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Designing features that influence decisions about sustainable products

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Designing features that influence decisions about sustainable products

by

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A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Mechanical Engineering

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Iowa State University
Ames, Iowa
2013

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NOMENCLATURE

AOI	Area Of Interest
AMT	Amazon Mechanical Turk
CASEMAP	Computer-Assisted Self-Explication of Multi-Attributed Preferences
CBC	Choice Based Conjoint
DBD	Decision-Based Design
EBA	Elimination By Aspect
FC%	Percentage Fixation Count
FIM	Function Impact Matrix
FT%	Percentage Fixation Time
IRR	Inter-Rater Reliability
LCA	Life Cycle Assessment
LiDS	Life-cycle Design Strategies
MAUT	Multi-Attribute Utility Theory
QFD	Quality Function Deployment
ST	Sustainability-Triggering
UDE	Unstructured Direct Elicitation
WH	Watts-Hours
WTP	Willingness To Pay

ACKNOWLEDGEMENTS

First, I would like to thank my advisor Dr. Erin MacDonald, for her rigorous research attitude, ability to motivate students, and friendly environment she always created. Thank you for letting me be a part of your IRIS design lab, where I felt at home, learned knowledge across so many interesting disciplines, and had opportunity to communicate with people from different areas. Thank you for teaching me the construct of a rigorous quantitative research, from basic hypothesis to details of experiment design, and how to tell a compelling story in papers and presentations. Thank you for the generous help with my research as well as personal and professional life. I was deeply touched by your kind mock interviews, the emails you sent to many of your connections to seek for help when I was in a need... It encouraged me to know you are such a great mentor, not only in research. Your generosity and encouragement made these years the most eye-opening period of my life.

I have been extremely fortunate to have four scholars of high caliber as my committee members: Dr. Robert Stephenson, Dr. Judy Vance, Dr. Song Zhang, and Dr. Seda Yilmaz. I want to especially thank for your support, time, and insightful suggestions throughout my research. Thank you, Dr. Stephenson, for teaching me clear thinking on experiment design and data analysis. Thank you, Dr. Vance, for your valuable suggestions and kind help. I have been touched by your open mindedness and down-to-earth personality. Thank you, Dr. Zhang, your insatiable passion for learning and conducting research sets a role model for me as a research scientist. Many thanks to Dr. Yilmaz, for all of your encouragement, insight, and thought-provoking questions. I

The unconditional love and encouragement provided by my family and Yanan are the invaluable support for me during the hard and easy times; thank you for always being there.

ABSTRACT

Engineers make continuous effort to improve the sustainability of products, such as using sophisticated manufacturing approaches, conducting rigorous sustainability analysis, and including materials that decrease environmental impact. However, thoughtful sustainability efforts are sometimes hidden from customers, which are wasted sales features if customers do not know or value them. As green marketing messages are not always trusted, another approach is to communicate sustainability to the customer through the product's visible features. This research proposes and tests a newly-created design technique that helps product designers communicate sustainability in the products they design and, in turn, helps customers to think about sustainability during purchase decisions. Three empirical studies, with designers and potential customers as subjects, are conducted.

Study 1 in Chapter 3 proposes and tests a new design technique that uses psychological priming to help designers generate product features that communicate sustainability to the customer, termed as sustainability-triggering, or *ST features*. Priming is a psychological experimental technique that uses an artifact, exposure, or experience to stimulate cognitive accessibility of specific mental content. Here, priming is used prior to a design task. The author investigates primes of sensory-and-sustainability-heightening activities, and compares these to existing primes and a control condition. The test primes are proven to be comparatively more effective in helping designers generate product features that communicate sustainability, as judged by both experts and customers.

Study 2 in Chapter 4 and Study 3 in Chapter 5 investigate customer evaluation of sustainable products. A selection of ST features generated from the priming-designer experiment were built into realistic plastic prototypes. Subjects participated in test versus control purchase experiments, in which some "customers" saw a subset of products with ST features during purchasing tasks and some did not. Study 2 demonstrates that exposure to ST features significantly increases thoughts of purchase criteria possibly or definitely related to sustainability. Study 3 investigates the purchase-related decisions with exposure to ST features. Analyzed at an aggregate level, subjects were more likely to choose the more sustainable product, though it was only significant at the $p<0.1$ level; and the presence of ST features significantly increased importance of sustainability in making purchase decisions, and motivated them to seek additional information on sustainability and devote more attention to it. Disaggregated results reveal that the ST features had a more significant influence on some choices than others.

To decrease the environmental footprint of a product to the greatest extent possible, it is necessary to help people change their product purchase and usage habits: a sustainable product that is not purchased does not help the environment. It is hoped that this research will facilitate the design of sustainable products that increase purchases and decrease environmental impact.

1. INTRODUCTION

1.1. Motivation

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 (see a short review in Section 2.3), 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 do not always succeed in the market [10-12]. Yet, consumer survey research suggests that customers prefer sustainable products and are even willing to pay a premium in some cases. For example, in [13], fifty percent of subjects responded that they are willing to pay extra for products produced with renewable energy. In Bask et al.'s mobile phone study [14], some customers are willing to pay ten percent higher than the current price for sustainable features, such as upgradable software or hardware and minimum amount of hazardous materials. It is possible that sustainability-related terms, such as "recycle" and "renewable energy" are explicitly mentioned in laboratory and survey research, which trigger subjects to think about sustainability.

However, in common purchase situations, it is unlikely that the majority of customers are naturally thinking about sustainability issues, as documented in marketing studies that separate the market into active "green" consumers (a minority of customers) and other groups [15]. The construction of preference [16] implies that the decision context plays a crucial role in whether or not the customer prioritizes or even considers sustainability during a purchase decision; sustainable preferences are context-specific, and can be activated by contextual cues. This idea is demonstrated to have market-changing potential by MacDonald et al. [17]. They found that activating customer preference for sustainable design, in this case recycled content in paper towels, potentially leads to substantially increased profitability and decreased GHG emissions.

Product sustainability is a relatively new and complex customer consideration, and thus the construction of sustainable preferences [16] is susceptible to biases and heuristics that are not always helpful [18]. It is often difficult for customers to trust, or even ascertain, the extent to which a firm's products and processes are sustainable [11, 19]. Some sustainable endeavors in product design are not readily apparent to customers during product evaluation. For example, customers cannot tell on first-investigation of a product that wind energy was used to power its manufacturing facilities. They also cannot see the use of biodegradable materials for internal parts. Design for remanufacturability (e.g., [20-22]) is useful at the end-of-life of a product, but is again often hidden within the product's internal design. Integration of human health assessment in material selections [23] is appreciated by customers, but something about

the product must motivate the customer to seek out this information about the product, because it cannot be learned in a cursory evaluation.

A number of firms communicate 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 forms of promotion [24]. However, firms face challenges with product labeling and claims, such as limited and competing uses of physical space on a product's packaging and difficulty in language determination [24]. More importantly, on-product messaging may not be effective because "people are busy, and may not be paying attention" [24]. With the public's growing concerns of "greenwashing," superficial environmentally friendly actions with a greater purpose of profit [25], customers might also not trust the on-product messaging [26]. For these reasons, some firms avoid on-product messaging altogether [24].

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 or traditional marketing messages. The definition of sustainability used throughout this dissertation is similar to that used by MacDonald and the author in [18], and refers to the intentional and methodical design and manufacture of a product to decrease environmental impact versus its competitors, using a scientifically based environmental impact assessment tool. This dissertation focuses on communicating reductions in environmental impact, as environmental impact is an important focus for engineers but difficult to communicate to the customer; refer to examples in paragraph

three of Section 1.1. In previous related work, MacDonald et al. found that for a product to be successful, it must not only have good engineering design, but also be preferred by customers in the market [27]. Addressing the customer-product relationship includes the fields of study of emotional design and product semantics. In [28], sustainable product semantics are developed; for example, people associate "metal," "simple," and "durable" with a sustainable product. Reid et al. [29] provide engineering methods that quantify sustainable preferences associated with a product's form. Srivastava and Shu [30] present an affordance transfer method for redesigning products to encourage pro-environmental behaviors. The recent work by MacDonald and the author [18] 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 [31] in their early design concepts [32].

To increase the priority of sustainability in customer preference, and the communication of sustainability hidden within a product, the dissertation aims to create and validate a new design technique that helps product designers communicate sustainability via product design, in turn, as depicted in Figure 1.1, helps customers to think about sustainability during purchase decisions. The ultimate goal is to encourage customers to look for hidden information on actual sustainability, and have this information affect their purchase decisions.
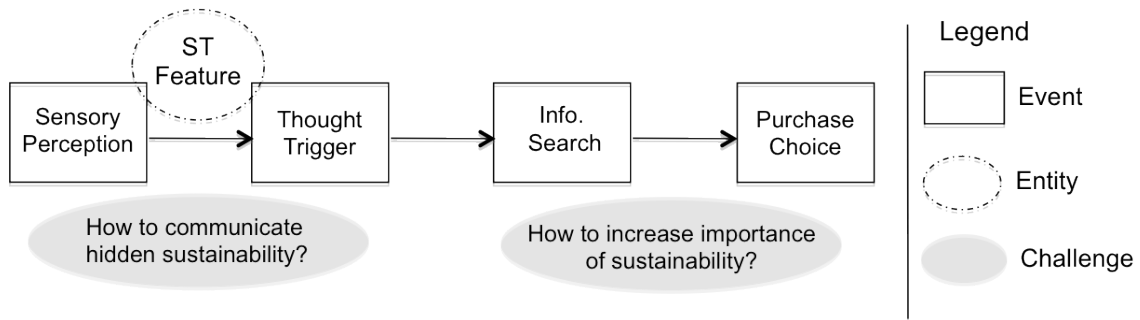
Figure 1.1. Theoretical ST (sustainability-triggering) effect on customer decision making regarding sustainable products in addressing research challenges.

1.2. Contributions

The contributions of this work address the challenges of increasing the importance of sustainability in customer preference and communicating sustainability hidden within a product. Product design is used as a means to address these challenges. The first research contribution is a design technique that uses priming to give a targeted enhancement to designer's skills, namely designing features that communicate sustainability (Study 1, Chapter 3). The second contribution (Study 2, Chapter 4) demonstrates that the inclusion of these "communication features" in products can cause the customers to seek different information about products, particularly information pertaining to sustainability. To test this, Study 2 uses a preference-elicitation method new to engineering community and combines it with physical prototypes in a novel way. The third contribution (Study 3, Chapter 5) is a test of the full power of these communication features in product design, and weakly indicates that they cause customers to make different choices. Study 3 also illustrates a wide variety of survey tools that thoroughly investigate the power of the communication features. Overall, the work shows that product features designed with a targeted communication purpose can

shape that customer's decision context, and uses a number of human-subject experimental approaches new to the engineering design community.

First, a design technique that uses priming to enhance the designer's ability to visually communicate sustainability is presented in Study 1. 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 [33], novel features [34, 35], relevant features [36], and address latent customer needs [33]; refer to Section 2.4.2 for a review of studies. The design technique presented in this research uses priming to help designers to generate design features that trigger customers to think about sustainability at the buying point. We call these features "sustainability-triggering" (ST) features. Feature is defined as a product attribute or characteristic that is visible to the customer when evaluating the product. Note that ST features may not be sustainable themselves. The underlying hypothesis, which will be carried into the follow-up studies, is that ST features inspire or cue customers to investigate real product sustainability, which may not be visible. It is sometimes referred as "communicating sustainability" for the purpose of brevity. The "help" that designers receive comes in the form of a priming exercise. The ability to communicate is related to perceptions (sight, sound, touch, smell, taste). Therefore the author tests priming stimuli that focus on sensory perceptions and sustainability. Two stimuli are proposed: in the form of a simple questionnaire or a collage activity. Results from Study 1 indicate that the priming technique can increase sustainability communication via features generated in early-stage product design. It

merits the further investigation of priming as an effective yet underutilized design technique to give a targeted enhancement to designer's skills.

Then, to further validate the design method and investigate customer thinking, ST features generated from Study 1, priming designer study, are applied in Study 2 to test the relationship between product design and customer thinking with physical prototypes. A selection of ST features were prototyped. Subjects participated in a test vs. control purchase experiment, in which some "customers" saw a subset of toasters with ST features during purchasing tasks and some did not. First, subjects selected a subset of toasters for purchase and then chose one from that set for a final purchase, - a consider-then-choose approach. Next, they wrote an email with instructions on how to select a toaster to a hypothetical purchasing agent, -an unstructured direct-elicitation (UDE) approach. Finally, they answered interview questions and rated/ranked toasters. Refer to Section 2.5.3 for the approaches used in this study. The coded qualitative data demonstrated that exposure to ST features significantly triggered the possible use of sustainability as a purchase criterion. The features were tested to successfully lead customers to consider sustainability at the buying point. Study 2 indicates that the inclusion of specifically-designed features in products can change decision context, and cause the customers to seek different information about the product. This is the first time a consider-then-choose approach and an unstructured direct-elicitation approach have been used in engineering design research. It is also the first time physical prototypes have been used in unstructured direct-elicitation in academic research.

Study 3 tests the robustness of ST features generated from the priming designer study in a more realistic situation, where a bunch of product attributes were provided, together with physical prototypes, including attributes that indicate sustainability of a toaster: average energy usage and shipping method. Various approaches were used to study subjects' decisions and decision making process, such as make a choice, indicate willingness to pay and trust, rank the attributes to know. Their areas of focus while reviewing stimuli were also captured with eye-tracking technique. The results showed that presence of ST features stimulated customers to care about the information on sustainability and increased possibility of choosing relatively sustainable products. Study 3 weakly indicates that (1) communication features can cause customers to evaluate related product attributes and result in different choices; and (2) engineers can do more to promote the success of their products by studying the intersection of people's behaviors and design. Studies 2 and 3 show that specially-designed communication features can shape customers' decision context, and shed light on usefulness of human-subject experimental approaches in engineering design research.

