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PRIMING DESIGNERS TO COMMUNICATE SUSTAINABILITY

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ABSTRACT

A prime is an artifact, exposure, or experience that stimulates increased cognitive accessibility of mental content. Priming designers has thus far focused on generating more features, novel features, relevant features, and addressing latent customer needs. This article presents a design method that uses priming specifically to help designers to communicate sustainability via design at an early stage in the design process. The authors have determined that sustainable products face a special challenge in the market because many of their best features, such as decreased energy usage, recyclability, or material selection, are hidden from the customer. Marketing messages are not always trusted. Designers need to communicate sustainability to the customer through product features that customer will identify as sustainable. We propose and test a new design method that designers can use to generate product features that communicate sustainability to the customer. The method involves priming the designer with a sensory-heightening activity before generating ideas for sustainable features. We investigate primes in the form of a questionnaire or a collage activity. The design method significantly helps designers to generate product features that communicate sustainability.

1 INTRODUCTION

Product design has a tremendous impact on global sustainability. Particularly, early design decisions such as material selection, structure and function affect a product's whole life cycle [1]. Design engineers have devoted much effort to improving product sustainability with cradle-to-cradle solutions [2], and investigating novel design methods and tools to support such movement, for instance, design guidelines and checklists [3, 4], Life Cycle Assessment (LCA), Life-cycle Design Strategies (LiDS) Wheel [5], the House of Ecology [6], the Function Impact Matrix (FIM) [7], and conceptual tools to resolve functionality-environmental contradictions [8]. For detailed reviews of sustainable design theory see [1, 9].

While design engineers have addressed technical sustainability issues in product design, the fruits of their labors have not met with much success in the market [10, 11], although consumer survey research has revealed that customers prefer sustainable products and are even willing to pay a premium in some cases [12, 13]. The success of sustainable products has suffered from customer indifference [14]. Two reasons identified in the literature are: (1) it is often difficult for customers, and other stakeholders to trust, or even ascertain the extent to which a firm's products and processes are sustainable [11, 15]; and (2) the constructive nature of preference [16] implies that the decision context plays a crucial role in customer sustainable choice and it is possible that customers are not thinking about sustainability issues when evaluating a product for purchase. Our work aims to address reason (2), the constructive nature of preference, by encouraging customers to think about sustainability when purchasing products.

A number of firms speak the sustainability of their products directly with product packaging details, including: sustainability logos, a statement combined with imagery, and third party certification. Firms may also advertise sustainability efforts through their website, social media, and other promotions [14]. However, firms face challenges with product labeling and claims, such as limited and competing uses of physical space on a product packaging, difficulty in language determination [14]. More importantly, on-product messaging may not be effective because "people are busy, and may not be paying attention" [14]. With the public's growing concerns of "green washing", customers might also not trust the on-product

messaging [17]. For these reasons, some firms avoid on-product messaging altogether [14] and typical marketing strategies have not been successful in communicating sustainability.

An outcome of this research is to improve the communication of a product's sustainability by imbuing this communication in the product's design, instead of relying on superficial marketing messages. In previous related work, MacDonald found that for a product to be successful, it must not only have good engineering design, but also be correlated with customer perceptions of the design [18]. Addressing the customer-product relationship is nothing new for designers, with fields of study such as emotional design and product semantics stretching back decades [19-21]. While this previous work investigates and identifies well-established relationships between the customer and the product, sustainable products are a relatively new option, and accordingly customers' decision rules and evaluation criteria are not well established, but some research has been successful in shaping sustainable preferences. In [21], sustainable product semantics are developed; for example, people associate "metal", "simple", "durable" with a sustainable product. Reid *et al.* [22] provide engineering methods that quantify sustainable preferences associated with a product's form. Our recent work [23] identifies seven cognitive concepts that are crucial to the success of sustainable design and emphasizes the importance of designing to the decision rules (heuristics) customers use to purchase sustainable products. Industrial designers attempt to purposefully shape behavior towards more sustainable practices by using eco-feedback, behavior steering, and persuasive technology [24] in their early design concepts [25].

In this paper, we present and test a design method that helps designers generate product features that trigger the customer to think about sustainability, to advance the product's ability to express its sustainability to the customer. We sometimes refer to this as "communicating sustainability" for the purpose of brevity. The "help" that designers receive comes in the form of a priming exercise.

Priming, a well-established concept in behavioral psychology, is used in the design community to augment mental activity by exposure to a stimulus. Design researchers have used priming during conceptualization to generate more features [26], novel features [27-29], relevant features [30], and address latent customer needs [26]; refer to Section 2.2 for a review of studies. The design method tested in this paper uses priming to enhance the designer's ability to communicate sustainability in his or her product concepts. The ability to communicate is related to perceptions (sight, sound, touch, smell, taste). Therefore we test primes that focus on sensory perceptions and sustainability. We propose that exposure to such primes will increase designer's ability to communicate sustainability.

In the following sections, a review of priming literature in psychology, marketing, as well as engineering design is presented, followed by the details of the empirical study. Section 3 and 4 formulate research propositions and introduce the primes. Section 5 describes experimental methods and measurement procedures. Results and discussion are contained in Section 6 and 7 respectively, and Section 8 provides conclusions and future work.

2 BACKGROUND

2.1 Overview of Priming
Psychologists use the term "priming" to describe what occurs in the mind when exposure to some stimulus, the prime, increases the accessibility of associated information or processes for a later activity. A prime is an artifact, exposure, or experience that stimulates increased cognitive accessibility of mental content [31, 32]. For example, it has been validated that (1) people behave more competitively when seeing a leather briefcase placed on the desk in an office [33]; (2) people are more likely to work together in resource-management games after reading cooperation-related words [34]; (3) people are able to overcome automatic stereotypes and associations when primed to think creatively [35]; and (4) people give alternate solutions more consideration in problem solving when they experience a scenario in which an alternative outcome almost occurs [36]. The effects of priming can be salient and long lasting, not only on simple recognition tasks [37, 38], but also on decision-making [32], behavioral change [39], creative thinking [35] and problem solving [36].

