasibility, using a variation of Besemer and O'Quin's [40] measures of creativity, and a 5-point scale of 1 = not novel/feasible to 5 = very novel/feasible. Table 1 shows, for example concepts, retail distance values and idea ratings. Kendall's Tau test of correlation was performed on the nonparametric data, with strong correlation for evaluations between raters for both novelty ($\tau = 0.302$) and feasibility ($\tau = 0.322$). For each concept, we then averaged the raters' evaluations for both novelty and feasibility, and compared them to the semantic/retail distance. We found novelty to strongly correlate with retail distance ($\tau = 0.303$), and feasibility to have a moderate inverse relationship with retail distance ($\tau = -0.28$) [41].

Our findings suggest that students' attempts to transfer affordances from distant products resulted in more novel ideas. This is consistent with Fu et al.'s [42] findings with near versus far analogies. However, many of the more novel concepts were not feasible in that as described, they would not form the basis of products that people would buy or continue to use. Students appeared to have difficulty: identifying appropriate source products, abstracting affordances from distant products, and applying them in a useful manner in their redesigns. We therefore explored sources of ideas from conceptually close categories, but those that had potential to be more novel.

4.2 Affordance Transfer From Lead-User Products. Although not planned as an affordance-based activity, we noted that a design-course laboratory exercise led to the identification of affordances from lead-user products that could be transferred to more mainstream products. In this exercise, we had 13 participants, a subset of the 4th year undergraduate students that participated in the previous study. This exercise was conducted at Mountain Equipment Co-op (MEC), a Canadian consumers'

Downloaded From: http://mechanicaldesign.asmedigitalcollection.asme.org/ on 09/23/2013 Terms of Use: http://asme.org/terms

Table 1 Examples of affordance transfer

Obstructing product	Behaviorally compatible product	Retail distance 1 close - 9 far	Average novelty 1 low - 5 high	Average feasibility 1 low - 5 high
Faucet	Bucket	9	4	1.5
	Aerator	1	2	4.5
Shower-head	Water timer	9	4	3
	Lavatory faucet aerator	1	2	4
Inflatable pool	Showerhead nozzle configuration	9	5	2
Water slide	Rain barrel	3	4.5	3
Car wash	Car wipes	1	3	3.5

cooperative that sells outdoor recreation gear, similar to Recreational Equipment Inc., in the United States. MEC, noted for its commitment to environmental protection, limits its offerings to those that support self or human-propelled outdoor activities.

4.2.1 Method. Students were asked to identify a product category they wanted to study, and explain how that product category is a lead-user version of a mainstream product (e.g., camping food containers versus domestic food containers). Next, they were to select 3 products in that product category, listing their main features by: reading the features listed on their packaging; listing any other noticeable features which may not be on the packaging; thinking about how/where these products are intended to be used; and asking store staff for help if needed to further explain the products. Students were then asked to identify the user needs that the lead-user products address (e.g., portability, price, waterproofing, and ease of assembly), compare to mainstream products and identify the drawbacks of the lead-user products. Finally, students were asked to identify how one could improve the mainstream product they selected.

4.2.2 Results. The results from the second study are promising. Of the 13 participants, 12 were able to identify affordances and features from lead-user products applicable to mainstream products.

Promising examples include transferring affordances of:

- Portability, waterproofing, ability to be ventilated from technical jackets and clothes to regular coats and clothes,
- Adaptability of carrying different objects from technical bags to regular bags,
- Nest-ability and detachable handles to improve storability from camping pots and pans to regular pots and pans
- Breathability, water-repellence, sun-protection from technical t-shirts to regular t-shirts
- Ease of one-handed operation (e.g., by using bite nozzle) from biking water bottles to regular water bottles.

Comparing overall average evaluations of the behaviorally compatible versus lead-user affordance-transfer concepts, the novelty was not significantly different, i.e., 2.80 versus 2.88 (both out of 5). However, the feasibility improved markedly, i.e., 2.9 for concepts developed by transferring affordances from behaviorally compatible products versus 3.69 for concepts developed from lead-user versions of products.