Contributions accomplished by this dissertation regarding the original challenges as related to sustainable products are summarized in Figure 1.2: presenting a priming design technique with a targeted enhancement on sustainability-communication, demonstrating the effect of communication features in causing customers to seek related information, and leading them to evaluate hidden attributes on sustainability and altering purchase choices. Broadly speaking, the research presented in this dissertation will help designers understand customer choices from a new perspective, and treat customers not

as completely rational decision makers with high cognitive ability at any circumstances, but as more realistic human beings, whose decisions are highly context-dependent. Furthermore, the priming techniques tested in this research could be a start point for researching on design methods to facilitate design of sustainable products that could translate into increased purchases and decreased environmental impact. Coordinating with policy makers, marketing researchers, engineering designers will also contribute on achieving positive changes in individual behaviors.
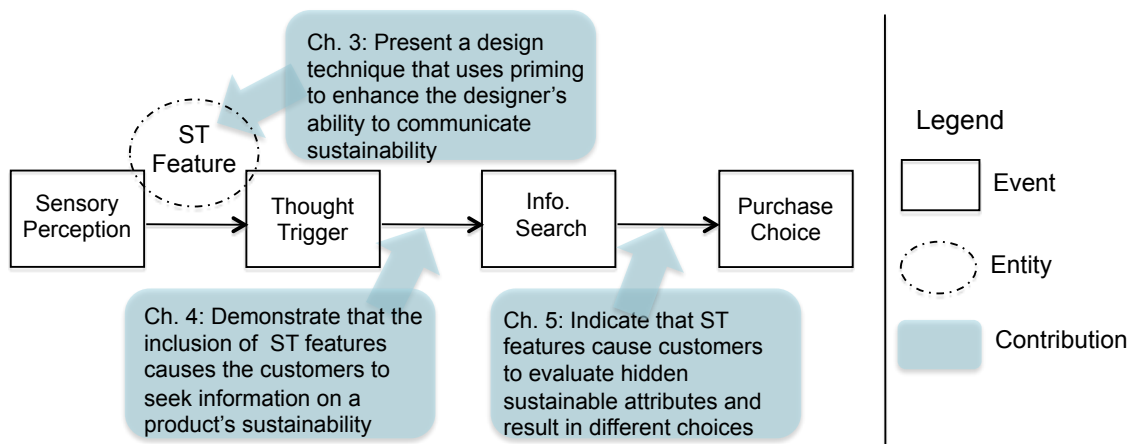
Figure 1.2. Contributions accomplished regarding the original challenges as related to sustainable products.

The document is organized as follows: Chapter 2 provides a literature review on findings from a number of disciplines as they are related to the early stage design of sustainable products. A priming design technique that designers can use to generate design features that facilitate customer decision making regarding sustainable products is detailed in Chapter 3. Chapters 4 and 5 depict two follow-up experiments to validate the features generated from the priming designer study, to test if ST features could trigger customers to think about sustainability with physical prototypes, and thus increase

sustainability considerations and even choices. Final conclusions and open questions are

discussed in Chapter 6.

2.   RELATED LITERATURE REVIEW

2.1. Introduction

The work described within this dissertation crosses disciplinary lines of engineering, psychology and marketing. This chapter provides related literatures from these areas, with the structure organized as follows:

The first three sections introduce literatures on design research, including creative design methods for conceptual phase in Section 2.2, commonly used sustainable design methods in Section 2.3. and psychological priming and its applications in design in Section 2.4. These three areas discussed do not have distinct boundaries, therefore one method mentioned in one section might be also mentioned in another. Section 2.5 reviews construction of preferences, customer decision-making models, and experimental approaches to study decision processes, which provides a foundation for readers to understand why the author begins the research from accommodating construction of presences.

2.2. Creative Design Methods for Early Conceptual Phase

Many methods are available to aid creative design in early conceptual design phase, and have been used successfully to assist with producing a range of new ideas for solutions. Formal conceptual design methods are broadly classified into two categories [37]: (1) intuitive methods, such as brainstorming [38], checklist, C-Sketch [39], and storyboarding; and (2) logical methods, such as history-based method TRIZ, and analytical method design-by-analogy [40]. New customer-centered methods have

emerged in the engineering design literature that ensure products' user-friendliness and market success, like lead users [41], empathic design [42], and empathic lead users [33]. Emotional design, product semantics, and affordance also fall into this category, as discussed in Section 1.1, Paragraph 6. The priming-designer technique proposed in this work enriches customer-centered design methods, with a target on generating communication features. For a review of conceptual design methods see [37, 43, 44].

In intuitive methods, brainstorming is the easiest one to develop and generate creative ideas. It encourages free idea flow without any criticism, but is limited to the experience of the attendees [38]. Checklist uses an established set of prompts -words or other stimuli, enabling idea generation to reach beyond a designer's normal mental repertoire [44]. The principle behind it is similar to the priming designer methods discussed in Section 2.4.2, -explore some useful associations. The difference is that designers are aware of the purpose of these stimuli while using checklist. Method 6-3-5 and C-Sketch [39] guide designers to generate ideas progressively by repeating several steps. With Method 6-3-5, each member of a six-person group writes down three ideas that are passed around, every member spending five minutes improving ideas proposed by others [44]. Collaborative Sketching (C-Sketch) extends Method 6-3-5 by restricting solution expressions to sketches and allowing adjustment on the number of designers and the time allocated for each designer to work on a sketch [39]. Storyboarding asks designers to conceive some characters and their activities in a scenario and create storytelling by sketching images in a sequential order. It is helpful in organizing ideas in some meaningful way.

Logical methods involve systematic analysis of the problem in solution-finding process [37]. The theory of solving inventive problems known by the Russian acronym TRIZ is an example of this class of methods [45]. It summarizes principles from global patents, recordings of documented inventions and intellectual property, and provides tools for solving technical problems of varying complexities and promote people to think out of box [45]. Analytical methods use much logical analysis, which map knowledge from one situation to another through a supporting system of relations or representations between situations [46]. For example, by analogizing memory and logical thinking process in human brain, artificial intelligence is created. The WordTree Design-by-analogy method helps designers to identify potential analogies and analogous domains which can be applied in a latter idea generation session. It takes the key functions or customer needs of a design problem as "problem descriptors", and systematically represents them through the intuitive knowledge of a designer until analogies are found [47]. This method is also discussed in Section 2.4.2 as an application of priming in design.

Customer-centered design methods are increasingly indispensible due to its value in enhancing market success of a design. Lead user is one example in this category. It identifies users who have advanced knowledge about product and usage, and analyzes their needs data to predict new products [41]. Difficulty in identifying lead users limits its application. In empathic design method, designers observe customers in their own environment while customers are using products [42]. This method is favored because of the potential to identify difficulties that customers may not even recognize and certainly

fail to mention in traditional interviews or focus groups [43]. One drawback is that this method relies heavily on the designer's powers of observation and innovation. Empathic lead user method overcomes difficulties yielded by the former two customer-centered methods, in terms of not relying on lead users and powers' of observation. It transforms normal users or designers into lead users by experiencing the product in radically new ways, via extraordinary user experiences [33], which is another application of priming in design. The extreme experience drives users to think out of box. Designing extraordinary user experience requires some effort.

2.3. Sustainable Design Methods

Product design has a tremendous impact on global sustainability. Early design decisions such as material selection, structure, and function effect the product's whole life cycle—for a review see [1]. Designers are increasingly involved in design for sustainability. A classification of sustainable design methods commonly used is shown in Figure 2.1.

Sustainable Design Methods

Design guidelines and checklists	Life-cycle assessment	Relative assessment	QFD-based methods	Methods to resolve functionality-environmental contradictions
		LiDS wheel	Function impact matrix	
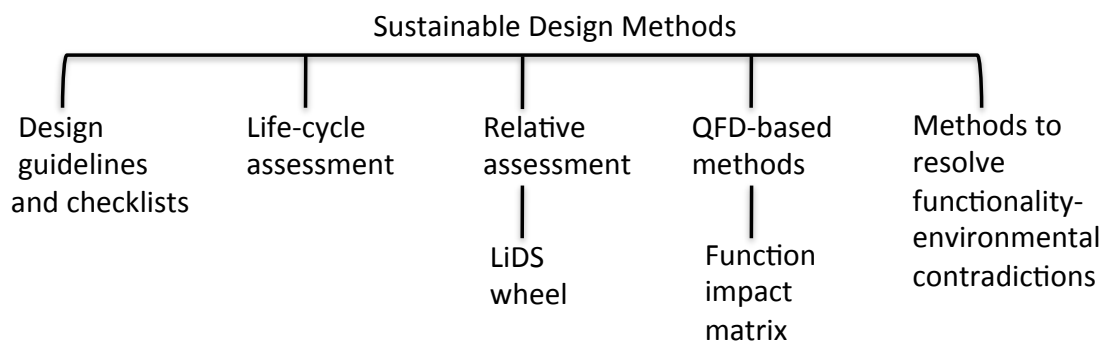
Figure 2.1. Classification of sustainable design methods.

Design guidelines and checklists [3, 4] are among the most easy-to-use design methods for considering sustainability issues [9]. They are especially developed for early design phase, which use a set of items to assess a product from the environmental perspective over its entire life cycle, such as investing in better materials, surface treatments or structural arrangements to protect products from dirt, corrosion and wear, using few, simple, recycled, not blended materials, using as few joining elements as possible, and so on [3].

Life Cycle Assessment (LCA) is the most comprehensive and detailed quantitative method available for evaluating the absolute environmental profile of a product or a process. It has been developed to identify environmental consequences of a product or process through each of its life cycle stages: from cradle to grave or from cradle to cradle. However LCA requires product information, is costly, time-consuming, and not design-oriented [1].

While LCA tools are suitable to assess absolute environmental impact of a product or a process, Life-cycle Design Strategies (LiDS) Wheel [5] is a less-consuming representative example of a relative improvement assessment. It asks designers to assess their current state with respect to eight life-cycle strategies: (1) new concept development, (2) low impact materials, (3) dematerialization, (4) cleaner production, (5) distribution, (6) use phase impact, (7) initial lifetime, and (8) end of life system [5]. Design guidelines are incorporated as part of the eight strategies in the wheel. Designers can map their current efforts in the spider diagram which highlights where their weak

areas are. Once improvements have been made, a new assessment can be mapped and overlaid on top of the previous one, thus showing relative improvements.

Some sustainable design methods expand traditional quality function deployment (QFD) by introducing the environmental impacts of the product into QFD as new customer needs, such as House of Ecology [6], QFD for Environment [48], and Function Impact Matrix (FIM) [7, 49]. However, they are not sufficient to handle trade-offs when more than one environmental impact category is considered, as well as trade-offs between environmental impact and product function.

Fitzgerald offers a conceptual design method that helps designers to resolve functionality-environmental contradictions in a product's design [8]. It summarizes examples of successfully designed products that simultaneously improve pairs of environmental and functionality dimensions, which serve as stimuli to inspire designers using analogy to identify strategies to overcome specific contradictions. This method does not attempt to address a product's overall sustainability, but focuses on the specific, practical and critical task of resolving a conflict between an aspect of product functionality and an environmental impact.

The sustainable design methods discussed above are all helpful to develop products with lower environmental impact in different ways. However, few methods consider customers in the design process, even though customers' perceptions and preferences play an important role in the market success of a product. MacDonald et al. [27] indicate that, for a product to be successful, it must not only have good engineering design, but be preferred by customers in the market. Preference for sustainability can

play an important role in dictating market choices, but only if it is active during decisions. In an experimental context of vehicle silhouette design, Reid et al. [29] find that visual cues affect the perception of sustainability. Improving market success of a sustainable product calls for extending design methods to include customer perceptions/preferences.

2.4. Priming and Its Applications in Design

2.4.1. Overview of Priming

Psychologists use the term "priming" to describe what occurs in the mind when exposure to some stimulus increases the accessibility of associated information or processes for a later activity. A priming stimulus is an artifact, exposure, or experience that stimulates increased cognitive accessibility of mental content [47, 50]. For example, it has been validated that (1) people behave more competitively when seeing a leather briefcase placed on the desk in an office [51]; (2) people are more likely to work together in resource-management games after reading cooperation-related words [52]; (3) people are able to overcome automatic stereotypes and associations when primed to think creatively [53]; and (4) people give alternate solutions more consideration in problem solving when they experience a scenario in which an alternative outcome almost occurs [54]. The effects of priming can be salient and long-lasting, not only on simple recognition tasks [55, 56], but also on decision making [50], behavioral change [57], creative thinking [53], and problem solving [54].

Sensory priming, the activating of a set of perception orientations via specific tasks, influences higher social cognitive processing. Ackerman et al. [58] 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 [59]. For instance, water seems to taste better from a firm bottle than from a flimsy bottle [59].

For a comprehensive review of priming studies in social psychology, see [47], which addresses priming of, for example, trait, expectancy, mindset, goal, behavior, and affect. Custers and Aarts discuss goal priming in Science and analyze the mechanism for how this may happen [57]. The following section discusses the applications of priming in designers' ideation processes.

2.4.2. Applications of Priming Related to Design

The designer's frame-of-mind during the conceptual design process has an important effect on the outcome of this process—see, for example, the issue of design fixation [60, 61]. 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 principle of priming (e.g., [62-64]), including role-playing (e.g., [65, 66]), questioning (e.g., [67, 68]), and improvisation (e.g., [68, 69])—although not all references mention priming explicitly. In the random stimuli technique [64], designers are presented with a word, a picture, or a heuristic, and are expected to explore some useful and unusual associations [44, 64]. Role-playing prompts designers to act out scenarios, helping them find insights into target customers that may be difficult to access directly [66]. 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 [67]. 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 [69]. This activity encourages a participant to be more responsive and appreciative of others' contributions, and to "let go" of any particular narratives forming in his or her head. Herring et al. [70] conducted a study that understands and compares how designers use examples to support the creative design process—these examples may be considered a priming stimulus. Shneiderman recommended ways in which technology can enhance creativity and encourages the development of creativity support tools through human-computer interaction; again, the technology likely plays the role of an implicit or explicit priming stimulus [71]. Fu et al. [72] found that initial events, such as exposure to a good or poor example in terms of cost, manufacturing, sustainability, and resources, can affect team convergence, and also the quality of the final design solution produced by the team.

The empirical lab experiments discussed below [33-36] demonstrate that priming can be used to enhance the design process in ideation, namely conceptual priming, sensory priming, affect priming, and mindset priming. The first three—concept priming [36], empathic lead user [33], and computational affective priming [34]—intentionally use a priming stimulus. In the WordTree method [35], 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 twelve minutes before a creative sketching task [36]. The results show that subjects who unscramble mildly hostile sentences prior to sketching include more hostile features, like features of spikes and claws, in their novel creations than 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 [47].

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 [33], 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. This priming stimulus is included as a condition in the experiment in Chapter 3 in order to benchmark the effectiveness of the proposed design technique.

Lewis et al. [34] studied 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 them to practice drawing with an image of a laughing baby as a background before they start, 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. This priming stimulus is also included as a condition in the experiment in Chapter 3 in order to benchmark the effectiveness of the proposed design technique.