Sensory priming, activating of a set of perception orientations via specific tasks, influences higher social cognitive processing. Ackerman *et al.* [40] report a series of studies demonstrating how weight, texture, and hardness non-consciously influence both social impression formation and decision-making. Their results show that heavy objects make job candidates appear more important (such as evaluating a resume on a heavy clipboard), rough objects make social interactions appear more difficult (such as rating social coordination after handling rough-feeling puzzles), and hard objects increase rigidity in negotiations (such as sitting in a hard chair while completing a negotiation task). Marketing researchers have studied the crucial role of non-diagnostic haptic cues of a product, such as packaging or serving container, and how these cues affect product evaluation [41]. For instance, water seems to taste better from a firm bottle than from a flimsy bottle [41].

For a comprehensive review of priming studies in social psychology, see [31], which addresses priming of trait, expectancy, mindset, goal, behavior, affect, etc. Custers and Aarts discuss goal priming in *Science* and analyze the mechanism for how this may happen [39]. An enormous number of papers from all over the world report on the effects of priming in many different scenarios, supporting the fact that responding to primes is part of being human and pervasive in our daily lives—a fact that can be applied to design research. Thus, the following section discusses the applications of priming, specifically priming customers' decisions and designers' ideation processes.

2.2 Applications of Priming

2.2.1 Priming customers

The notion of bounded rationality [42] implies that customers often do not have well-defined preferences for utility maximization. Instead, they construct preferences case-by-case when prompted to make a decision [43]. As a result, preferences are remarkably pliable, sensitive to the way a choice problem is described or "framed" and to the mode of response used to express the preference [16, 43].

Mandel and Johnson demonstrate how the visual primes can influence product choice [32]. In their study, groups of customers went shopping for hypothetical products in identical online shopping environment, except for the background pictures and colors of a Web page. In an experimental task of a sofa purchase, the authors find that a blue background with fluffy clouds increases the importance of comfort information in searching information and also the likelihood that a more comfortable sofa is selected. In contrast, a green background with pennies increases the importance of price information.

Haubl and Murray [44] examine "inclusion effect" in a controlled agent-assisted online shopping experiment. They vary attributes included in a recommendation agent to compare products, and find that everything else being equal, the attributes mentioned by the recommendation agent are more important in customers' purchase decisions. Moreover, this "inclusion effect" can persist and affect subsequent purchase decisions in different shopping environments.

Unlike Mandel and Johnson [32] and Haubl and Murray [44], who investigate priming effect on choice, Nedungadi [45] focuses on the early stage in the customer decision process.. In a memory-based choice experiment, priming of a brand increases the probability of retrieving, considering, and choosing that brand, although the corresponding brand evaluation does not change. The author suggests that brands sometimes benefit from their own advertising and that of highly similar competitors as well, due to a priming effect—advertising increases customer awareness of the category of products advertised.

2.2.2 Priming designers

The initial state-of-mind for the designer in the conceptual design process has an important effect on the outcome of the design process—see, for example, the issue of design fixation [46, 47]. Designers use longstanding knowledge as well as recently introduced information to generate new and creative products. Likewise, they pull together experiences both old and new. The incorporation of newly-acquired information and new experiences can be a source of priming in the design process, and a number of ideation techniques are based on the priming principle, such as stimuli (e.g., [48-50]), role-playing (e.g., [51, 52]), question technique (e.g., [53, 54]), and improvisation (e.g., [54, 55])—although not all references mention priming explicitly. In the random stimuli technique [50], designers are presented with a word, a picture, or a heuristic, and are expected to explore some useful and unusual associations [50,

56]. Role-playing prompts designers to act out scenarios, helping them find insights into target customers that may be difficult to access directly [52]. Question technique, a recognized way to induce imagination, can give designers conscious guidance to their thinking by asking a series of questions about each step in the design problem [53]. Improvisation activities, implemented in different forms, are helpful in breaking design fixations. For example, a group of people stand in a circle to tell a story; one person says one word at a time until the story is completed [55]. This activity encourages people to be more responsive and appreciative of others' creation, and thus less likely to focus on already generated words. Herring, et al. [57] conducted a study that understood and compared how designers use examples to support the creative design process. Shneiderman recommended ways in which technology can enhance creativity and encouraged to develop creativity support tools through human-computer interaction [58].

The empirical lab experiments discussed below demonstrated that priming could be used to enhance the design process in ideation, namely conceptual priming, sensory priming, affect priming, and mindset priming. The first three, concept priming [30], empathic lead user [26] and computational affective priming [27] intentionally a use prime. In the WordTree method [28, 29], priming is probably an influence rather than the first goal of the design method.

In a problem-solving study, subjects were asked to unscramble either neutral or hostile sentences for 12 minutes before a creative sketching task [30]. The results showed that subjects who unscrambled mildly hostile sentences prior to sketching included more hostile features, like features of spikes and claws, in their novel creations than did subjects in the control conditions. When a design problem can be solved in a variety of ways, the design results are most likely in a direction associated with the concept that is primed [31].

The empathic lead user technique leads to breakthrough product ideas via pushing designers to interact with products under extreme circumstances. In Lin and Seepersad's experiment [26], subjects were asked to assemble a two-person tent in the dark and with oven mitts on their hands. The results indicate a significant increase in latent needs discovery with the empathic lead user technique versus other design methods. The authors propose that the heightened senses associated with a loss of sight and dexterity guide perceptions and thinking.

Lewis et al. [27] study affective (mood) priming in design and demonstrate that inducing positive affect using digitally embedded stimuli on a simple sketching application facilitates creative performance. Subjects in the positive affect condition, which allowed subjects to practice drawing with an image of a laughing baby as a background before they started, created more original sketches with more elaborations. This effect is attributed to the fact that positive affect enhances motivation, broadens attention and leads to an increase in the numbers of cognitive elements treated as related to the problem.

The WordTree method proposed by Linsey et al. [28, 29] is based on keywords. Designers are tasked with describing the

key functions or customer needs of a design problem as "problem descriptors", and systematically representing them in a diagram known as a WordTree. Then potential analogies and analogous domains are identified and applied in a group idea generation. When designers are working on the WordTree task, not only specific contents but also relevant cognitive procedures become activated. Effects on subsequent design tasks may then be driven by these procedures themselves as well as specific content that is primed [31].