4.2.3 Discussion. The participants in this study successfully identified affordances of lead-user products that would also improve the design of regular products if applied to them. However, when asked to think of how those affordances could be embodied in the regular products, the participants tended to carry over the feature unchanged from the lead-user product. For example, one participant noted that a lead-user jacket exhibited portability as it could be folded into its own pocket, and that portability could be useful if incorporated into conventional jackets. When considering options of how this portability would be embodied in a regular jacket, the participant carried over the very same mechanism, that of folding into a pocket. It is of course, possible to enable portability in a jacket in many other ways, e.g., rolling up, or disassembling, etc. This result could suggest that this type of affordance transfer, where the product used for inspiration is very similar to the product to be improved, discourages designers of thinking broadly about how to embody particular affordances.

However, because affordances are transferred between similar products, features that enable such affordances can be copied more directly without compromising product feasibility.

4.3 Affordance Transfer Versus Brainstorming. To further investigate the affordance-transfer method, a third study was conducted to compare affordance transfer versus, and in conjunction with, traditional brainstorming.

4.3.1 Method. Thirty-three students from various university disciplines were recruited for an idea generation study. The participants were asked to redesign a kitchen faucet and a showerhead in a way that would encourage reduced water usage.

There were two conditions. In the control (brainstorming) condition, participants were asked to use unstructured brainstorming to develop concepts. In the treatment (affordance-transfer) condition, participants were provided a catalogue of four water-saving products. Similar to the water-saving products used for inspiration in the first study, these included a rain barrel, a water meter that attaches to a garden hose, a collapsible water container with filter, and a bottom-mount water cooler. Participants were free to choose any of these products for inspiration and were instructed to first list all its possible uses and then think of how the product facilitated water conservation. Finally, they were asked to devise concepts based on features of the inspiring product. We asked participants to develop concepts under both conditions to maximize the amount of information we could collect from a limited sample size. Participants were instructed to generate as many concepts as possible. Concepts were typically in the form of sketches and verbal descriptions. The order of the conditions was randomized but we watched for learning effects.

Two expert raters, neither of whom conducted the experiment, reviewed the concept features. As most participants produced multiple concepts each with multiple features, it was difficult for the raters to evaluate each participant's overall performance. There were also similar features that appeared multiple times across participants. For example, many participants devised showerhead and faucet concepts involving the use of proximity sensors to control the flow of water. Thus, all the concepts were decomposed into features, verbal descriptions of which, e.g., "An alarm that goes off if the faucet is left running beyond a prescribed period," were provided to raters. The two raters were asked to evaluate each feature on a five-point scale along three dimensions: *novelty, feasibility, and usefulness.* Novelty referred to how unfamiliar that feature seemed to the rater, feasibility had to do with how technically feasible the feature was, and usefulness was an assessment of how effective that feature would be in reducing water consumption. An evaluation rubric, shown in Table 2, was provided to raters to increase rating consistency. Each

Downloaded From: http://mechanicaldesign.asmedigitalcollection.asme.org/ on 09/23/2013 Terms of Use: http://asme.org/terms

Table 2 Concept feature rating rubric

	Novelty	Feasibility	Usefulness
1	Already well-known/common solution	Impossible for it to exist or work properly	Not relevant to the problem of water use reduction/won't lead to water use reduction
2	Likely already exists/easy to see how it could already exist	Likely will not work	Is likely to have only minor/temporary water use reduction
3	Might exist but definitely not mainstream	Some aspects realistic, others require modification to work	Can see how this would reduce water usage but users could conceivably bypass or overcome it
4	Likely does not exist	Based on sound principles	Will likely reduce water usage
5	Definitely does not exist	Demonstrably can exist/Already exists	Will definitely reduce water usage

participant's score was then calculated as the average of the scores of all the features in their concepts.

4.3.2 Results and Discussion. As shown in Table 3, there was a statistically significant effect of the affordance-transfer method on the usefulness of concepts generated.

As some participants given the treatment condition (affordance transfer) first, carried over ideas from the inspiring product into the control condition (brainstorming), we also compare ratings between conditions based on the order of conditions. Table 4 presents averages for participants who performed affordance transfer before brainstorming and Table 5 presents averages for participants given the reverse order.

Separating the data by order of conditions confirmed a learning or carryover effect. Affordance transfer significantly increased the usefulness of concepts when performed after brainstorming, but not when performed before brainstorming.

Similar to the use of design examples in fixation and design-by-analogy studies, the concepts generated copy features of the examples provided. We also noted that when performing affordance transfer, participants tended to devise concepts using fewer water saving features overall than with unstructured brainstorming. On average, participants generated 3.5 water saving features in the control condition and 2.5 in the treatment condition ($p = 0.0043^{**}$). This appears to confirm the limiting effects of examples on the number of "wild and crazy" ideas, resulting in concepts with fewer and possibly less novel features. The use of the affordance-transfer method did however help participants think of concepts with more useful features, i.e., those features that may be more effective in reducing water usage.