The WordTree method proposed by Linsey et al. [35] is based on keywords. Designers were 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 were identified and applied in a group idea generation. When designers were working on the WordTree task, not only specific contents but also relevant cognitive procedures became activated. Effects on subsequent design tasks might then be driven by these procedures themselves as well as specific content that is primed [47].

2.5. Customer Decision-Making

2.5.1 Construction of Preferences

The notion of bounded rationality [73] 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 [74]. 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, 74]. For instance, preference reversal phenomena systematically exist when the same problem is presented in different ways [75, 76]. Because of the constructive nature of preference, the potential for influencing choice is very significant.

An example of how the choice environment can influence revealed preferences is contained in [50] by Mandel and Johnson. In their study, groups of customers went shopping for hypothetical products in online shopping environments that were identical except for the background pictures and colors of the Web page. In an experimental task of a sofa purchase, they found 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. This study demonstrates that even wallpaper, a seemingly inconsequential element of a computer-based environment, can influence choice.

Haubl and Murray [77] examined an "inclusion effect" in a controlled agent-assisted online shopping experiment. They varied attributes included in a recommendation agent to compare products, and found 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 [50] and Haubl and Murray [77], who investigated environment effect on choice, Nedungadi [78] focused 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.

Above empirical studies show the constructive nature of preferences and highlight the importance of decision context. More generally, Slovic [74] summarized construction of preferences:

"...Construction strategies include anchoring and adjustment, relying on the prominent dimension, eliminating common elements, discarding nonessential differences, adding new attributes into the problem frame in order to bolster one alternative, or otherwise restructuring the decision problem to create dominance and thus reduce conflict and indecision. As a result of these mental gymnastics, decision-making is a highly contingent form of information processing, sensitive to task complexity, time pressure, response mode, framing, reference points, and numerous other contextual factors."

2.5.2. Established Models of Customer Decision-making

In order to understand the importance of customer preference in engineering design, it is necessary to understand the many ways customer preference is modeled,

namely the different models of customer decision-making. An important distinction among the models is the degree to which they are compensatory. A compensatory model requires explicit trade-offs among attributes. For example, how much more one is willing to pay for a longer rather than standard warranty in a car involves making an explicit trade-off between warranty and price. Unlike compensatory models, in non-compensatory models, a good value on one attribute cannot make up for a poor value on another [79].

Researchers identify two basic types of compensatory models, weighted adding and simple adding [80]. A weighted adding rule consists of considering one alternative at a time, examining each of the attributes for that option, multiplying each attribute's subjective value with its importance weight, and summing these products across all of the attributes to obtain an overall value for an option—multi-attribute utility theory (MAUT) is a formalized model category of such a rule. Options with higher utility are preferred [79]. The simple adding rule is a special case of weighted adding if unit weights are assumed.

There is a rich set of non-compensatory models identified in the literature. These models endorse bounded rationality, the notion that decision makers have limitations on their capacity for processing information [73]. A bounded rational decision maker attempts to attain some satisfactory level of achievement [73]. The most commonly studied non-compensatory models are lexicographic, elimination-by-aspect (EBA), conjunctive, disjunctive, and subset conjunctive rules. The lexicographic rule plays a "winner takes all" game with dimensions, inferring which of two alternatives has a

higher criterion value by searching sequentially through attributes in the order of their importance until one discriminating attribute is found [80]. Elimination-by-aspects (EBA) eliminates options that do not meet a minimum cutoff value for the most important attribute. This elimination process is repeated for the second most important attribute, with processing continuing until a single alternative remains [81]. Whereas the two former rules involve processing by attribute, the conjunctive rule entails processing by alternative. As with elimination-by-aspects procedure, the decision maker establishes cutoffs (minimal values) for each attribute. An alternative that meets all of the cutoffs is favored, but failure to meet any one cutoff leads to rejection of the alternative or resetting of the cutoffs [80]. If a customer accepts alternatives that satisfy at least one criterion, then a disjunctive rule could be used to model this process [82], for instance, consider any high MPG vehicles. In subset conjunctive rules, customers consider the products if they satisfy any set of S must-have or must-not-have criteria [82]. It generalizes disjunctive (S>=1) and conjunctive (S=number of attributes) rules.

Compensatory and non-compensatory decision making rules are combined to model customer decisions, typically a consider-then-choose process, which posits that customers first identify a set of products, the consideration set, for further evaluation, and then choose from that set [83]. Due to limited cognitive ability, a typical customer only considers a few alternatives at a time rather than all when facing with many products. A consider-then-choose model [83, 84] seems more descriptive of how people actually make decisions. It is validated that 80% of the uncertainty in choice models can be explained by simply knowing the consideration set [85]. This fact drives the

expectation that identifying attributes that lead to the consideration is vital and improving considerations/ thoughts on sustainability might contribute significantly to the success of sustainable products.

2.5.3. Experimental Approaches to Reveal Customer Stated Preferences

Researchers have explored a variety of approaches to elicit customer preferences. In this review, approaches are classified as compositional or decompositional. Further approaches combine the two, but are not discussed here. In a compositional approach, preferences are investigated by recording explicitly how subjects evaluate product attributes; in a decompositional approach, a product profile is evaluated as a whole [86]. In other words, the former approach uses attribute-based evaluation, and the latter uses alternative-based evaluation.

Compositional Approaches

One of the compositional approaches elicit customer preferences by evaluations on the importance and value of each attribute. In [87], subjects were asked to rate their preference on each attribute level from 1 to 10, and then allocate a constant sum (e.g., 100) to all attributes to indicate their importance.

CASEMAP (computer-assisted self-explication of multi-attributed preferences) results in more descriptive data with narrative questions. In CASEMAP, subjects are questioned to indicate totally unacceptable attribute levels, their most- and least-preferred levels for each attribute, determine the most critical attribute, rate the importance of other attributes relative to the critical attribute, and report preferences of

different acceptable levels within each attribute [88]. Partworths for acceptable attribute levels are obtained by multiplying the importance rating and preference rating.

Ding et al. [89] explore an unstructured direct-elicitation (UDE) approach, in which subjects write an email to an agent to explain what type of products they would like to own and ask the agent to buy one for them. This approach is used by the study in Chapter 4. Except for a requirement to begin the email with "Dear friend," subjects can use any format to describe their decision criteria. In Ding's work, the "email" approach is incentive-aligned, and subjects are entered into a lottery with a chance to receive a product that closely matches the one they described (this is not done in Study 2 reported in Chapter 4) [89]. This improves accuracy and specificity. Note that before prompting subject to write an email, UDE requires some initial tasks that involve subjects thinking deeply about their decision process (e.g., CASEMAP, answer discrete choice questions, select some products from a larger set).

Another compositional approach is Web-based upgrading method, which mimics the experience of purchasing a computer from build-your-own-goods Web sites (e.g., Dell). At the beginning, each subject is endowed with a particular version of the product. The subject is allowed to upgrade it to a more desirable product configuration, one attribute at a time, and asked to state his or her willingness to pay (WTP) for each level to which he or she is interested in upgrading for that attribute [87]. A cutoff price generated randomly by the computer for each level of that attribute will determine which level is upgradable. The process is iterated until the subject decides not to upgrade it any

more. In this way, subjects only evaluate attributes and levels they are interested in and the tasks are more natural.

Decompositional Approaches

In decompositional approaches, product profiles are evaluated, typically in comparisons. In a conjoint survey, products profiles are created from combinations of different attribute levels and subjects are asked to indicate their preferences among profiles by ranking, rating, or choosing [90]. Customer preferences are estimated as a combination of the "partworths" of the attribute levels [90]. Choice-based conjoint (CBC) analysis is the most commonly-used conjoint method. To obtain accurate estimates of preferences, conjoint analysis requires a minimum number of profiles to be evaluated; this number increases exponentially as the number of attributes/levels increases and results in tremendous cognitive burden on conjoint subjects [87, 91].

The "consider-then-choose" approach first asks subjects to state their consideration sets. A consideration set is a subset of presented profiles. Hauser et al. [92] use a web page interface. Product profiles are displayed on the left side of the webpage, represented as icons. When the mouse selects a profile icon, the attributes are displayed in the middle of the screen, and subjects are asked whether or not they would consider purchasing the profile. If the "Consider" button is clicked, the product is displayed in a consideration set on the right side of the webpage. Subjects then choose a product from this set as their final choice and/or rank every product in the set. This is another approach adapted for use in Study 2, but uses real prototypes instead of a computer screen.

3.   PRIMING DESIGNERS TO COMMUNICATE SUSTAINABILITY

3.1. Introduction

Design techniques that use priming have thus far focused on generating more features, novel features, relevant features, and addressing latent customer needs, as discussed in Section 2.4.2. This chapter presents a design technique that uses priming to give a targeted enhancement to designer's skills. The design technique presented here enhances the designer's ability to communicate the sustainability of a product to the customer. The author has determined in Chapter 1 that sustainable products face a special challenge in the market because thoughtful sustainability features such as decreased energy usage, use of recycled materials, or manufacturing considerations are sometimes "hidden" from the customer. It is necessary for designers to communicate sustainability to the customer through product features that customer will identify as sustainable. The author proposes and tests a new design technique that uses psychological priming to help designers generate product features that communicate sustainability to the customer. The technique involves performing a sensory-and-sustainability-heightening activity before generating ideas for product features. The chapter presents an investigation of priming stimuli in the form of a questionnaire and a collage activity, and compare these techniques along with other existing priming-based techniques to a control condition. The new technique is expected to be more effective in helping designers generate product features that communicate sustainability.

Sections 3.2 and 3.3 formulate research propositions and introduce the priming stimuli used in Study 1. Section 3.4 describes experimental methods and measurement

procedures. Results and discussion are contained in Sections 3.5 and 3.6 separately, and Section 3.7 provides summaries.

3.2. Research Propositions

This chapter proposes that the design capabilities of engineers can be extended by heightening their sensory perceptions and sustainability considerations, and thus improve their ability to communicate sustainability via product design.

Proposition: Exposing designers to a priming stimulus 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" [93]. Heightening perceptions via priming increases the cognitive accessibility of anything that may be related, which in turn drives individuals to discover the "blind spots" in thinking and design, refer Section 2.4 on priming for more details. It is this heightening of perceptions that the current research wishes to exploit in the design technique.

The motivation for this proposition comes from the challenges of designing sustainable products, as detailed in Section 1.1, paragraphs 2 and 3. It is expected that this technique helps the designer simultaneously consider technical- and customer-centric concerns, and create design features that communicate sustainable design efforts to the customer.

The research proposition phrases the goal as generating design features that "communicate sustainability to the customer." In the experiment detailed in Section 3.4, features are judged on their ability to "trigger the customer to think about sustainability." This specific phrasing was chosen in conjunction with follow-up research, which uses 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.

3.3. Priming Stimuli

3.3.1. Proposed Priming Stimuli

To test the proposition above, an experiment was created, in which subjects (designers) were exposed to a priming stimulus and then asked to design a product. Two stimuli 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 or the other, not both. The stimuli 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 (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 stimuli were worded to be inclusive of both cleaning implements.

The priming stimulus product (sponge) is different from the concept generation product (toaster, described in Section 3.4.1) 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 priming stimulus, 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 the product's features.

The questionnaire consists of an exercise, in which subjects 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 in their description some or all of the five senses (sight, sound, touch, smell and taste). The maximum time spent on the questionnaire is ten minutes. The motivation behind this priming stimulus is as follows: by actively thinking about the answers, the associated mental content of perceiving sensory information and sustainability may be vividly aroused and become highly accessible in the ideation process. Based upon the findings of the mechanism of priming effect [47], 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.

For the collage priming stimulus, subjects arrange pictures of sponges on a white background. The exercise is based on the work of Guyton [28], who develops sustainable product semantics and establishes a set of design recommendations for sustainable product designers, as 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, the author combines 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 Figure 3.1. In the exercise, 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 maximum time spent on the collage is ten minutes.
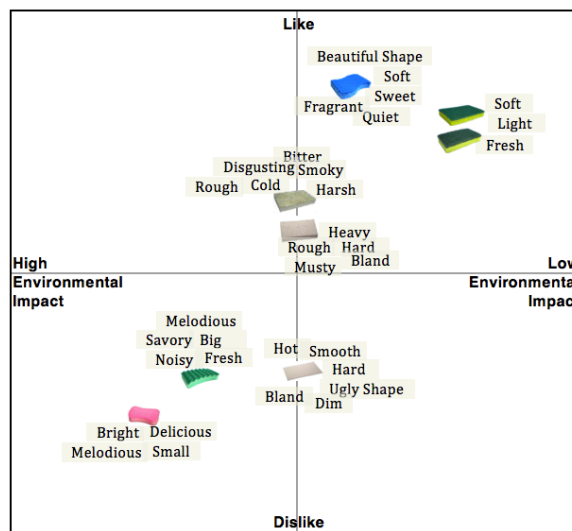
Figure 3.1. Demonstration of a collage output.

Based on findings from the priming literature mentioned in Section 2.4, it is likely that performing the collage exercise activates specific cognitive orientations and relevant cognitive procedures. Effects on subsequent design tasks may then be driven by both the orientations and procedures. It is anticipated that the collage priming stimulus

would be more effective than the questionnaire one, as rich, frequent, and recent priming stimuli are often especially effective [47], and lead to more spreading activation [94] and require more extensive 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 cognitive processing.

3.3.2. Benchmark Priming Stimuli

Two established priming techniques are included as experimental conditions to test if existing techniques can lead to improved sustainability communication. This finding would eliminate the usefulness of the proposed method, thus it should be checked. Empathic lead user [33], described in Section 2.4.2, is adapted to the toaster design task by asking subjects to toast two pieces of bread only using their right hand while wearing an oven mitt and a pair of scratched goggles (Figure 3.2, left). Positive affective priming stimulus [34], described in Section 2.4.2, is also included. Subjects are asked to draw anything they want on a sheet of paper with a laughing baby image as a background (Figure 3.2, right), adapted from Lewis et al.'s iPad approach.
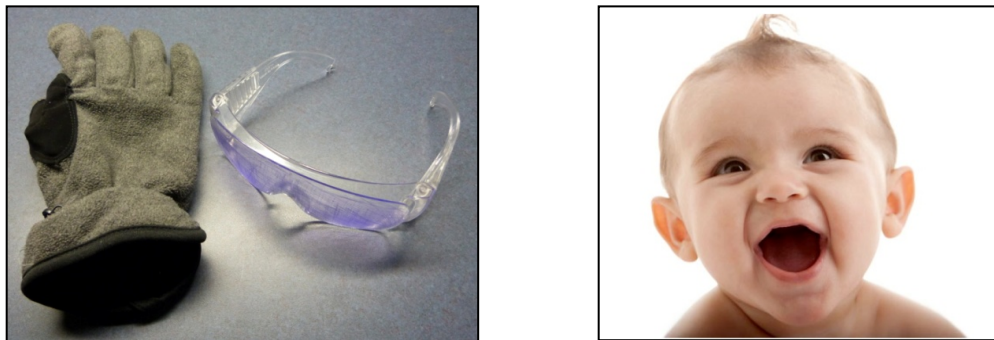
Figure 3.2. Empathic devices (left) and positive priming image, Lewis et al. [34] (right).