3 RESEARCH PROPOSITION

We propose that we can extend the design capabilities of engineers by heightening their sensory perceptions and thus improve their ability to communicate sustainability via a product's design.

Proposition: Exposing designers to a prime on sensory perceptions and sustainability will increase their ability to generate design features that communicate sustainability to the customer.

The basis for this proposition comes from the literature: priming has been demonstrated to provide a "perceptual readiness" [59]. Heightening perceptions via priming increases the cognitive accessibility of anything that may be related, which in turn drive individuals to discover the "blind spots" in thinking and design. It is this heightening of perceptions that we wish to exploit in our design method.

The motivation for this proposition comes from the challenges of designing sustainable products, as detailed in Section 1. Typically, design engineers focus on sustainability from an engineering standpoint, such as material impact, energy use, and the more formal methods discussed in the introduction section. We want to create design features that communicate these "hidden" efforts to the customer, and help the designer simultaneously consider technical- and customer-centric concerns.

The research proposition phrases the goal as generating design features that "communicate sustainability to the customer." In the experiment detailed in the Section 5, features are judged on their ability to "trigger the customer to think about sustainability." This specific phrasing was chosen in conjunction with future research, which will use the best features generated by the subjects in this experiment to design products that trigger customer preference for sustainable products. In the proposition, "Communicating sustainability" is used as a generalization of this phrase.

4 PRIMES

To test the proposition above, an experiment was created in which subjects (designers) were exposed to a prime and then asked to design a product. Two primes on sensory perceptions and sustainability were used in this experiment: a written questionnaire activity and a physical placement (collage) activity. Subjects were exposed to one prime or the other, but not both. The primes involved a focal product, a kitchen sponge. The selection of this product occurred in a pilot study. The kitchen sponge was selected for a number of reasons: (1) it is ubiquitous; (2) it engages all five senses during use—there are smells, sounds, textures, appearances, feelings of hot and cold, and even the recollection of the taste of a good meal associated with a kitchen sponge; (3) the senses may be engaged in a positive and negative way while cleaning dishes and leading; and (4) there are sponges with readily apparent sustainable features (natural fibers and dye-free) available on the market. Pretests revealed that some cultures use a rag instead of a sponge to clean dishes, thus the primes were worded to be inclusive of both cleaning implements.

The prime product (sponge) is different from the concept generation product (toaster, described in Section 5.3) in order to reduce potential design fixations [60] caused by working with the same product in the two stages of the experiment. In the questionnaire prime, subjects might have fixated on the features of the toaster they currently own. In the collage activity, subjects evaluate existing products, and therefore may have fixated on their features. Additionally, using a different product in the first and second stage is perhaps a deeper challenge of prime, as it will need to be more salient in order to transfer between activities involving two different products.

In the questionnaire prime, subjects answer a ten-minute questionnaire in which they write about: (1) three examples of things that they have done to reduce their environmental impact; and (2) the sponge or cloth they use at home to clean dishes using some or all of the five senses (sight, sound, touch, smell and taste). The motivation behind this questionnaire prime is as follows: by actively thinking about the answers, the associated mental content of perceiving sensory information may be vividly aroused and become highly accessible in the ideation process. Based upon the findings of the mechanism of priming effect [31], the mindset activated in the questionnaire activity will continue to be active during a subsequent design task, without subjects necessarily being aware of or intentionally choosing this mode of thought.

In the collage prime, subjects arrange pictures of sponges on a white background. The activity is based on the work of Guyton [21], who develops sustainable product semantics and establishes a set of design recommendations for sustainable designers, previously discussed in the introduction, with collage activities. To develop these recommendations, Guyton asked subjects to place images of sustainable products on a two-axis diagram. One axis tracked preference, from "like" to "dislike", and the other environmental impact, from "high impact" to "low impact." In order to prime perceptions, we combine Guyton's axis-placement activity with a sensory description activity, in which product images are matched with 28 sensory words, such as bright, harsh, cold, smoky, and bland, as shown in Fig. 1. In the second prime, subjects: (1) place eight images of dish sponges on the axes; and (2) place the sensory descriptor terms around the products. Subjects can use one term multiple times but must use all 28 terms at least once. They can also use their own words to describe the products. The activity takes ten minutes to complete.

The motivation behind the collage prime is as follows: when subjects are working on the collage exercise, not only specific cognitive orientations but also relevant cognitive procedures become activated. Effects on subsequent design tasks may then be driven by both the orientations and procedures. We anticipated that the collage prime would be more effective than the questionnaire prime, as rich, frequent, and recent primes are often especially effective [31], and such primes lead to more spreading activation [60] and require higher extent of cognitive processing. Subjects in the collage group physically interacted with a variety of sponge images and sensory descriptors. They repeatedly made judgments about perceptions and preferences, which required deeper and more frequent processing of the information presented to them. We expected such "rich" priming would better help designers focus their abilities on sensory experiences.
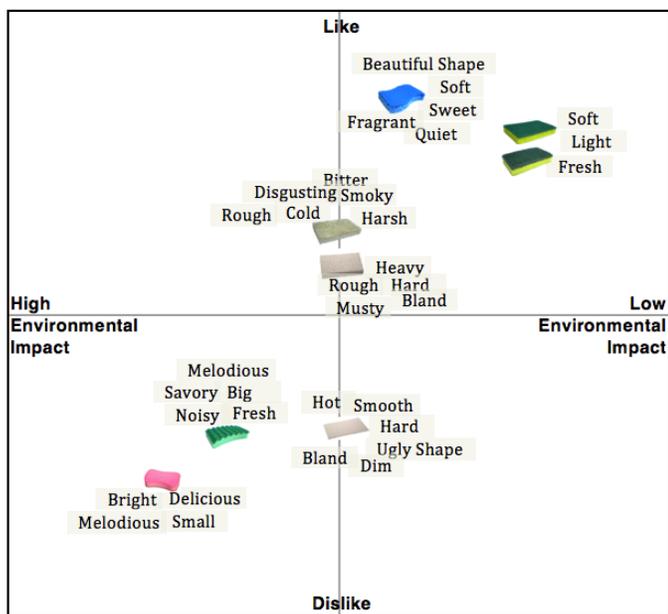

FIGURE 1. Demonstration of a collage output.