Table 3 Average ratings between conditions ($n = 33$)

	Novelty/5	Feasibility/5	Usefulness/5
Control (Brainstorming)	2.24	4.45	2.96
Treatment (Affordance transfer)	2.60	4.18	3.55
p value (<0.05 for significance)	0.08	0.09	0.01**
Inter-rater agreement	0.47	0.21	0.49
(Kendall's Tau)	(Strong)	(Moderate)	(Strong)

Table 4 Average ratings for cases where affordance transfer was performed before brainstorming ($n = 14$)

	Novelty/5	Feasibility/5	Usefulness/5
Treatment (Affordance transfer)	2.57	4.28	3.34
Control (Brainstorming)	2.29	4.43	3.10
P value (<0.05 for significance)	0.43	0.55	0.40

Table 5 Average ratings for cases where brainstorming was performed before affordance transfer ($n = 19$)

	Novelty/5	Feasibility/5	Usefulness/5
Control (Brainstorming)	2.19	4.46	2.87
Treatment (Affordance transfer)	2.62	4.10	3.71
P value (<0.05 for significance)	0.09	0.10	0.01**

5 Conclusion and Future Work

We believe that affordances provide a useful and thus far, underutilized way of describing customer needs, which is structurally similar to the function-based approaches familiar to engineering designers, but thematically similar to intuitive customer-needs methods favored by industrial designers. Affordances can be much deeper than a statement of typical customer needs as they have to do with how customers perceive physical objects, whether they are aware of it or not. As such, affordances provide a powerful way for designers to understand product designs from the user's perspective. The effectiveness of the affordance-based methods lies in the emphasis on determining what a user will think of doing with an object, not just as idealized notions of the functions that objects perform. This may enable designer awareness of how users can be guided to interact with the product in different ways. Understanding the cues for perception allows designers to create products that may intentionally trigger users to behave in particular ways, which is a novel approach to design.

For our work, we abstracted the desired affordances from patterns and principles we observed to support ECB, and generated concepts by enabling those affordances. As a possible shortcut to identifying and implementing relevant affordances, we introduced the affordance-transfer method. This method involves altering a product's affordances to add desired features from related products. Promising sources of affordances, i.e., behaviorally compatible products, include lead-user, and other products that support resource conservation.

We examined how novice designers would apply the two potential sources of affordance transfer. Our first study suggests that our student participants (1) had difficulty in selecting products that supported resource-conserving behaviors at the chosen retail location where the study was conducted, (2) developed more novel concepts by transferring affordances from more semantically distant products, yet (3) had more difficulty developing feasible concepts from semantically distant than close products. A second study was conducted at a retailer that offered more lead-user products. While the novelty of concepts developed did not change significantly, the feasibility of concepts improved. That is, transferring affordances from lead-user versions of similar products may lead to more feasible concepts than transferring affordances from conservation-compatible versions of products. A third study compared affordance transfer with unstructured brainstorming and confirmed that affordance transfer increases the usefulness of concepts generated, particularly when performed after brainstorming. The affordance-based methods we described

Downloaded From: http://mechanicaldesign.asmedigitalcollection.asme.org/ on 09/23/2013 Terms of Use: http://asme.org/terms

can easily be used in conjunction with other eco-design principles and inspirational and prescriptive methods; these methods simply offer another, hitherto underutilized perspective.

There are several outstanding challenges in developing an affordance-based method to support ECB. These include identifying ideal ECB supporting products to serve as sources of affordances when so few such products exist. While design-by-analogy methods tend to focus more on transferring functions than affordances, we observed similar difficulties with fixation and transfer of superficial features rather than deeper strategies. We believe that successful ECB supporting products must achieve a balance between negative affordances that thwart users' inertia toward wasteful behavior, and positive affordances that persuade a user to adopt an ECB supporting product, or use an existing product in a less wasteful manner. Finally, we intend to observe the use of such products over time to determine whether these products do in fact affect behavior.

Acknowledgment

We thank our study participants and the Natural Sciences and Engineering Research Council of Canada.