3.4 Method

3.4.1. Experiment Design Overview

A controlled experiment was designed and conducted to test the priming effect on ideation under four priming conditions: (A) Questionnaire, (B) Collage, (C) Empathic lead user, and (D) Positive affective, as described above. A control condition of (E) No priming stimulus was also included. After interacting with a priming stimulus (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 and were asked to concentrate on the five senses (Design Phase 2). After that, subjects provided some demographic and purchase information. Finally, subjects elaborated on their designs, counted the features they generated, and described their thinking process. Figure 3.3 provides an overview of the experiment, and procedure details are provided in Section 3.4.2.
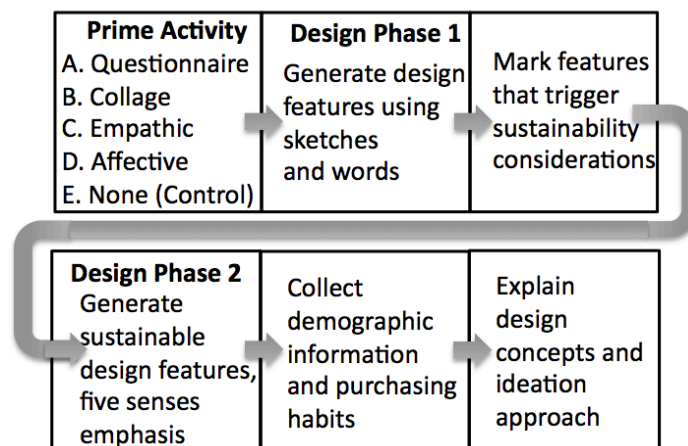
Figure 3.3. An overview of the experiment.

The research proposition in Section 3.2 is broken down into hypotheses that are tested using this experiment:

Hypothesis 1a: The questionnaire increases the ability of features to trigger thoughts of sustainability when compared to no priming stimulus.

Hypothesis 1b: The questionnaire increases the number of features generated that trigger thoughts of sustainability when compared to no priming stimulus.

Hypothesis 2a: The collage increases the ability of features to trigger thoughts of sustainability when compared to no priming stimulus.

Hypothesis 2b: The collage increases the number of features generated that trigger thoughts of sustainability when compared to no priming stimulus.

Hypotheses 3 and 4 proposed benchmark conditions against the no priming stimulus condition, to test the necessity of the new proposed technique. If these hypotheses are accepted, the new technique is not needed.

Hypothesis 3a: The empathic lead user increases the ability of features to trigger thoughts of sustainability when compared to no priming stimulus.

Hypothesis 3b: The empathic lead user increases the number of features generated that trigger thoughts of sustainability when compared to no priming stimulus.

Hypothesis 4a: The positive affective priming stimulus increases the ability of features to trigger thoughts of sustainability when compared to no priming stimulus.

Hypothesis 4b: The positive affective priming stimulus increases the number of features generated that trigger thoughts of sustainability when compared to no priming stimulus.

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 [95, 96]. The author recruited 50 students from the departments of Mechanical Engineering and Industrial Engineering at Iowa State University to participate in the experiment. They were compensated with $10, $15, or extra credit. The experiment was conducted in two sessions. The first one compared the proposed priming stimuli (questionnaire and collage) to the control condition, as reported in [97]. In order to benchmark the effect of the proposed priming stimuli against existing techniques, two additional conditions (empathic lead user and positive affective priming stimuli) were added in the second session. Both expert designers and potential customers rated design solutions to test the hypotheses, as discussed in Section 3.5.

3.4.2. Procedure

Subjects were assigned randomly to one of the five conditions, with 10 subjects per condition. 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 four

priming stimuli (or none for the control). The maximum time limit for the priming activity was 10 minutes, and a subject could move on to 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 such: "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 such: "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." The rationale behind Design Phase 2 is that many creativity design experiments explicitly ask subjects to design as many creative solutions for a design problems as possible, then measure how creative each solution is, and how many creative solutions subjects generated. This is a congruous task. 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 [98]. This exercise served to explore the subjects' cognitive processes and ensure the documented data accurately reflected intent. Subjects also confirmed the numbering of features on their experimental materials. Subjects in the collage condition were questioned about their rational for the collage task. Finally, subjects were debriefed on the purpose of the experiment.

3.4.3. 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. [99, 100] (see Table 3.1), the experiment administrator checked the self-counts of features. Compiled ideas and scanned sketches were entered into a web survey so that judges could rate them.

3.4.4. Measures

Shah et al. [37, 101] point out two basic criteria for evaluating ideation methods: (1) how well does the method explore the design space, and (2) how well does the method expand the design space. Based on these two criteria, they propose four

effectiveness measures: quality, quantity, novelty and variety of the ideas generated using that method. In some cases it is appropriate to use a subset of these metrics. For example, Yang [102] finds that quantity of ideas generated in early phase is significantly correlated with the quality of design outcome, in terms of students' design grade in her study, but does not investigate novelty or variety. Here, this chapter defines quality as specific to the hypotheses at-hand. Novelty is among the dimensions rated by judges, but does not produce significant/interesting results. Considering the target of the technique investigated in this work, three metrics are involved in the analysis:

Table 3.1. Quantity counting rules summary [99].

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.

ST rating: the ability of a feature to trigger a customer's sustainability considerations, as judged by experts and potential customers. A rating of "1" corresponded to "strongly disagree," and a rating of "5" corresponded to "strongly agree."

Measure A: the average ST rating of the features generated per designer subject, averaged across judges' ratings (expert and customer judge ratings are kept separate) and across features generated by a designer.

Measure B: the count of effective features generated per designer. An effective feature is defined as having an average ST rating above 'neutral' (any number greater

than three); ratings averaged across judges, with expert and customer ratings averaged separately. Refer to Figure 3.4 for examples of effective features.
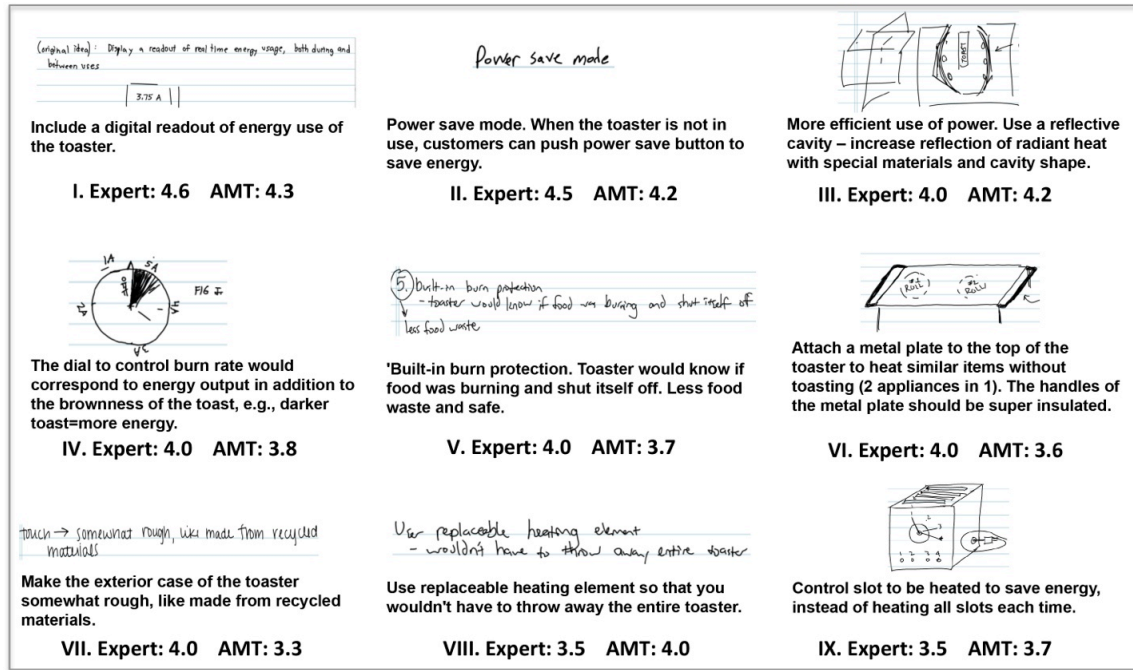
Figure 3.4. Example effective features on ST, with average ratings from expert judges and/or AMT judges separately; rated from 1 strongly disagree to 5 strongly agree that a feature can trigger customers to think about sustainability.

3.4.5. Judging of Measures

Judging of ST ratings, and thus the basis of measures A and B, were conducted by two groups: experts (designers) and novices (consumers). Design features from conditions A, B and E were rated by two expert judges, hypotheses were tested, and are also reported in [97]. Once the basic viability of the technique was proven with expert judges, additional analysis was undertaken: (1) testing the effectiveness as judged by novice raters (potential customers), and (2) testing existing priming techniques against the control condition, to verify the usefulness of the proposed new technique. Both of these analyses add rigor and scrutiny to further substantiate claims of the technique's

effectiveness. Design features from conditions A, B, C, D, and E were rated by potential customers on Amazon Mechanical Turk (AMT), to be referred to as "AMT judges." AMT is an efficient platform for crowdsourcing user studies [103] due to the low recruitment costs and immediate access to hundreds of subjects. Expert judges rated all design features generated from the conditions A, B and E, which took approximately eight hours; while AMT judges rated a subset of 31 design features across all conditions, which took approximately 30 minutes. Rating correlation between the two judge types was 0.7 on shared conditions, as discussed in Section 3.5.4. This good correlation indicates that there was no need to collect rating data from expert judges for the remaining two conditions (C and D), which was time-consuming, and costly.

Shared judging context across expert and novice: Both sets of judges saw the same format of stimuli, as close as possible to the original submissions of the experimental subjects and were blind to the hypotheses of the experiment. Both sets of judges saw the same examples of an effective ST feature and a "bad" ST feature for training purposes before beginning. Both sets of judges rated each feature on novelty, perceptibility, sustainability trigger, and feasibility. The dimensions other than sustainability trigger are not discussed as no significant differences were found between the test conditions and the control. The features described by the experimental subjects using only text were shown to the judges as only text. The features described with sketches/text were shown to judges as sketches/text. The features described by subjects with only sketches had text added to the stimuli shown to the judges, taken from the audio record of the experiment.

Differences in judging context: Expert judges rated the features in a lab and the experiment administrator answered any questions they had during rating. AMT judges rated features on their own computers without access to clarification. Expert judges saw the "raw" or original concept descriptions from designers, while AMT judges saw some slight rephrasing of concept descriptions when the raw descriptions were deemed difficult for a non-designer to understand, as determined by the two authors and an independent editor. Within the AMT survey, for cases of multiple designers describing the same feature with different phrasing, this feature was rephrased to a "universal phrasing" and only appeared as one feature in order to streamline data collection and processing, and avoid surveys that might ask multiple questions about the same feature but with different phrasings (confusing to respondent). Additionally, only expert judges rated features on the dimension "relatedness to engineering design." There was also a slight difference in rating task wording, as detailed below.

Expert judging details: The expert judges who rated features were two graduate students in Mechanical Engineering with different design backgrounds. The male judge is a first-year Ph.D. student with a sustainability-related background in class and research projects, which involve a wind turbine model design, automotive emissions regulation study, Magnetorheological Elastomers (MREs) categorization (for energy reclamation and reduction of bridge maintenance). The female judge is a second-year Master's student with five years of design experience in industry, and two years' experience as a teaching assistant for an engineering design class that includes sustainability-related teaching material. Judges were asked how likely a feature is to

trigger customers to think about sustainability upon interacting with that feature. The definition of triggering sustainability considerations was given as, "The feature causes customers to think about reducing environmental impact. For example, a hand-powered toaster might cause them to think about sustainability, while a digital control panel on a toaster might not cause them to think about sustainability." The judges were told that they might see some similar design features during evaluation, and requested to try their best to be consistent in the whole process. In order to calibrate their ratings, the judges rated two example features, and discussed the rationale for their ratings until they agreed with each other, and the experiment administrator answered any questions they had. During this discussion, the judges agreed that a sustainable trigger feature must be noticeable when users interact with the product, and must be related to sustainability in some way, such as lower environmental impact. The degree to which the features trigger sustainability considerations depends on judges' own subjective evaluations. Take "using recycled materials" as an example, this feature lowers environmental impact, but whether or not it will trigger customers to think about sustainability is highly dependent on specific implementation in the design, which was not always specified by the subject. Thus, when a feature is described as "using recycled materials, such as aluminum," it could be rated as "4" or "5"; but simply "using recycled materials" could be rated as "3" or "2." Then judges rated each feature on a five-point scale from 1 (strongly disagree) to 5 (strongly agree) regarding the degree to which the feature can trigger customers to think about sustainability.

To evaluate the reliability of the judges' ratings, 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 [104]. 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' ratings and 0.9 on their ratings after discussion of disagreements, demonstrating that the rating task was well-understood and consistently performed by the judges.

AMT judging details: The AMT judges were 174 AMT workers located in US; the average respondent took 14 minutes to complete the survey. They were compensated via Amazon with $1.50. These AMT judges come from more than 60 different occupations; 51% are female; 78% have bought sustainable products in the past; and 88% have used toasters in the past twelve months. Other demographic information of the AMT judges is summarized in Table 3.2. Three respondents were screened out because they were an engineering designer or product designer. An additional 21 respondents were screened based on spending nine minutes or less on the survey task. Screening AMT respondents for time spent on the survey task is a recommended approach to reduce noise due to respondents choosing random answers, see [103, 105]. The authors identified ten minutes as the fastest time that they personally could take the survey and still read all of the feature descriptions. Analyzing the subject data, the distribution of time spent shows an obvious drop-off at nine minutes. In the survey, ST was defined as: "The feature causes you to think about reducing environmental impact. For example, a

hand-powered toaster might cause you to think about sustainability, while a digital control panel on a toaster might not cause you to think about sustainability." To calibrate their ratings, the AMT judges first answered an example question about a feature that should likely be rated "agree;" and were then shown the rating and explanation. After that, they rated each feature on a five-point scale, from 1 (strongly disagree) to 5 (strongly agree) that "The feature makes me think about sustainability."