5 METHODOLOGY

5.1 Design of the experiment

A controlled experiment was designed and conducted to test the priming effect on ideation under three prime conditions: (1) a questionnaire prime, (2) a collage prime, and (3) no prime, serving as a control condition. For details of (1) and (2) see Section 4. After interacting with either prime (or none in the control condition), subjects designed new features for a target product (Design Phase 1). Then, they evaluated the features they had generated for their ability to trigger thoughts of sustainability. Next subjects specifically designed features to trigger thoughts of sustainability (Design Phase 2). After that, they provided some demographic and purchase information. Finally, subjects elaborated on their designs, counted the features they generated, and described their thinking process.

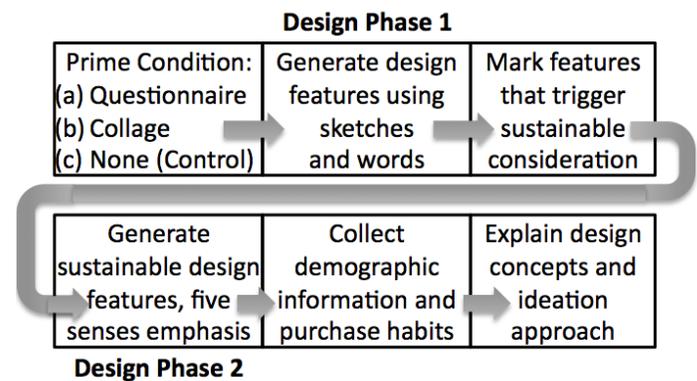Fig. 2 provides an overview of the experiment.

FIGURE 2. An overview of the experiment.

The research proposition described in Section 3 was broken down into hypotheses that are tested using this experiment:

Hypothesis 1a: The questionnaire prime increases the ability of features to trigger thoughts of sustainability.
Hypothesis 1b: The questionnaire prime increases the number of features generated that trigger thoughts of sustainability.

Hypothesis 2a: The collage prime increases the ability of features to trigger thoughts of sustainability.
Hypothesis 2b: The collage prime increases the number of features generated that trigger thoughts of sustainability.

Hypothesis 3a: The collage prime increases the ability of features to trigger thoughts of sustainability more than the features generated under the questionnaire prime.
Hypothesis 3b: The collage prime results in higher numbers of features generated that trigger thoughts of sustainability than the questionnaire prime.

5.2 Subjects

Subjects were 30 undergraduate students. All subjects have an engineering design background, and at minimum have taken one engineering design or product design class. Fourteen subjects were recruited in the Summer of 2011 from Mechanical Engineering and Industrial Engineering and compensated with $15 for their participation. Sixteen subjects were recruited in the Fall of 2011 from Mechanical Engineering and compensated with extra credit or $10 for their participation. Subjects were randomly assigned to the three conditions, ten in each condition.

5.3 Product Selection

A bread toaster was selected as the product focus for ideation. This is a common product with a variety of opportunities to improve its sustainability with respect to both engineering design and customer perception. A toaster is suitable for lab experiments involving students as it has low

technical barriers to designers and has been used in other studies on creativity and sustainability of products [61, 62].

5.4 Procedure

Subjects were partially informed that the purpose of this study was to investigate the design process and understand how designers solve a design problem. Due to the implicit nature of priming technique, the objective of the experiment was not fully revealed to the subjects (IRB-Approved). All instructions throughout the survey were given both in writing and verbally. First, subjects performed one of the two primes (or none for the control). The time limit for the priming activity was 10 minutes and a subject could move onto the design problem when ready.

Next, in Design Phase 1, subjects generated new design features for a next generation toaster in 15 minutes. The task was phrased as: "Imagine that you are working as a product designer in a design consulting firm, and that you are asked to design a next generation toaster. What new product features do you want to add into your design? How do you want to improve existing features?" After completing the design exercise, subjects marked any features they had generated that could trigger customers' sustainability considerations.

In Design Phase 2, subjects were directly instructed to generate such sustainable features for the same design problem in 12 minutes; the task was phrased as "Now please generate additional features that can trigger customers to think about sustainability for this design problem. Feel free to think about solutions that involve any of the five senses." In both Design Phase 1 and 2, designers were encouraged to sketch and/or write as many creative features as they could, number each different feature, and elaborate in writing, using labels and descriptions if necessary. Subjects were encouraged to think-aloud and their solutions and words were documented with an electronic audio recording pen.

Subjects answered a short post-experimental survey, providing information on demographics, purchasing, sustainability knowledge, environmental control belief, associations with sustainability, and evaluation of performance.

Then, subjects were interviewed about their design solutions. They were asked to review their sketches/words, and to verbally describe the features they generated, how they moved from one feature to another, and their approaches to ideation [63]. The numbering of features was confirmed. This exercise served to: explore cognitive process and ensure the documented data reflected intent. In addition, subjects in the collage condition were questioned about this task as well. Finally, subjects were debriefed.

5.5 Data Processing

Visual data, in the form of sketches and writing, were reviewed. Verbal data from the recording pen were transcribed to supplement the visual data. For those features with only sketches or unclear descriptions, written explanations were added according to the designers' audio record. Based on the quantity counting rules adapted from Linsey *et al.* [64] (see Table 1), the experimenter checked the self-counts of features.

Compiled ideas and scanned sketches were entered into a web survey so that judges could rate them, some examples of judge ratings are shown in Fig. 3.

TABLE 1. Quantity Counting Rules Summary [64].

1	The same feature (or component) being used in multiple places counts as one feature.
2	Each feature counts as only a single feature even if it solves more than one function.
3	New combinations of already-counted features are counted in a separate measure.
4	Categories of ideas only count as ideas when no subordinates are given.
5	Features count even if they are not needed or cause the systems to not function.
6	Features must be shown and not just implied.