References

[1] Sorrell, S., Dimitropoulos, J., and Sommerville, M., 2009, "Empirical Estimates of the Direct Rebound Effect: A Review," Energy Policy, **37**(4), pp. 1356–1371.
[2] Stern, P., 2000, "Toward a Coherent Theory of Environmentally Significant Behavior," J. Soc. Issues, **56**(3), pp. 407–424.
[3] Abrahamse, W., Steg, L., Vlek, C., and Rothengatter, T., 2005, "A Review of Intervention Studies Aimed at Household Energy Conservation," J. Environ. Psychol., **25**(3), pp. 273–291.
[4] Steg, L., and Vlek, C., 2009, "Encouraging Pro-Environmental Behavior: An Integrative Review and Research Agenda," J. Environ. Psychol., **29**(3), pp. 309–317.
[5] Duflou, J. R., Sutherland, J. W., Dornfeld, D., Herrmann, C., Jeswiet, J., Kara, S., Hauschild, M., and Kellens, K., 2012, "Towards Energy and Resource Efficient Manufacturing: A Processes and Systems Approach," Ann. CIRP, **61**(2), pp. 587–609.
[6] Srivastava, J., and Shu, L., 2011, "Encouraging Environmentally Conscious Behavior through Product Design: The Principle of Discretization," Proceedings of the ASME IDETC, Washington, DC, Aug. 28–31, DETC2011-48616.
[7] Srivastava, J., and Shu, L., 2012, "Designing Products to Encourage Conservation: Applying the Discretization Principle," *Leveraging Technology for a Sustainable World*, Proceedings of the 19th CIRP International Conference on Life Cycle Engineering, Berkeley, CA, May 23–25, Springer, Berlin Heidelberg, pp. 569–574.
[8] Srivastava, J., and Shu, L., 2013, "Encouraging Resource-Conscious Behavior Through Product Design: The Principle of Discretization," ASME J. Mech. Des., **135**(6), p. 061002.
[9] Scarantino, A., 2003, "Affordances Explained," Philos. Sci., **70**, pp. 949–961.
[10] Gibson, J., 1979, *The Theory of Affordances: In the Ecological Approach to Visual Perception*, Houghton Mifflin, Boston, MA.
[11] Norman, D., 1988, *The Design of Everyday Things*, Basic Books, New York.
[12] Norman, D., 1999, "Affordance, Conventions, and Design," Interactions, **6**(3), pp. 38–42.
[13] Tucker, M., and Ellis, R., 2004, "Action Priming by Briefly Presented Objects," Acta Psychol., **116**(2), pp. 185–203.
[14] Buccino, G., Sato, M., Cattaneo, L., Roda, F., and Riggio, L., 2009, "Broken Affordances, Broken Objects: A TMS study," Neuropsychologia, **47**(14), pp. 3074–3078.
[15] Borghi, A. M., and Riggio, L., 2009, "Sentence Comprehension and Simulation of Object Temporary, Canonical and Stable Affordances," Brain Res., **1253**, pp. 117–128.
[16] Bub, D. N., Masson, E. J., and Cree, G. S., 2008, "Evocation of Functional and Volumetric Gestural Knowledge by Objects and Words," Cognition, **106**(1), pp. 27–58.
[17] Pols, A., 2011, "Characterising Affordances: The Descriptions-of-Affordances-Model," Des. Studies, **33**(2), pp. 113–125.
[18] Jacquet, P. O., Chambon, V., Borghi, A. M., and Tessari, A., 2012, "Object Affordances Tune Observers' Prior Expectations about Tool-Use Behaviors," PLoS ONE, **7**(6), p. e39629.
[19] Maier, J., and Fadel, G., 2006, "Affordance Based Design: Status and Promise," Proceedings of IDRS, Seoul, South Korea, Nov. 10–11.
[20] Maier, J., and Fadel, G., 2009, "Affordance Based Design: A Relational Theory for Design," Res. Eng. Des., **20**(1), pp. 13–27.
[21] Maier, J., and Fadel, G., 2009, "Affordance-Based Design Methods for Innovative Design, Redesign and Reverse Engineering," Res. Eng. Des., **20**(1), pp. 225–239.
[22] Hauser, J. R., and Clausing, D., 1988, "The House of Quality," Harvard Business Rev., **66**, pp. 63–73. Available at: http://hbr.org/product/house-of-quality/an/88307-PDF-ENG
[23] Pahl, G., Beitz, W., Feldhusen, J., and Grote, K., 2007, *Engineering Design: A Systematic Approach*, Vol. 3, Springer, New York.