Table 3.2. Summary of demographic information of AMT judges from AMT (N=150).

Age		Education		Income		Knowledge of design	
18-25	36%	High school	10%	< $25k	29%	None	64%
26-35	31%	College	77%	$25k-$50k	34%	A little	25%
36-45	17%	Master	10%	$50k-100k	23%	Some	8%
46-55	11%	PhD	1%	>$100k	11%	Good amount	3%
56 +	5%	JD,MD	2%	No Answer	3%	Expert	0%

3.5. Results

3.5.1. Overview

In total, 550 features were generated by 50 subjects in both design phases. Designers did not ideate enough sustainability-triggering features in Design Phase 1 to test the hypotheses; the priming stimuli had a testable effect only in Design Phase 2, when subjects received explicit instructions to design features that trigger sustainability considerations. Thus, the author analyzed features generated in Design Phase 2. However, the results of Design Phase 1 indicate that the collage priming stimulus resulted in a larger number of features generated per subject than no priming stimulus (8.2 vs.4.7, p<0.05) [97] . An overview of results is shown in Table 3.3.

Table 3.3. Overview of Results ("*" p<0.05, "." p<0.1, compared to the control condition, "----" = Not Rated).

Condition	Number of Subjects	Design Phase 1	Design Phase 2 Detailed Metrics					
		Average Number of Features Per Subject	Average Number of Features Per Subject (as presented in AMT survey)	Average Feature Rating Per Subject (Measure A)		Average Number of Effective Features Per Subject (Measure B)		
				Expert	AMT	Expert	AMT
A. Questionnaire	10	6.2	5	3.1.	3.6	2.9*	3.6
B. Collage	10	8.2*	6.8*	3.5*	3.6	4.8*	4.9*
C. Empathic	10	5.8	4.2	----	3.12	----	2.1
D. Affective	10	6.4	4.3	----	3.87	----	3.6
E. Control	10	4.7	3.4	2.5	3.4	1.3	2.2

Between-subjects analysis of variance (ANOVA) on measures A and B tested hypotheses using expert and AMT ratings. ANOVAs were conducted with the priming stimulus condition as an independent variable, and subject-level measures A and B as dependent variables. Measure A was obtained by averaging ST ratings across the judges (expert and AMT separately, never combined) and the design features generated per designer. Measure B was calculated by counting the number of effective features generated by a designer, as defined in Section 3.4.4. All the data satisfy the assumptions for a standard ANOVA except for small departures from normality of measure B as suggested by Shapiro-Wilk's test [106]. A further analysis of the expert ratings for testing hypotheses 1a and 2a was also included, involving use of a linear mixed model (LMM) without averaging ratings across two expert judges or features generated by a designer. Section 3.5.2 presents the results based on expert judges' ratings, followed by analysis of AMT judges' ratings in Section 3.5.3, and then a comparison of the two in Section 3.5.4. Table 3.4 presents a summary of the hypothesis testing results.

Table 3.4. Summary of hypothesis testing.

Hypothesis	Sig. Level (Experts)	Sig. Level (AMT)	Measures Related	Evidence Presented In
1a: The questionnaire increases the ability of features to trigger thoughts of sustainability when compared to no priming stimulus.	P<0.1 •	P>0.1	Measure A	Table 3.3, Fig. 3.5, 3.6
1b: The questionnaire increases the number of features generated that trigger thoughts of sustainability when compared to no priming stimulus.	P<0.05 *	P>0.1	Measure B	Table 3.3, Fig. 3.5, 3.6
2a: The collage increases the ability of features to trigger thoughts of sustainability when compared to no priming stimulus.	P<0.05 *	P>0.1	Measure A	Table 3.3, Fig. 3.5, 3.6
2b: The collage increases the number of features generated that trigger thoughts of sustainability when compared to no priming stimulus.	P<0.05 *	P<0.05 *	Measure B	Table 3.3, Fig. 3.5, 3.6
3a: The empathic lead user increases the ability of features to trigger thoughts of sustainability when compared to no priming stimulus.	----	P>0.1	Measure A	Table 3.3, Fig. 3.6
3b: The empathic lead user increases the number of features generated that trigger thoughts of sustainability when compared to no priming stimulus.	----	P>0.1	Measure B	Table 3.3, Fig. 3.6
4a: The positive affective priming stimulus increases the ability of features to trigger thoughts of sustainability when compared to no priming stimulus.	----	P>0.1	Measure A	Table 3.3, Fig. 3.6
4b: The positive affective priming stimulus increases the number of features generated that trigger thoughts of sustainability when compared to no priming stimulus.	----	P>0.1	Measure B	Table 3.3, Fig. 3.6

3.5.2. Expert Judge Results

<u>ANOVA on Measures A and B</u>

The expert ratings analyzed with ANOVA show significant differences for both measures A and B across the three conditions, and provide strong support for hypotheses 1b, 2a and 2b. Comparing with the control condition, as demonstrated in Figure 3.5, designers from the collage condition generated features with significantly higher ratings on measure A than those from the control condition (3.5 vs. 2.5, $p<0.05$). A similar trend is also observed for the questionnaire, which leads to 11% increase, although it is only significant at the 0.1 level (3.2 vs. 2.5, $p<0.1$). For quantity measure (B), number of

effective features, both the collage and the questionnaire contribute significantly (collage vs. control: 4.8 vs. 1.3, p<0.05; questionnaire vs. control: 2.9 vs. 1.3, p<0.05).
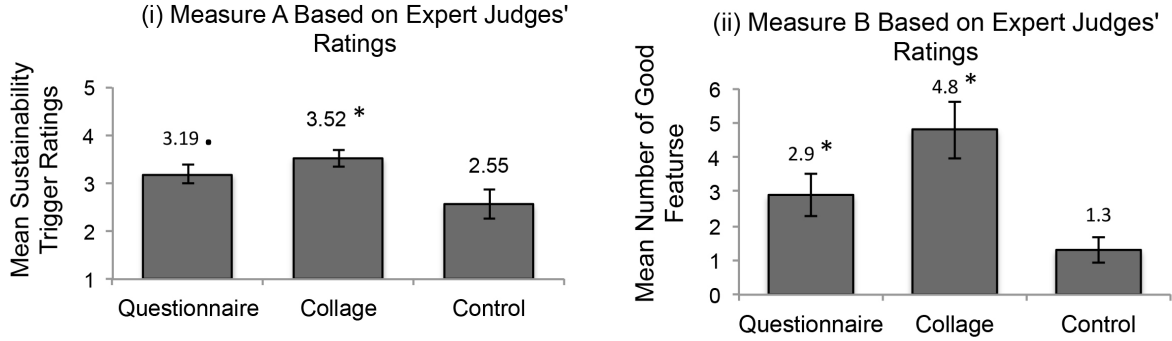
Figure 3.5. Comparison of measures across priming conditions based on expert judges' ratings ('*' p<0.05, ".'' p<0.1, compared to the control condition); error bars show ±1 standard error.

Linear Mixed Model on ST Ratings

This chapter also analyzed ST ratings using a linear mixed regression model with subjects as a random factor, and priming 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 [107]. The regression model is represented by Eq. (1):

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

Where:

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

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

ST refers to judge's rating; C_1 and C_2 are dummy variables to indicate the priming 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 3.5. The 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 [108]. Given the large number of observations (298) in the 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 [109]. The obtained t-statistics in Table 3.5 show that both contrast 1 (Questionnaire vs. Control) and contrast 2 (Collage vs. Control) reach the 0.05 significance level in terms of ST ratings. Hypotheses 1a and 2a are supported by LMM results, as β_1 and β_2 in Table 3.5 are statistically significant at 0.05 significance level.

Table 3.5. 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

Comparison of ANOVA and LMM on Hypotheses 1a and 2a

The results of the LMM (taking raw ST ratings as observations) are similar to ANOVA (taking measure A as observations) in supporting hypothesis 2a. Hypothesis 1a is tested to be more significant by the LMM model than AVOVA (significant at 0.05 level vs. 0.1 level), i.e., designers from the questionnaire condition generated features

with significantly higher ability to trigger customers' sustainability thoughts than those from the control condition. This is likely because ANOVA takes mean rating for features generated by a subject and rated by two judges as an observation, while LMM takes raw data (without any average) as observations. The errors caused by the averaging process affected the results.

3.5.3. AMT Judge Results

ANOVA reveals no significant effect of priming stimuli on measure A, i.e., hypotheses 1a, 2a, 3a, and 4a are not supported (Figure 3.6 (i)). However, there is a trend that designers' features from the affective, collage and questionnaire conditions have higher ST ratings relative to the control condition. ANOVA testing of measure B (see Figure 3.6 (ii)) significantly supports hypothesis 2b, that the collage priming stimulus increases the number of effective features that trigger thoughts of sustainability when compared to no priming stimulus (collage vs. control: 4.9 vs. 2.2, $p < 0.05$), while hypotheses 1b, 3b, and 4b are not supported. Further, the trends on measure B suggest that designers in the questionnaire and affective condition may generate more effective features than the empathic and control condition.
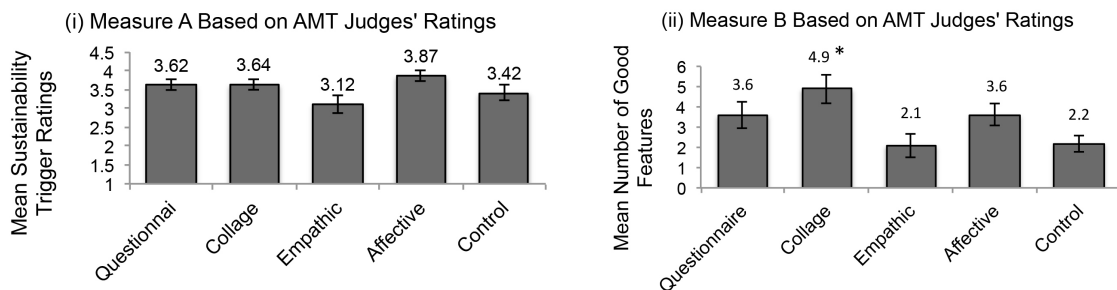
Figure 3.6. Comparison of measures across the five priming conditions based on AMT judges' ratings ('*' $p < 0.05$, compared to the control condition); error bars show ±1 standard error.

3.5.4. Comparison of Expert Judge and AMT Judge Ratings

Figure 3.7 shows the rating correlation between expert and AMT judges for features in priming conditions A, B, and E, on a per-designer basis, with a Pearson correlation at 0.7. Experts have a lower average rating across designers (mean: expert vs. AMT: 3.1 vs. 3.6, $p < 0.05$). Table 3.6 shows the distribution of the ratings. For example, for features rated about 3 or lower, the majority of the expert ratings fall between 1 and 2, while most AMT ratings are between 2 and 3.

Table 3.6. Distribution of the ratings from expert judges and AMT judges.

Rating Range	[1,2]	(2,3]	(3,4]	(4,5]
Expert	28%	12%	30%	30%
AMT	9%	21%	31%	39%
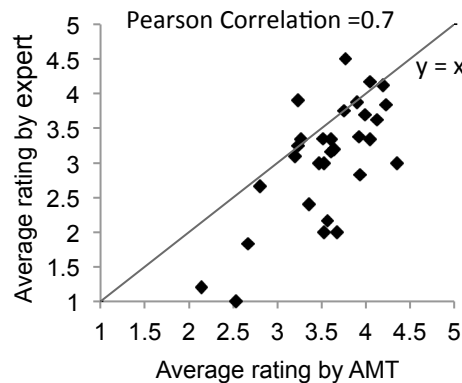
Figure 3.7. Comparison of expert and AMT judges' ratings, in conditions A, B, and E, (N=30) on Measure A.

3.5.5. Post-experimental Survey Results

A post-experimental survey of all experimental subjects (not the judges) measured a variety of items: sustainability knowledge, design experience, design interest, self-perceived performance on the design task, evaluations on the ideation

session, and environmental control belief [110]. ANOVAs show that no ratings on these items are significantly different across conditions. The mean values for items by conditions are reported in Table 3.7.

Table 3.7. Likert-scale post experimental survey results show no significant difference on means across priming conditions (Items marked with "^" are inverse items - lower ratings on these items mean stronger environmental control belief).

Categories	Survey Items	Priming Conditions				
		Question naire	Collage	Empathic	Affective	Control
Self-evaluation	I am knowledgeable on sustainability. 1=Strongly Disagree, 5=Strongly Agree	3.8	4.1	3.4	3.5	3.7
	How experienced are you in design? 1=Inexperienced, 5=Experienced	3.6	3.3	3.4	3.5	3.4
	How interested are you in design? 1=Not at all, 5=Very interested	4.1	4.6	4.5	4.3	4.4
	My performance on the design task was: 1= Poor, 5=Excellent	3.6	3.6	3.5	3.3	3.4
Evaluation of the ideation session	How do you think about this idea generation session?					
	1=Difficult, 5=Easy	3.5	3.3	3.1	3.3	3.2
	1=Boring, 5=Fun	3.7	4	4.4	3.9	3.9
	1=Confusing, 5=Clear	4.2	3.9	4.3	3.9	4.1
	1=I didn't have enough time, 5=I had enough time	4.2	3.7	4.4	4.4	3.9
Environ-mental control belief	^There is nothing the average citizen can do to help stop environmental pollution. 1=Strongly Disagree, 5=Strongly Agree	1.5	1.2	1.4	1.2	1.4
	My involvement in environmental activities today will help the environment for future generations. 1=Strongly Disagree, 5=Strongly Agree	4	3.9	3.8	4	3.8
	^I would not carpool (share cars with others) unless I was forced to. It is too inconvenient. 1=Strongly Disagree, 5=Strongly Agree	1.9	1.8	1.9	1.9	1.6

3.6. Discussion

This experiment demonstrated that exposing designers to a collage priming stimulus that causes them to think about sensory perceptions and sustainability helps them generate more product features that communicate sustainability to the customers, as judged by experts and customers (AMT). Subjects interacted with images of products and sensory words, and repeatedly made judgments about sensory perceptions and

preferences, which, in theory, stimulated them to think about the sustainability communication of the product. Other existing priming techniques were not effective at a statistically significant level, as rated by AMT judges. The experiment supports the research proposition: priming can be used to improve design ideation for successfully communicating sustainability.