5.6 Measures

Shah *et al.* [65] point out two basic criteria for evaluating ideation method: (1) how well does the method expand the design space, and (2) how well does the method explore the design space. Based on these two criteria, they propose four effectiveness measures: quantity, quality, novelty and variety of the ideas generated using that method. Due to the targeted nature of the method investigated in this paper, we focus primarily on the first two measures and recast them as:

A. *Number of features* generated. Counts were based on counting rules adapted from Linsey *et al.* [64] (see Table 1). The authors checked the self-counts of features. Judges were not used for this dimension.

B. *The ability to trigger a customer's sustainability considerations*, as discussed above in Section 3, and referred to as sustainability trigger. This dimension was rated by judges as detailed below.

C *Number of good features*, where a "good" feature is defined as having an average sustainability trigger rating of three or higher on a five-point scale, where the higher the rating, the better the feature in triggering sustainability considerations (as rated in B above).

D. *Percentage of good features*, with "good" defined same as in C.

On subjective and qualitative measurements of design features at the conceptual phase, such as creativity or ability to trigger sustainability considerations, it is common to rely on judges' subjective evaluations and check for reliability between judges [27, 30, 63, 66]. We adopted this subjective method on measure B, the sustainability trigger, which is rated for each feature (a feature-level measure). Measures A, C, and D, apply to the entire set of features generated by a subject (subject-level measures). Section 8 discusses other evaluations planned for the future. Measures A, B, C, and D were analyzed separately without weighting and combining because each is of value in validating the proposed design method, which is worth using if it can significantly improve designers' performance along any of the measures [65].

Two graduate students in Mechanical Engineering with different design backgrounds rated features for measure B. The male judge is a first-year PhD student, with a design background in undergraduate and graduate class projects. The female judge is a second year Masters student with five years of design experience in industry. Both judges were blind to the conditions of the experiment and the hypotheses. The definition of measure B was provided as "How likely a feature is to trigger customers to think about sustainability upon interacting with that feature." This statement was discussed and explained to the judges for full understanding. In order to calibrate their ratings, the judges first rated a small set of example features from a pilot study and discussed their ratings until they agreed with each other. Then they rated each of the 341 features generated on a five-point scale, from 1 (strongly disagree) to 5 (strongly agree) that the feature can trigger customers to think about sustainability. Example features generated in this study are shown in Fig. 3 with the judges' ratings below (which were identical for the features shown).

Next, average ratings for measure B were calculated and features that with averages higher than 3 were identified and used to calculate measures C and D.

5.7 Testing Inter-rater Reliability of Measure B

To evaluate the reliability of the judges' ratings on all 341features generated by the subjects, the Cronbach's alpha statistic was used. It is known as an internal consistency estimate of agreement among raters of a performance test with a possible range from 0 to 1.00 [67]. A higher alpha value indicates a higher reliability of measurements, and a value of 0.9 or above is used frequently as an indicator of good to excellent inter-rater reliability (IRR). Cronbach's alpha was 0.84 on the initial judges' evaluations and 0.9 on their evaluations after discussion of disagreements, demonstrating that the rating task for measure B was well-understood and consistently-performed by the judges.
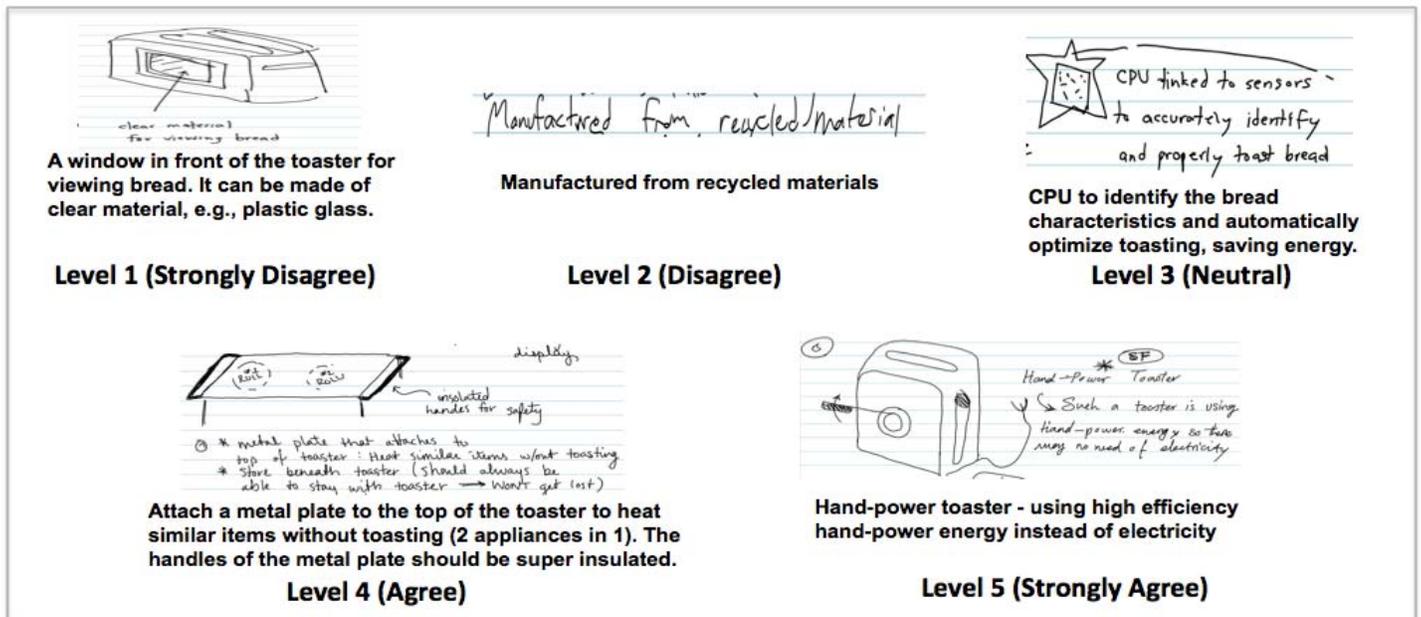

FIGURE 3. Example features at each level on sustainability trigger, rated from 1 strongly disagree to 5 strongly agree that the feature can trigger customers to think about sustainability.