[24] Brown, D., and Blessing, L., 2005, "The Relationship between Function and Affordance," Proceedings of ASME IDETC, Long Beach, CA, Sept. 24–28, Paper No. DETC2005-85017.
[25] Kouprie, M., and Visser, F., 2009, "A Framework for Empathy in Design: Stepping Into and Out of the User's Life," J. Eng. Des., **20**(5), pp. 437–448.
[26] Galvao, A., and Sato, K., 2005, "Affordances in Product Architecture: Linking Technical Functions and Users' Tasks," Proceedings of ASME IDETC, Long Beach, CA, Sept. 24–28, DETC2005-84525.
[27] Hsiao, S., Hsu, C., and Lee, Y., 2011, "An Online Affordance Evaluation Model for Product Design," Des. Studies, **33**(2), pp. 126–159.
[28] Telenko, C., and Seepersad, C. C., 2010, "A Methodology for Identifying Environmentally Conscious Guidelines for Product Design," ASME J. Mech. Des., **132**(9), p. 091009.
[29] Hannukainen, P., and Hölttä-Otto, K., 2006, "Identifying Customer Needs—Disabled Persons as Lead Users," Proceedings of ASME IDETC, Philadelphia, PA, Sept. 10–13, Paper No. DETC2006-99043.
[30] Lin, J., and Seepersad, C., 2007, "Empathic Lead Users: The Effects of Extraordinary User Experiences on Customer Needs Analysis and Product Redesign," Proceedings of ASME Int. Design Engineering Technical Conference, Las Vegas, NV, Sept. 4–7, Paper No. DETC2007-35302.
[31] von Hippel, E., 1986, "Lead Users: A Source of Novel Product Concepts," Manage. Sci., **32**(7), pp. 791–805.
[32] Son, J., and Shu, L., 2012, "Role of Transformation Principles in Enabling Environmentally Significant Behavior," *Leveraging Technology for a Sustainable World*, Proceedings of the 19th CIRP International Conference on Life Cycle Engineering, Berkeley, CA, May 23–25, Springer, Berlin, pp. 563–568.
[33] Singh, V., Skiles, S., Krager, J., Wood, K., Jensen, D., and Sierakowski, R., 2009, "Innovations in Design Through Transformation: A Fundamental Study of Transformation Principles," ASME J. Mech. Des., **131**(8), p. 081010.
[34] Momoh, David A., 2011, "Environmentally Significant Behavior of Adopting Warm Energy Conserving Temperatures in Offices: Identifying and Overcoming the Obstacle of Thermal Comfort Through Direct Cooling," M.E. thesis, Mechanical and Industrial Engineering, University of Toronto, Canada.
[35] Connelly, T., 2011, personal communication.
[36] Anderson, C., Istchenko, A., Loberto, N., MacNeil, C., Martin, T., and Peruzzo, R., 2007, "Helmet Design Alternatives for Casual Bicycle Users," Mechanical Design Theory & Methodology, Department of Mechanical/Industrial Engineering, University of Toronto, Term Project Report, MIE440F.
[37] Pienkow, A., Xie, J., and Giribaldi, R. S., 2011, "Keeping the Reusable Fluid Container Clean,", Department of Mechanical & Industrial Engineering, University of Toronto, MIE440 Final Project Report.
[38] Budanitsky, A., and Hirst, G., 2006, "Evaluating WordNet-Based Measures of Lexical Semantic Relatedness," Comput. Linguist., **32**(1), pp. 1–35.
[39] Bloch, P., 1995, "Seeking the Ideal Form: Product Design and Consumer Response," J. Market., **59**(3), pp. 16–29.
[40] Besemer, S., and O'Quin, K., 1986, "Analyzing Creative Products: Refinement and Test of a Judging Instrument," J. Creat. Behav., **20**(2), pp. 115–126.
[41] Blake, C., 2012, "Nominal Measures of Association," www.jmu.edu/polisci/bios/blake/295/nom_ord8.rtf
[42] Fu, K., Chan, J., Cagan, J., Kotovsky, K., Schunn, C., and Wood, K., 2012, "The Meaning of Near and Far: The Impact of Structuring Design Databases and the Effect of Distance of Analogy on Design Output," Proceedings of ASME International Design Engineering Technical Conferences, Chicago, IL, Aug. 12–15, Paper No. DETC2012-70420.

Downloaded From: http://mechanicaldesign.asmedigitalcollection.asme.org/ on 09/23/2013 Terms of Use: http://asme.org/terms