The questionnaire was also successful, but to a lesser extent, with only the expert ratings supporting its significance on improving the number of effective features generated. The goal of including the questionnaire was to test if the same effect as the collage could be generated with less effort. Less effort was indeed expended in the experiment, as subjects primed with the questionnaire spent less time on the exercise (most of them used 5 to 6 minutes) than those in the collage condition (most of them used 10 minutes). But the effect was less-strong in the questionnaire condition. This follows the prediction of the "richer" the priming stimulus, the stronger the effect [47]. The questionnaire encompasses no visual stimuli or kinetic participations, termed as "less stimulation." It is possible that less stimulation might lead to fewer spreading activations and require less cognitive processing. Finding the biggest lift in ideation performance for the smallest amount of extra effort, or priming efficiency, remains a possible goal for future research.

The two benchmarks, the empathic lead user and positive affective stimulus, did not show significant effect on designers for the hypotheses tested; thus not all priming stimuli are equally effective at generating ST features. This suggests that, in some cases, stimuli perform better when tailored to match a specific goal of the ideation process. It

does not suggest that these other stimuli are less effective in general, see Section 2.3.2. These priming stimuli may be more effective than the collage for other design tasks. The benchmarks may have been more effective if not taken as literally from the previous research and instead adapted. For example, the smiling baby could have been wearing a cloth diaper. However, as the goal was to test against baseline, the authors attempted to remain as true to the original stimuli as possible. Although the empathic lead user stimulus is also sensory-related, it did not have the same effect as the collage and questionnaire. A possible explanation is that the empathic stimulus pushed designers to explore extremes and limitations of visual and tactile interactions, thus focusing mainly on the user-product physical interaction.

An interesting finding is that ST ratings of design features created in the positive affective condition were the highest (on average) of all conditions, although not significantly higher than the two test conditions. This trend suggests that the effect of positive emotion is not negligible, and could potentially be combined with other stimuli to improve results.

The ratings between experts and customers (AMT) were well-correlated at 0.7. In general, AMT judge ratings are not as polarized as the expert ratings (see Section 3.5.4). This lack of polarization led to weaker trends in measures A and B across conditions, but the main finding is still significant at the $p < 0.05$ level: the collage is tested to be effective in helping designers generate more effective features (Measure B). The expert and customer feature ratings in this study can serve as additional data in understanding how design judgments correlate between experts and novices. Expert judges evaluated

from the third person, focusing on the customer's likelihood of thinking about sustainability when encountering the feature. AMT judges used the first-person or self-report, evaluating the effectiveness of communication directly with them. No actual purchase decisions were tested in this experiment. It is possible that the expert judges had a broader understanding of sustainability than the novices (AMT judges), due to their qualifications, yet this difference did not manifest in any noticeable way in the results, as correlations in ST judgment between the two groups was high. As the judges were not asked to assess the actual sustainability of the designs, differences in technical qualifications between the two groups should and did have limited impact. The post-experimental survey showed no significant difference between conditions in subjects' in design interest, design experience, and environmental control belief. This corroborates that the proposition that the effect on communicating sustainability was due to the priming stimuli. Above-average ratings on the evaluation of the ideation session and subjects' performance indicated that the design problem used in the study was well-understood, subjects had enough time to work on the ideation, and they were satisfied with their performance.

3.7. Summary

Results shown by this study are a promising indicator that priming exercises 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 collage activity significantly increases the number of design features judged to trigger sustainability considerations. The results

merit the further investigation of priming as an effective yet underutilized design technique. However, the study presented here is limited to the design of one product, and all subjects were students. A generalized study of a variety of target products and subjects with different levels of design experience would further test the hypotheses; and the effect of varying stimulus exposure time, or a wider variety of sustainability-triggering conditions, would provide additional insight. This study did not attempt to identify heterogeneity in customer response to ST features, due, for example, to different forms of feature embodiment (descriptions vs. prototypes) or customer demographic information.

The work is differentiated from past priming studies in that the improvement in feature design 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 a designer's 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 with the collage activity 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 traditional quality metrics of LCA.

As corroborated by other work, this research further suggests that priming is useful in design. It is envisioned that priming exercises 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. Additionally, a priming exercise might be used to address negative tendencies such as design fixation [60]. Preparing the technique for use by "real-world" designers presents other research challenges: in this study, the subjects were not intentionally informed of the purpose of the exercises. 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 positive effect of priming on sustainability communication also presents a number of research opportunities. The following two chapters discuss two new studies, one purpose of which was to spot-check some of the highest-rated features generated in this experiment, confirming that they trigger customers to think about sustainability while deciding between and "purchasing" toaster prototypes. The studies investigate how engineering design facilitates customer decision making regarding sustainability.

4.   TRIGGER FEATURES ON PROTOTYPES INCREASE CONSIDERATIONS OF SUSTAINABILITY

4.1. Introduction

Researchers have focused on incorporating customer preferences into engineering design decision making, for example, mapping customer desires to engineering design attributes that can be represented quantitatively [111], coordinating a marketing profit maximization objective between a choice model of customer preference and an engineering design model [112], incorporating construction of preferences into an integrated marketing and engineering design optimization for sustainable products [11]. This chapter presents a lab study to explore a hidden construct in customer preferences in engineering design: considerations/thoughts triggered by specifically-designed features.

Chapter 1 proposes that carefully designed features that could trigger customers to think about sustainability (ST features) might be instrumental in addressing the gap between customers wanting and buying sustainable products. Chapter 3 proposes a priming-designers technique to support concept generation for such features, and the ST features generated have been initially tested to be effective by using judges. This chapter examines the effect of ST features on changing customer decision context and seeking related information in a realistic purchase scenario with consider-then-choose approach [92], and an unstructured direct elicitation (UDE) approach (write an email to an agent) [89], as introduced in Section 2.5.3. In uncovering customer decision process and predicting considerations, Ding et al. [89] showed that capturing the decision process in

an email/narrative format is more effective. Because the e-mail (UDE) task is more natural, making it easier for subjects to articulate their decision criteria. Consider-then-choose makes the hidden construct, considerations, observable. However, due to its quantitative nature, information on the decisions revealed are limited, and additional qualitative questions are required to get a more comprehensive understanding of decision process. For example, some subjects might consider features or associated emotions beyond the predefined scope in a consider-then-choose experiment design, but the email task can capture them easily. To study customer considerations quantitatively and qualitatively, both consider-then-choose and email approaches were employed.

A selection of ST features generated from Chapter 3 was designed into realistic toaster prototypes. Subjects performed a set of simulated-purchasing tasks in a test versus control experimental design, including consider-then-choose and write an email. Both qualitative and quantitative results were analyzed. It is expected that ST features would trigger thoughts of sustainability during the purchasing tasks and motivate subjects to seek different information, as illustrated in Figure 4.1, the shaded part.
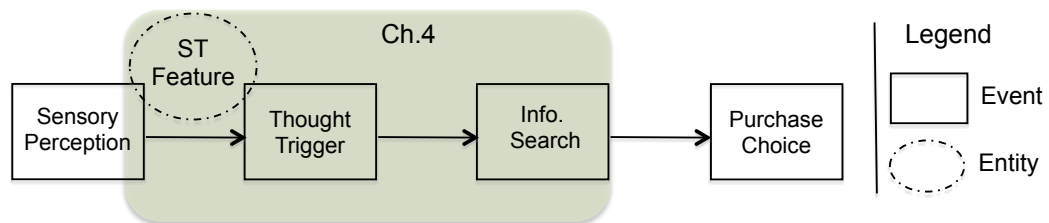
Figure 4.1. Theoretical ST effect on customer decision making regarding sustainable products (The shaded part is tested in Chapter 4).

The chapter proceeds as follows: The next section depicts the detailed experimental process. Results and discussion are contained in Sections 4.3 and 4.4 respectively, and Section 4.5 provides a summary.

4.2. Method

4.2.1. Design of the Experiment

Subjects were exposed to a set of products, with ST features (features designed to trigger thoughts of sustainability) present in test condition A and no ST features, but instead extra features, in control condition B. In the consider-then-choose task, subjects were explicitly asked to form a consideration set first, then make a purchase from that set. In the email task, subjects typed an email to an agent explaining the toaster to buy. They began with "Dear Friend" and then could use any format to describe their preferences. Then subjects answered two interview questions: (Q-Info) what additional information would you like to know about the toasters shown; and (Q-Rationale) what is your rationale for the decisions in the first decision task? The qualitative answers to email and interview were coded by two judges on three dimensions:

D1: What toaster feature does the instruction talk about? (List of features, check all that apply)

D2: Does that information reveal that the subject is considering sustainability? (Yes/ Could be interpreted as yes/ No)

D3[1]: What is the preference of a criterion expressed in that information? (Essential/ Preferred but not essential/ Acceptable but not preferred or essential/ Trivial/ Must not have)

The author proposes that sustainability-triggering features of a product lead subjects to seek more information on sustainability and increase their considerations of sustainability during purchasing decisions. This proposition is broken down into hypotheses (Table 4.1) that are tested using this experiment, in the order of data collected.

Table 4.1 Hypotheses to be tested in the order of data collected.

Hypotheses	Tested with …
H1a: Subjects in condition A consider products from the ST set more frequently than subjects in condition B consider products from the extra set.	Consideration data
H1b: Subjects in condition A purchase products from the ST set more frequently than subjects in condition B purchase products from the extra set.	Choice data
H2: Sustainability is more frequently mentioned as a purchasing instruction by subjects in condition A than subjects in condition B.	Email data on D2
H3: Subjects in condition A more frequently seek information of the products on sustainability than subjects in condition B.	Q-Info data on D2

4.2.2. Stimulus Preparation

Selection of product features and levels: Consistent with the priming designer study [97, 113] in Chapter 3, bread toasters were selected as the case product. Customer interviews and web research identified brand, price, capacity, color, and slot size as key attributes. Brand, price, and color were not considered in this study, as they are product attributes that easily dominate choice decisions, and with few subjects and limited prototypes, the experiment could not be complex enough to counteract this effect.

---

[1] Including D3 for judging aimed to examine how customers process sustainability-related items during decision making. However, no interesting findings were found. Thus results related to D3 are not reported.

Common features: All of the toasters were in black color, of non-specific brand, and were described as costing the same. Their dimensions were 9.4 by 5.5 by 6.3 inches and they had 2 slots, 4.9 inches in length. Three Base features were included in various configurations across all profiles: slot size (regular/bagel), dial shape, and dial metrics (with numbers or darkness).

Varied features across conditions: Features, and levels of features that varied across experimental conditions are listed in Table 4.1, which includes a description of all toasters shown to subjects in various combinations, termed profiles. Five ST features or feature levels were included in the study. These were selected from the 171 "good" ST features generated during the design exercise in Chapter 3 [97, 113]. The criteria for selecting the features were as follows: (1) have a top rating on triggering thoughts of sustainability across expert and customer judges; (2) have a top rating of feasibility across expert and customer judges; (3) be easily incorporated as a design feature in a prototype; and (4) be applicable in daily use for US customers.

The five features are labeled in Figure 4.2: (A) a flip-cover that keeps in heat, (B) two activation levers—one for each piece of bread, (C) a power save mode, (D) an embossed leaf pattern, and (E) a dial with power levels. The power levels around a dial ("600 Watts," "800 Watts," and "1100 Watts") represent the rate of energy consumed at each darkness level. The flipping covers sit on the top of each slot, which are opened by pressing an "Open Cover" button on the front of a toaster, and are automatically closed by the activation level (non-functional in prototype). Two activation levers enable users to heat each slot independently or as a combination, saving energy. A power save button

theoretically helps to save energy usage when the toaster is connected to an electric outlet but not toasting, but it is unlikely it would have any real effect on energy usage for a manual toaster. The embossed leaf pattern raises up some areas on housing surface to make them look like or feel like leaves. Features (A), (B), (D), and (E) are originated in the collage or questionnaire subject-generated design features- collage and questionnaire are two techniques proposed by the authors in [97, 113] to support designers in communicating sustainability via design in conceptual phase. Feature (C) is originally generated by a designer in the control condition. Similar concepts to Features (A) and (B) are also generated by designers in other conditions investigated in that study. Again, it is not necessary that the ST features be sustainable themselves, but rather that they trigger thoughts of sustainability.

(i) Toasters as shown in purchase task

(ii) Close-up 1   (iii) Close-up 2

Figure 4.2. (i) shows a purchase task. (ii) and (iii) show ST features (A) flip-cover that keeps in heat, (B) two activation levers, (C) power save button, (D) embossed leaf pattern, and (E) dial metric writing in watts (power level).

To balance the experiment, two Extra features were added to the toasters presented in the control condition. These were extra lift and defrost, both represented as buttons on the toaster, and selected by the authors randomly. They were not classified in the experiment of Study 2 [97, 113] as "good" ST features, nor mentioned at all.

Profile design: Subjects each saw a set of eight prototypes with design profiles from Table 4.2. These included four toasters shared between the test and control conditions, and four toasters for each condition (Figure 4.3). Toasters 1-8 are a fractional factorial selection of Base and Extra features. Toasters 1-4 were shared by both conditions and only include base features, they are called the base set. Toasters 5-8 only appeared in the control condition B and include extra features, called the extra set. Toasters 9-16 have ST features and are shown in the test condition, called the ST set.
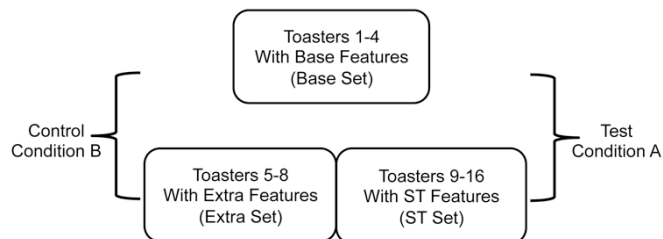
Figure 4.3. Toasters seen in the test and control conditions.

Prototype fabrication: Thermal forming was used to make toaster prototypes out of ABS (acrylonitrile butadiene styrene) plastic over a foam model with removable components (to create narrower bread slots and leaf patterns). 3D printing was used to create realistic dials, levers, and buttons. Words were printed onto black stickers and affixed to the toasters where labeling was required. Figure 4.2 shows some examples of the finished prototypes, including two close-ups, which highlight all of the ST features.

Great care was taken to maintain consistency amongst prototypes; it took over 90 hours to create the 16 prototypes used in the study.

Table 4.2. Feature level combinations for each profile (grey color indicates a feature or feature level appears in that profile).