6 DESIGN PHASE 2 RESULTS

6.1 Overview

In total, 341 features were generated by 30 subjects in both phases, 149 of which were from Design Phase 2 the phase of the experiment in which subjects were explicitly instructed to design features for triggering customers' sustainability considerations. Results from Design Phase 2 are discussed first, as they are the most useful in the testing of the hypotheses. The

results of Design Phase 1 will be discussed in Section 7. In this section, we report the result analysis from Design Phase 2 in two steps. The first part presents the results of the feature-level measure (B) Sustainability Trigger, followed by analysis of subject-level measures (A, C, D). A summary of means and standard deviations of measures A, B, C and D, and the total sums of measures A and C in each group from Design Phases 2 are listed in Table 2. Table 3 presents a summary of the hypothesis testing results, and the detailed evidence for each hypothesis is reported in section 6.2 and 6.3.

TABLE 2. Measurement values in collage, questionnaire and control conditions in design phase 2 ('*' p<0.05, compared to the control group).

Measures	Collage			Questionnaire			Control		
	Total	Mean	(SD)	Total	Mean	(SD)	Total	Mean	(SD)
Measure A: Number of features	66	6.60*	(3.20)	50	5.00	(2.45)	33	3.30	(1.06)
Measure B: Sustainability trigger	-	3.52*	(0.58)	-	3.19*	(0.68)	-	2.50	(0.96)
Measure C: Number of good features	57	4.80*	(2.62)	31	2.90*	(1.97)	16	1.30	(1.16)
Measure D: Percentage of good features	-	70%*	(21%)	-	54%	(25%)	-	39%	(30%)

TABLE 3. Summary of hypothesis testing.

Hypothesis	Conclusion	Significance Level	Measures Related	Evidence Presented In
1a: The questionnaire prime increases the ability of features to trigger thoughts of sustainability.	Accepted	P<0.05	Measure B	Table 2, Table 4, Fig. 4
1b: The questionnaire prime increases the number of features generated that trigger thoughts of sustainability.	Accepted	P<0.05	Measure C	Table 2, Fig.5
2a: The collage prime increases the ability of features to trigger thoughts of sustainability.	Accepted	P<0.05	Measure B	Table 2, Table 4, Fig. 4
2b: The collage prime increases the number of features generated that trigger thoughts of sustainability.	Accepted	P<0.05	Measure C	Table 2, Fig.5
3a: The collage prime increases the ability of features to trigger thoughts of sustainability more than the features generated under the questionnaire prime.	Rejected	P>0.1	Measure B	Section 6.2
3b: The collage prime results in higher numbers of features generated that trigger thoughts of sustainability than the questionnaire prime.	Marginally Accepted	P<0.1	Measure C	Section 6.3

6.2 Analysis of Measure B

The analysis of measure B is used to test Hypotheses 1a, 2a, and 3a. Fig. 4 shows the mean values of measure B, the judges' rating of the ability of a feature to trigger a customers' sustainability considerations,
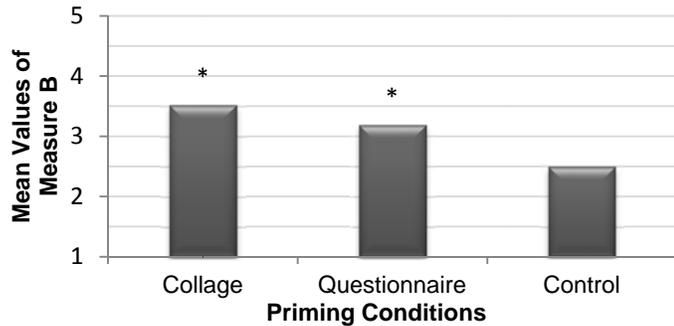

FIGURE 4. Effect of primes on measure B ('*' p<0.05, compared to the control group).

6.2.1 ANOVA with averages (less accurate)

Analysis of measure B began with an analysis of variance (ANOVA), a commonly used method. ANOVA averages the B rating by subject, across all the design features produced by the subject and the individual ratings of the two judges. We obtained 298 observations (149 design features*2 judges), but due to averaging ANOVA was conducted only on 30 observations, thus disguising judging and feature variance. The features from the collage group were rated significantly higher than those from the control (3.52 vs. 2.50, p<0.05). The

questionnaire prime leads to 11% increase on measure B compared with the control group, although the increase is only significant at 0.1 level (3.19 vs. 2.50, p<0.1). No dramatic difference between the collage and the questionnaire group was found (3.52 vs. 3.19, p>0.1).

6.2.2 Linear mixed model (LMM) (more accurate)

We next analyzed measure B using a linear mixed regression model with subjects as a random factor, and prime conditions and judges as fixed factors. The benefit of this approach is that the variances of the judges and features generated by one subject are modeled as well, rather than hiding them in the average. For more details about mixed models, see [68]. The regression model is represented by Eq. (1):

$$ST = \beta_0 + \beta_1 C_1 + \beta_2 C_2 + \beta_3 D + \beta_4 R + \beta_5(C_1 R) + \beta_6(C_2 R) + \varepsilon \quad (1)$$

where:

$$[C_1 \quad C_2] = \begin{cases} [1 \quad 0] & \text{If condition is questionnaire prime} \\ [0 \quad 1] & \text{If condition is collage prime} \\ [0 \quad 0] & \text{Otherwise (Control condition)} \end{cases} \quad (2)$$

$$R = \begin{cases} 1 & \text{If judge is judge 2} \\ 0 & \text{If judge is judge 1} \end{cases} \quad (3)$$

ST refers to judge's rating; C_1 and C_2 are dummy variables to indicate the prime conditions, shown in Eq. (2); D represents subjects (designers), which is modeled as a random

factor as subjects are randomly selected from the population; R is a dummy variable representing the judges, defined in Eq. (3); $\beta_0 \sim \beta_6$ are regression coefficients; and ε is the error term. The fixed effect estimates are listed in Table 4. Our criterion for significance is a coefficient magnitude of at least two standard errors (SE) (i.e., absolute t-values > 2). The degrees of freedom for t-values are not known exactly for a LMM [69]. Given the large number of observations (298) (in our analysis, the t-distribution has converged to the standard normal distribution. In this case, the 2SE criterion is close to the conventional two-tailed 0.05 level of significance [70]. The obtained t-statistics in Table 4 show that both contrast 1 (Questionnaire vs. Control) and contrast 2 (Collage vs. Control) reach the 0.05 significance level in terms of sustainability trigger. With the questionnaire group as the baseline, the t-statistic (t=1.06<2) for the contrast of Collage and Questionnaire was not significant.