Toaster #	Appeared in Condition ...	Basic Features/Levels						ST Features/Levels				Extra Features	
		Slot size		Dial shape		Dial metric		Power level	Flipping covers	Two activation levers	Power save	Embossed leaf pattern	Extra lift	Defrost
		Standard	Extra wide (Bagel)	Round dial 1	Round dial 2	Numbers	Darkness							
1	A&B	■			■		■							
2	A&B		■		■		■							
3	A&B		■	■			■							
4	A&B		■		■		■							
5	B		■		■		■							
6	B	■			■		■						■	
7	B	■		■			■							
8	B		■		■		■							■
9	A				■							■		
10	A	■			■				■					
11	A		■	■			■			■				
12	A		■		■						■			
13	A				■		■	■						
14	A	■			■			■		■				
15	A			■			■					■		
16	A		■		■			■						

4.2.3. Subjects

Twenty-two subjects were recruited from Iowa State University campus and the surrounding area by email, Craigslist advertisement and fliers, with $5 cash compensation. 55% are female and 86% have purchased sustainable products in the past. Table 4.3 summarizes subject demographic information by condition. Note that the majority of participants were college staff.

Table 4.3. Summary of demographic information of subjects in each condition (N=11 per condition).

Age	Con. A	Con. B	Income	Con. A	Con. B	Education	Con. A	Con. B	Occupation	Con. A	Con. B	Purchased sustainable products	Con. A	Con. B
18-25	4	3	<25k	3	2	Some college	1	0	Student	4	4	Yes	10	9
26-35	2	4	25k- 50k	3	3	College degree	3	6	College staff	7	7	No	1	2
36-45	0	3	50k-100k	3	4	Masters degree	6	3						
46-55	3	1	>100k	1	2	Doctoral degree	1	2						
56+	2	0	N/A	1	0									

4.2.4. Procedure

Figure 4.4 provides an overview of the procedure. Eleven subjects were randomly assigned to each condition. To mimic a real shopping experience, eight toasters were placed on the shelf, in combinations noted in Section 4.2.2, Figure 4.3 and Table 4.2. All the toasters shown were placed in random order. Subjects were told, "The purpose of this study is to learn about customer decision making regarding consumer products. Toasters are the example products. You will perform a set of simulated purchasing tasks and answer some survey questions. Your participation will last for about 30 minutes." and were free to examine the toasters at their own pace. They were all asked to purposefully place products they would consider purchasing on a table, and then choose a final one from that set. Next, for the email and interview task, subjects responded to a Qualtrics survey, as described in Section 4.2.1.

Decision	Email	Interview	Rate & Rank
Make a consider-then-choose decision	Write an email to an agent to buy a product	(Q1) Additional information to know (Q2) Decision rationale	Rate on sustainability trigger, and rank on sustainability
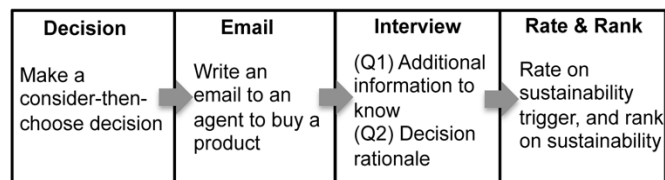
Figure 4.4. Experimental flow for the main procedures.

Next subjects rated eight or nine toasters on how likely each of the toasters was to trigger them to think about sustainability and ranked their sustainability in order. Subjects in the control condition evaluated half of the toasters that they saw previously (toasters 1-4), and five new toasters, each with one ST feature (toasters 9-13). This captured evaluations for individual ST features without previous exposure in the choice task. Subjects in the test condition evaluated the toasters from their choice task.

The experiment concluded with a post-experiment survey to collect demographics, purchasing habits, sustainability awareness, and so on.

4.2.5. Data Processing

Consideration sets and final purchases: Toasters were clustered into three sets, as depicted in Figure 4.3. The set with extra features, and the set with ST features were presented as unique set for control and test conditions, respectively. First, number of toasters considered from either of these two sets was counted per subject. Similar counting process was then conducted for the choice data.

Email, Q-Info, and Q-Rationale: Two judges, who were blind to the hypotheses and the test conditions of the subjects, coded Email, Q-Info, and Q-Rationale as described below. In the first stage, written answers by each subject were parsed into individual items, each of which must only contain one product feature or other requirement, while keeping raw description as much as possible. For example, "Dear Friend" emails were parsed into individual instructions. The number of items that each answer was separated into was counted and compared between judges to check for consistency. The overall Person correlation between the two judges was 0.74 initially. Then the two judges met to discuss and reconciled differences to complete agreement.

In the second stage, these individual items were judged on the three dimensions D1, D2, and D3 (see Section 4.2.1) by marking in a spreadsheet. Detailed definitions, rules, and examples of the three dimensions were provided both in written and orally, and the judges were trained on a coding example with discussion prior to working individually. For D2 the two judges made an agreement on their understanding: "yes"

(definitely) indicates one's motivation is to be sustainable (e.g., I am also interested in a "green" product beyond energy conservation, such as being made free of lead); and "could" (possibly) means one's behavior or choice has a positive effect on sustainability, but the motivation may or may not be about sustainability (e.g., I like to have a power save function since my utility bills are high). The judgments were conservative, as evidenced in Table 4.4 through Table 4.6, which list all elements judged to definitely or possibly mention sustainability. For D1, D2, and D3 combined, initial agreement between judges on the 274 individual items was 74%. The other 26% were re-judged and discussed to 100% agreement.

Table 4.4. Individual instructions judged as related to sustainability in emails: definitely or possibly mentioned sustainability.

#	Individual instructions judged as related to sustainability in emails	Considering sustainability?	
		Yes	Could be
1	I would like to save power, so a toaster that minimizes power consumption during or not during use is an added bonus.	1	
2	Any sorts of energy saving features are important to me. With that in mind, if there is an option to engage an energy saving mode on the toaster, I would most certainly prefer that toaster. [Importance order: 1a]	1	
3	Any sorts of energy saving features are important to me. With that in mind, if there is an option to engage an option to only use one of the toaster "slots" during the operation, I would most certainly prefer that toaster. [Importance order: 1b]	1	
4	I am not interested in a product, which has digital read-outs or a clock or any "indicator" lights that will require energy usage when the toaster is not in operation or extra energy use when the toaster is in operation. [Importance order: 2]	1	
5	I am also very interested in a "green" product beyond energy conservation. With that in mind, if the product has been made with recycled content materials, been made free of lead and other toxins in the production process, has a return option for recycling at the end of its useful life for me, and/or a donation to a non-profit is made as a result of purchasing the product, these are things I would like to support and would be interested in that product. [Importance order: 6]	1	
6	Power saving ([I] tend to use a lot of electricity and my bills are high and [I] am very forgetful with things. Therefore this option best suits a lazy person) [required, importance order: 1]		1
7	Heating options (this is standard with toasters but if there are toasters with more than three options it would be better) [required, importance order: 2]		1
8	Extra features (like heating slices individually) [required, importance order: 3]		1
9	[E]rgonomics features (it shouldn't allow too much heat to transfer to the outer walls of the toaster) [required, importance order: 4c]		1
10	[A] cover is not needed as I consider it just another part that can break down		1

Table 4.4. Individual instructions judged as related to sustainability in emails: definitely
or possibly mentioned sustainability (Continued).

#	Individual instructions judged as related to sustainability in emails	Considering sustainability?	
		Yes	Could be
11	[O]ther considerations are: quality of craftsmanship ([I] prefer sturdy metal body, [k]nobs/buttons/slider should not be flimsy)		1
12	[O]ther considerations are: energy efficiency		1
13	The most important aspect to consider is build quality - I'd rather have a toaster with fewer features that will last longer than one that with all the features but breaks in the first year.		1
14	Please choose a toaster that has individual controls for toasting either one slice of bread or two, I'm the only one who will be eating and sometimes I would like to just have one slice instead of two.		1
15	Price is not a concern for me. I am expecting the price to be fairly expensive, but I would rather purchase a reliable toaster (last longer) now and spend a little extra, rather than have to purchase another one 3 or 4 years down the road.		1
16	I would prefer the longest warranty, just in case something does happen.		1
17	Even though I definitely want two slots, I would like a toaster that has two separate levers for each slot. Sometimes I am not toasting two pieces and I hate when one side is on and burning the crumbs inside.		1
18	I am also very interested in the integrity of the product and durability. One of the best ways I have found to gauge this is by the warranty offered by the manufacturers. With this in mind, a product having a warranty of two years or more would be a preferred product. [Importance order: 3]		1

Table 4.5. Individual questions judged as related to sustainability in Q-Info:
definitely or possibly mentioned sustainability.

#	Individual questions judged as related to sustainability in Q-Info	Considering sustainability?	
		Yes	Could be
1	Are there other environmental features, besides energy savings (if applicable) of the product, if so what are they?	1	
2	Which one is more durable?		1
3	Which one is faster in achieving the needed heating?		1
4	[H]ow long can I use for this toaster? Is it easy to broken?		1
5	Is the power level adjusted by the knob [dial] or just the toasting time [is adjusted by the dial]?		1
6	How sturdy is the construction of these?		1
7	What material is the body made of (Metal? Plastic?)		1
8	How much power would it need at maximum brown[ness]?		1
9	How hot are the three temperature settings?		1
10	What is the power save?		1
11	The power. Are all models have same heating time?		1
12	Are all models turn off by themselves after the toasting is done?		1
13	What is the build quality like between the toasters? Are they all equal?		1
14	[R]eliability - how long will they last?		1
15	Is there a warranty available for the toasters?		1
16	How long is the average lifespan of the toasters- will I need to buy another in a few years?		1

Table 4.5. Individual questions judged as related to sustainability in Q-Info: definitely or possibly mentioned sustainability (Continued).

#	Individual questions judged as related to sustainability in Q-Info	Considering sustainability?	
		Yes	Could be
17	What is the energy usage?		1
18	Are there energy saving features, if so what are they?		1
19	What is the product's warranty?		1
20	Do they have any warranty?		1

Table 4.6. Individual reasons judged as related to sustainability in Q-Rationale: definitely or possibly mentioned sustainability.

#	Individual reasons judged as related to sustainability in Q-Rationale	Considering sustainability?	
		Yes	Could be
1	[F]unctions available- power save.	1	
2	Power saving was the best as it had a bagel option as well.		1
3	Next [I] chose the one with a single slice toasting option incase [I']m not too hungry.		1
4	[E]ndurance.		1
5	Don't really know the effect of the closing doors on the top but I doubt the added effect (shorter time to brown?) would be worth the potential hassle and change to break down. I would use it as a major criterion if it would save a lot of power, though.		1
6	I chose the toaster that had two levers for each slot- although I'm not sure if this would make a difference, but it could be helpful if you needed to adjust one slice differently than the other.		1
7	I then looked at the features that seemed more relevant or useful to my needs. The energy saver mode on the toaster I chose was not a feature that I commonly would have pursued, but it seemed like a nice useful feature especially since I do not use my toaster frequently and so that toaster seemed to have the greatest number of features that I found useful.		1
8	I liked the one that allowed for toasting one slice instead of two.		1
9	[E]ase of use- proper function all of the time.		1
10	[E]ssential functions (toaster function has to work every time).		1
11	I also then took into account if the toasters had one or two levers for each slot.		1
12	Also, I noticed one of the toasters had a "Power Save" button, which ultimately ended up being my number one choice.		1
13	Energy savings features - preference was given to the toaster with a specific power save feature.		1
14	Energy savings features - preference was given to the toaster with the ability to engage one "slot" of the toaster rather than only both slots during operation.		1
15	Simplicity of design - preference was given to toasters that did not have a lot of extra features or gadgets as part of the operation such as digital printouts.		1

4.3. Results

The 22 respondents provided 120 individual instructions (Email), 67 questions asking for additional information (Q-info), and 88 individual components of their rationales for the decisions they made (Q-Rationale). For the control condition, Toasters

8 and 3 were selected for purchase most frequently, and Toaster 12 for the test condition. On average, there were 3 toasters in a subject's consideration set in the test condition and 3 toasters in a control condition consideration set.

Table 4.7 summarizes the results for each hypothesis. Overall, only 7 items were classified by the judges as definitely related to sustainability while 46 were classified as possibly related to sustainability (see Table 4.4 through Table 4.6 for details). In this section, the two categories are combined and abbreviated as "def/pos" in writing and in tables and analysis.

Table 4.7. Summary of hypothesis testing.

Hypotheses	Quantified relationship	Data used	Sig. level	Evidence presented in
H1a: Subjects in condition A consider products from the ST set more frequently than subjects in condition B consider products from the extra set.	$ST_A >$ Extra $_B$	Consideration (counts)	p>0.1	Section 4.3.1
H1b: Subjects in condition A purchase products from the ST set more frequently than subjects in condition B purchase products from the extra set.	$ST_A >$ Extra $_B$	Choice (counts)	p>0.1	Section 4.3.1
H2: Sustainability is more frequently mentioned as a purchasing instruction by subjects in condition A than subjects in condition B	% (Def/pos=1) $_A$ > % (Def/pos)=1) $_B$	Email (binary)	p<0.05 *	Table 4.8, Fig. 4.5
	Def/pos $_A >$ Def/pos $_B$	Email (counts)	p<0.05 *	Table 4.8, Fig. 4.5
H3: Subjects in condition A more frequently seek information of the products on sustainability than subjects in condition B	% (Def/pos=1) $_A$ > % (Def/pos=1) $_B$	Q-Info (binary)	p>0.1	Table 4.8, Fig. 4.5
	Def/pos $_A >$ Def/pos $_B$	Q-Info (counts)	p>0.1	Table 4.8, Fig. 4.5

The email data had 17 def/pos sustainability-related-instructions in the test condition and 1 in the control. No interesting findings were found on patterns of decision making rules and thus the data on D3 are not reported here. In Q-Info, 20 individual questions were identified as def/pos related to sustainability, with the large majority (14) coming from subjects in the test condition. In Q-Rationale, 14 out of 15 def/pos sustainability-related-reasons were from the test condition.

4.3.1. Testing on Considerations and Choices

Analysis of variance (ANOVA) approach was used to compare the quantity of toasters considered from the targeted toasters, those from the extra set or the ST set. ANOVAs were conducted with total number of the targeted toasters "considered" by each subject as responses and "condition" as an independent variable. No significant differences were found in considerations (test vs. control: 1.9 vs. 1.7, $p > 0.1$). Nominal logistic regression on whether the final purchase made by a subject was from the targeted toasters or not did not show significance either ($p > 0.1$). 73% subjects in test A purchased targeted toasters, while the corresponding number in control B is 55%. Thus Hypotheses 1a and 1b are not supported.