TABLE 4. LMM estimates of fixed effects ('*' p<0.05).

	Coefficient	Estimate	SE	t
(Intercept)	β_0	2.60	0.29	9.10*
Contrast1 (Questionnaire vs. Control)	β_1	0.84	0.39	2.16*
Contrast 2 (Collage vs. Control)	β_2	1.22	0.38	3.22*
Judge 2	β_3	-0.21	0.29	-0.72
Questionnaire*Judge 2	β_4	-0.27	0.28	-0.71
Collage*Judge2	β_5	-0.33	0.36	-0.93

Thus, LMM and ANOVA lead to very similar conclusions, but differ a little with regard to the contrast of measure B between the questionnaire group and the control group. Because the corresponding p-value from ANOVA is also very small, 0.08, we think this weakened p-value resulted from average errors and are more confident with the results from LMM. Hypotheses 1a and 2a are accepted, as β_1 and β_2 in Table 4 are statistically significant. Hypothesis 3a is rejected as measure B of the collage and the questionnaire groups (Table 3) are found to only trend in the predicted direction, but the statistics generated by ANOVA and LMM are not significant.

6.3 Analysis of Measures A, C and D

Recall that good features are quantified as features with an average sustainability trigger rating (Measure B) of three or higher on a five-point scale rating. The data satisfies the assumptions for a standard ANOVA except for small departures from normality as suggested by Shapiro-Wilk's test [71]. Therefore, ANOVA is still robust and can be used on these subject-level measures.

Fig. 5 shows measures A (number of features), C (number of good features) and D (percentage of good features) for each experimental group. Measures A and D increase by almost 100% for both primes versus the control, and measure C increases by 269% for the collage versus control condition. ANOVAs of the collage and control groups show statistically significant difference at the 0.05 level for all quantity measures (measure A: 6.6 vs. 3.3, p<0.05; measure C: 4.8 vs. 1.3, p<0.05; measure D: 70% vs. 39%, p<0.05). The questionnaire prime significantly increases measure C compared with the control group (2.9 vs. 1.3, p<0.05), but is less effective at increasing measure C than the collage group with p-value at 0.08 (2.9 vs. 4.8, p<0.1).
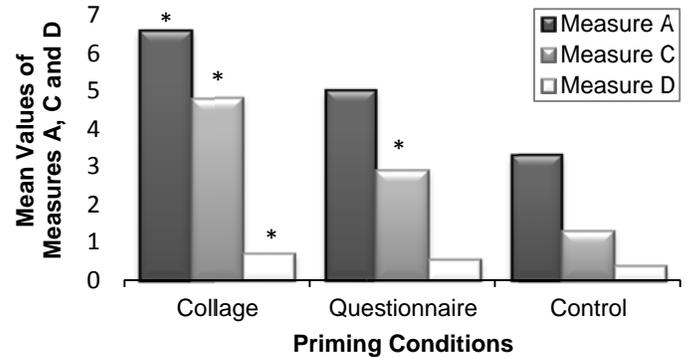

FIGURE 5. Effect of primes on measures A, C and D ('*' p<0.05, compared to the control group).

Hypotheses 1b and 2b have strong support as both primes significantly increase measure C: the number of good features. In addition, the collage prime also leads to a larger number of features generated in total and increases the efficiency of good feature ideation (percentage of good features). Hypothesis 3b has marginal support, with collage prime performing only slightly better than the questionnaire prime on measure C at the 0.1 significance level.

There is a high correlation between the number of features and the number of good features with a Pearson correlation coefficient of 0.88, as shown in Fig. 6. This result is consistent with the findings that quantity increases quality [53, 72]. In this context, quantity facilitates better communication of sustainability.
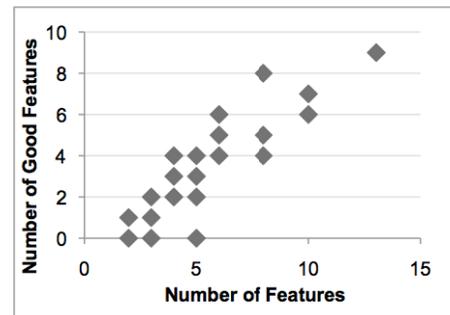

FIGURE 6. A larger number of product features results in more good features.

7 DESIGN PHASE 1 RESULTS

Recall that Design Phase 1 of the experiment subjects were asked to design a toaster and not given any instruction related to communicating sustainability. Phase 1 generated 192 features in total, 43% from the collage group, 32% from the questionnaire group, and 25% from the control group. ANOVA of the data from Design Phase 1 shows that measures A and C are significantly higher in the collage group than in the control group. Measure A, the number of features generated was: 8.2 vs. 4.8, $p<0.05$; Measure C, the number of good features was: 0.9 vs. 0.3, $p<0.05$). Hypothesis 2b is accepted, demonstrating that the collage prime improves the quantity of features generated and also guides designers to think about communicating sustainability through design, even without explicit instruction on such purpose. The other hypotheses were not accepted with the Design Phase 1 data.
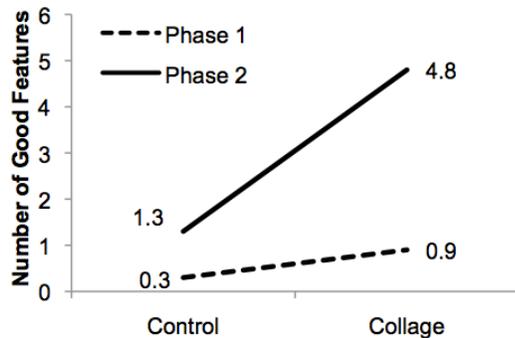

FIGURE 7. Comparison of the collage prime effect on two phases.

8 DISCUSSION

The experiment supports the research proposition: priming can be used to improve design ideation for sustainability communication. Exposing designers to a prime that causes them to think about sensory perceptions and sustainability did, in fact, help them to generate design features that communicate sustainability to the customer. An important condition to this finding is that this communication of sustainability was rated by judges (that did have excellent inter-rater reliability). The next step in this research is to test some of the generated design features with actual customers, to see if their consideration of sustainability is indeed triggered by including these design features in products (toasters).

As predicted in Hypotheses 1 and 2, a questionnaire or collage prime that heightens sensory perceptions improves the ideation process for design features that trigger customers' sustainability considerations, in terms of higher quantity and higher level of sustainability trigger.

Our findings also demonstrated the importance of the starting point or the initial condition for the conceptual design process [46]. When a design problem can be solved in a variety of ways, the mindset that is primed is cognitively most accessible and most likely to guide and affect the design results [31]. Both primes activated the notion of sustainability communication and an associated world of cognitions,

attitudes, values, norms, procedures, techniques, and feelings, thereby increasing designers' propensity to think of and incorporate such features into their designs. Further, both primes pushed designers to think as customers. One subject in the collage group said, "I was more thinking about how customers think about my design, can they understand it or like it… " It is crucial to consider how customers perceive the products when developing new products.

The collage prime has slightly stronger effect than questionnaire prime in terms of number of good features generated, although the statistical analysis only shows marginal significance. In the experiment, subjects primed with the collage activity interacted with images of products, made more judgments, and spent more time (most of them used 10 minutes) in the prime; while those primed with the questionnaire simply answered two questions and spent less time on this part (most of them used 5~6 minutes). Subjects in the collage prime condition were more deeply involved than those in the questionnaire prime. The level of involvement might also contribute to the strength of the prime effect for our specific design objective.

Despite being less engaging, the questionnaire prime does achieve significant improvements. This suggests that priming designers does not necessarily need to be a deep and active experience. This is good news for designers—they do not have to do a very involved activity to see improvement. This is also of note to researchers, as these findings suggest exploring at least two prime conditions, a deep condition and a less-involved condition (such as answering a questionnaire) in a study. With this approach, designers can be sure the lengths that subjects must go to to achieve a primed state are beneficial.

Another implication from our study is that for a targeted design problem, explicit instruction on the design objective increases the measureable effect of the prime.. Instructed to create design features for a toaster in Design Phase 1, which only included general design task instruction, subjects were significantly more likely to generate features to communicate sustainability in the collage group than in the control group. However, the magnitude of this significant effect is relatively small when compared to that of Design Phase 2, which included explicit instruction. Further the output of Design Phase 2 allowed for acceptance of more of the research hypotheses. One possible explanation could be that without clear objectives, there are too many competing directions asking for attention. Hence, we expect even stronger priming effect if subjects started the design activity directly from Design Phase 2 after priming.

9 CONLUSIONS AND FUTURE WORK

Results shown by this study are a promising indicator that primes can be targeted to increase designs for sustainability communication in ideation, beyond increasing the sheer number and novelty of features. Specifically, priming designers with heightened sensory perceptions in the form of a simple questionnaire or a collage activity significantly increases the number and effectiveness of design features judged to trigger

sustainability considerations. Furthermore, the collage prime is tested to be a little better than the questionnaire prime in facilitating design ideations of sustainability communication.

The work is different from past priming studies in that the improvement in quality is geared in a new direction, stimulating designers to design features that communicate sustainability to the customer. Past priming studies have focused on improving or heightening designer's already key skills, such as uncovering new user needs, moving past fixation, and improving the ability of design features generated to satisfy engineering design goals. The proposed approach benefits ideation in a different area. For example, if a number of life-cycle analysis (LCA) engineers were primed as proposed in this work, they may not produce higher-quality LCA results from the products they designed. Instead, they might refocus their design activities on communicating the sustainability of the products. The ideas that they generate might actually be worse in terms of their traditional quality metrics of LCA, but potentially more likely to be trusted and accepted by the customer.

The positive effect of priming on sustainability communication presents a host of research opportunities. The results are contingent on the rating effectiveness of the two judges. Although the judges differ in work experience, educational background, and gender, the results would be better validated with additional ratings from consumers. This is an area of planned future research in which we will administer an online survey and collect ratings from Amazon Turk. Another direction of future research will investigate if other primes, previously documented as increasing creativity and number of design features, also help designers communicate sustainability, to confirm that our method offers a distinct advantage. We are conducting experiments to compare our priming technique to benchmark techniques listed in the literature review.

We also plan to spot-check some of the highest-rated features from this experiment and confirm that they trigger customers to think about sustainability with built prototypes. These prototypes will be used to investigate how engineering design facilitates customer decision making regarding sustainability and contribute to bridging the gap between engineering and marketing regarding sustainable products.

In addition to this planned future work, reviewers insightfully noted that: a generalized study of a variety of target products and subjects with different levels of design experience would further test our hypotheses; the effect of varying exposure time for the primes could provide useful insight to their effectiveness; and a study of primes used in group design could address the risk of unintentionally priming "groupthink".

Preparing the method for use by "real-world" designers also presents new research challenges: in this study, the subjects were not intentionally informed of the purpose of the primes. However, a designer in practice would certainly be cognizant of the role of the priming activity. Therefore, future work could investigate how implicit/explicit knowledge of the purpose of priming affects results.

The research here demonstrates that primes can be targeted to extend the skills of designers out of their comfort zone. This should be useful in academic situations, where students are frequently asked to extend their design skills beyond their limited training. Primes can be created to address specific challenges found in academic design problems, such as customer-centered failure analysis, form design, and teamwork challenges. It also suggests applications of targeted priming to industry, in which engineering designers could "wear more hats" or act in a more interdisciplinary fashion with appropriate priming. Priming could potentially be used to give designers from different perspectives or backgrounds a shared mindset or complimentary additional skills.

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