4.3.2. Testing on Mentions of Sustainability

To test Hypotheses 2 and 3, the coding data were processed in two ways: first, individuals were coded as binary data: 1= definitely "Yes" or possibly "Could", or 0= "Not" mentioning sustainability; next, individuals were coded by count of the number of times they def/pos mentioned sustainability. A logistic regression analysis was applied on the binary data, while ANOVA was conducted for the counts. A summary of number of subjects that def/pos mentioned sustainability, mean counts of mentions per subject per condition, and statistical significance are shown in Table 4.8. It indicates that the responses classified as possibly mentioning ("Could") sustainability dictate whether or not the differences between the test and control condition are found to be significant. Definite and possible mentions of sustainability are combined, termed "def/pos" in the tables. This is noted as limiting the strength of the differences. Two graphs in Figure 4.5

depict percentage of subjects' def/pos mentioning sustainability (i), and mean counts of mentioning (ii) for each condition in Q-Info and email task, respectively.

Table 4.8. Logistic regression and ANOVA reveals that subjects in condition A are more likely to def/pos mention sustainability. ('*' p<0.05, compared to control condition B)

		Number of subjects that mention suitability			Mean count of mentions per subject		
		Logistic regression			ANOVA		
		Yes	Could	Def/pos	Yes	Could	Def/pos
Email	A	2	6 *	8 *	0.5	1.1 *	1.5 *
	B	0	1	1	0	0.1	0.1
Q-Info	A	1	7	8	0.1	1.2	1.3
	B	0	5	5	0	0.5	0.5
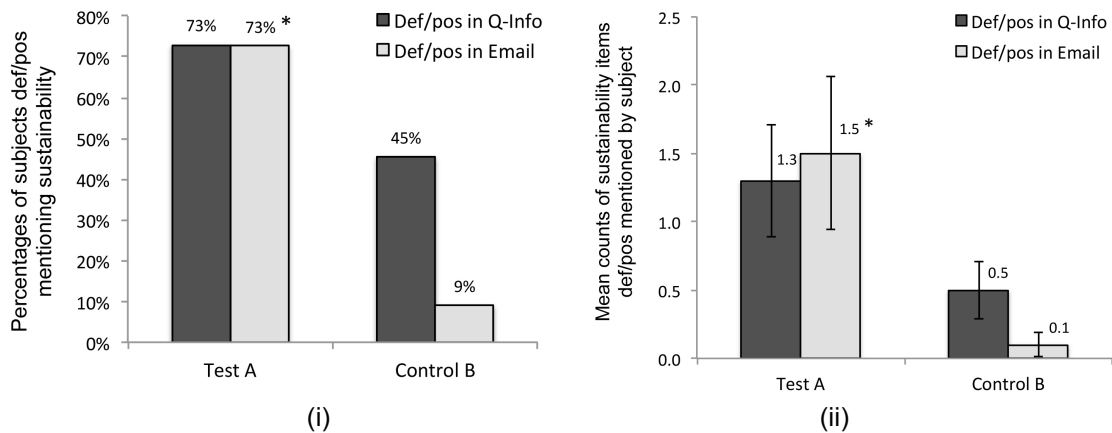
Figure 4.5. (i) More subjects def/pos mention sustainability in the test condition. (ii) Subjects def/pos mention sustainability more frequently in the test condition; error bars show ±1 standard error.

On email data, the logistic analysis revealed that more subjects in the test condition definitely or possibly mentioned sustainability than in the control condition (73% vs. 9%, p<0.05). More sustainability-related criteria, definitely or possibly, were mentioned to instruct an agent to buy a toaster in the test condition as supported by ANOVA (1.5 vs. 0.1, p<0.05). Therefore, H2 is supported.

No dramatic difference was found in Q-Info between the test and control conditions, either by logistic analysis on binary data (73% vs. 45%, p>0.1) or ANOVA on counts (1.3 vs. 0.5, p>0.1). H3 is not supported.

4.3.3. Sustainability Instructions Mentioning ST Features vs. Not Mentioning

Email instructions and Q-Info items were categorized as mentioning ST features (ST) and not (No-ST), based on judgments on D1 (See Section 4.2.1 for the definition of D1). Mentioning an ST feature is different than being judged as def/pos mentioning sustainability. ST features are designed to trigger thoughts of sustainability, and are not the same as actual sustainability. For example, an embossed leaf pattern does not make a toaster more sustainable. The classification in these separate dimensions is detailed in Table 4.9. ANOVA on email data shows that def/pos sustainability-related instructions mentioned ST features significantly more in the test than control (0.6 vs. 0.0, p<0.05). Additionally and importantly, instructions not mentioning ST features also reached significance at p<0.1 level (1.0 vs. 0.1, p=0.0501<0.1).

Table 4.9. ANOVA shows that def/pos sustainability instructions, even those that do not mention ST features, are more prevalent in the test condition. ('*' p<0.05, "." p<0.1)

Sustainability	Condition	Mention ST Feature	Not Mention ST Feature
Def/pos=1 (mentioned)	Test A	0.6 *	1.0 .
	Control B	0.0	0.1
Def/pos=0 (Not)	Test A	0.4	4.9
	Control B	0.1	4.5

4.4. Discussion

The experiment only supports hypothesis 2 (see Table 4.7 in Section 4.3 for a summary): sustainability-triggering features of a product increase thoughts of

sustainability during purchasing decision making. There is one caveat to this: the hypothesis is tested on a combination of data that definitely and possibly mentioned sustainability vs. did not mention sustainability. There was not enough data judged as definitely mentioning sustainability to analyze this category on its own. Review Table 4.4 through Table 4.6 to see how judges conservatively distinguished between definitely and possibly mentioning sustainability- the items in the "Could" category do demonstrate a change in perspective for the subjects. The difficulty of judging an instruction as definitely mentioning sustainability is due, in part, to the nebulous nature of the term, and customer misunderstanding of what is sustainable. With this caveat in mind, subjects that were exposed to ST features did def/pos mention more sustainability-related instructions in their emails to a toaster-buying agent. Significance in both the number of subjects that def/pos mention sustainability and frequency of mention in the email task suggest that subjects in the test condition had heightened sustainability awareness.

One possible explanation of the difference in the mention of sustainability is simply that the subjects in the test condition were mentioning ST features in their instructions, features that the control condition did not see. The results in Section 4.3.3 suggest that this is not the case. Email instructions that were judged as def/pos related to sustainability, but did not mention ST features, are significantly more frequent in the test condition at $p=0.0501$. This suggests that evaluating products with ST features activates customer thoughts of sustainability or associated feelings such as social responsibility. For example, emails from the test condition mentioned good insulation, longer life-span,

durable knobs and buttons, energy efficiency, and donations to a non-profit with purchase. The theory of construction of preference explains this observation: the presence of ST features changes decision context. It may be that well-designed ST features heightens sustainability awareness and activates sustainable behavior. It may be that ST features align with customer interests in cutting bills or having more options, and this activates other latent preferences. It is also possible that the presence of ST features in the choice context lessen frustrations with lack-of-options for addressing sustainability, and thus causes the subject to request even more options.

While decision context and decision approach changes towards a more sustainable mindset in the test condition, the resulting purchases patterns are similar to a control that simply included extra features. The extra lift and defrost functions influence final purchase and consideration set formation about as much as the ST features do. Therefore it is not possible to say that these particular ST features cause a change in purchase behavior that is larger than randomly-added features. This implies that while choice context changed, it did not change final purchase in a manner that was noticeably different from a control condition. Note, again, that the ST features presented do not necessarily decrease the environmental, economic, or societal impacts of a toaster. An embossed leaf pattern is not a sustainable feature. Thus, it is reasonable that final purchase pattern would not change in the presence of these ST features, because subjects were looking for additional information on sustainability that was not provided—this idea is examined and supported by the research presented in the next chapter. Purchase pattern may have changed if had the subjects been given the additional information on

the true sustainability of the products as they requested in the course of the study (Q-Info). Further, price was not included in the study- had it been, it is possible that subjects were willing to pay more for toasters with ST features than extra features.

4.5. Summary

This research examined how carefully-designed product features can influence product decision context. It determined that the presence of features specifically designed to trigger thoughts of sustainability caused subjects to think about sustainability and increased their requests for sustainable products in a purchase task. The results are significant only when both possible and definite mentions of sustainability are pooled in the tests.

A toaster is a low-price, low-risk product with few features and options, therefore, the results should be applied with care to high-price products with many features. Also, the subject pool was educated, with slightly more than half of the subjects having received masters or doctoral degree. Most of the subjects indicated having purchased a sustainable product in the past, but the overall commitment to sustainability was not tested. While education and purchasing habits may limit the generalization of the findings, they did not confound the triggering effect of ST features, as education and sustainable purchases were distributed almost equally between the test and control conditions. Unlike other engineering design research that considers final choices of customer decision making (e.g., [11, 111, 112]), the study reported in this chapter examines shaping of decision context of customer decisions: it demonstrates that specifically-designed features can change customer thoughts about related topics, cause

them to seek different information. The marketing experimental approaches: consider-then-choose and unstructured direct-elicitation are the first time used in engineering design research to see if design can change customer considerations and perceptions. UDE proves to be useful, while the application of consider-then-choose is limited for this small scale study with simple products, which have very few features included.

The effect of communication features on final choices is still unknown, due to lack of product information provided in Study 2. It is of interest to engineers and marketers about what will happen when the information as requested by the subjects in Q-Info is offered. Chapter 5 will investigate if the presence of ST features positively influences preference for sustainable products with information on actual sustainable attributes, such as energy usage and shipping method. Price differentials are also included. This will be measured using search, choice, and willingness-to-pay tests.

5.   TRIGGER FEATURES INCREASE CHOICES FOR SUSTAINABLE PRODUCTS

5.1. Introduction

Since the 1960s, qualitative tools such as quality function deployment (QFD) have helped designers transform customer needs into design quality while considering tradeoffs amongst technical characteristics. More recently, researchers have incorporated explicit and quantitative models of customer preferences into engineering design decision-making, as in the examples given in Section 4.1. While realizing the importance of incorporating customer preference in engineering design, little has been done to understand how design features shape decision context and thus affect preferences within the engineering community. This Chapter explores the preference-building, particularly for sustainable products, with various user research approaches.

Chapter 4 demonstrates that ST features cause subjects to think about sustainability but does not cover final product choice. This chapter tests if ST features can alter customer choices when actual sustainable attributes compete with other attributes in a choice scenario while investigates underlying reasons for the changes. The work presented here is an application of Tybout and Hauser's customer behavior model (Figure 5.1) [114] to sustainable products. This models customers as perceiving the products, aggregating perceptions, forming preferences, and subsequently making choices under constraints. In the context of the current study, customers perceive the ST features, the features make them think about sustainability, motivate them to search for information on actual sustainability, and finally affect choices.
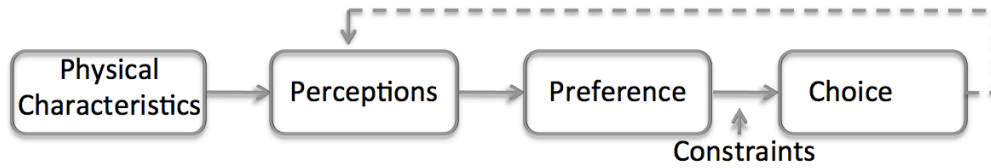
Figure 5.1. Tybout and Hauser's customer behavior model, adapted from [114].

It is expected that viewing ST features leads customers to seek hidden information on product sustainability, increases the importance of attributes that state a product's sustainability, and shifts purchases towards more sustainable products, as illustrated in Figure 5.2. In this study, subjects performed tasks, such as making choices, ranking attributes, and providing willingness to pay. Capturing changes in choices is the main goal of this study, with approaches such as trust/importance rating and eye tracking employed to identify underlying reasons for these changes.
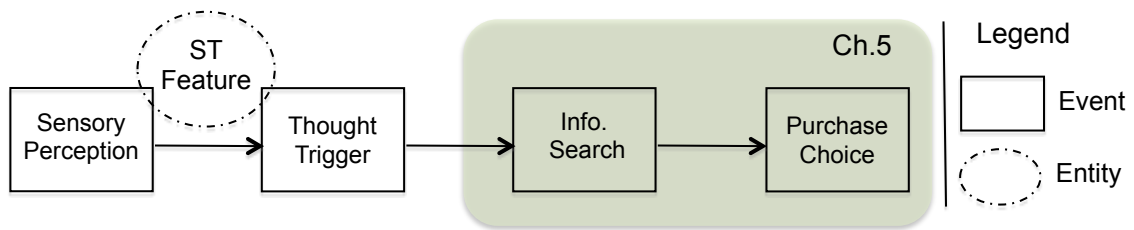
Figure 5.2. Theoretical ST effect on customer decision-making regarding sustainable products (The shaded part is tested in Chapter 5).

Eye-tracking is a relatively new technique in engineering design. It is based on the principle that eye movements provide a window into cognition [115], i.e. gaze data captured from eye tracker provides insights into human cognitive processes to facilitate the understanding of decisions or behaviors. This chapter uses gaze metrics, such as fixation time (duration of each individual fixation within a predetermined area), and

fixation count (number of times a participant fixates on an area) [116] to explore how subjects' attention is allocated when evaluating a product on the screen.

In Sections 5.2 and 5.3, the research proposition and associated hypotheses are presented, followed by experimental process. Sections 5.4 and 5.5 detail results and discussions. The chapter is concluded with a summary of findings.

5.2. Research Hypotheses

The author proposes that ST features not only trigger customers to think about sustainability, as tested in Chapter 4, but also result in the purchase of the sustainable product option. In this context, energy usage and shipping method are two hidden attributes on actual sustainability of a toaster, represented in written form within a long list of other attributes. A sustainable product is defined as a toaster with less energy usage and/or shipped by boat instead of plane.

The proposition is formulized as more specific hypotheses in Table 5.1, to explore ST effect on choices, willingness to pay, trust, importance of sustainability, information search, and attention during product evaluation.

Table 5.1. Hypotheses to be tested.

Hypotheses		
The presence of ST features	H1	increases choice for a sustainable product.
	H2	increases the difference in WTP between sustainable and "normal" products.
	H3	increases ranking of sustainable attributes in the list of attributes to know.
When subjects review products on the screen, the presence of ST features	H4a	increases percentage fixation time on sustainable attributes.
	H4b	increases percentage fixation count on sustainable attributes.
The presence of ST features	H5	increases the importance of a product's sustainability in choices.
	H6	increases trust of a product's sustainability.

5.3. Method

5.3.1. Subjects

Thirty-eight subjects were recruited from Iowa State University campus and the surrounding areas by email, Craigslist advertisement, and fliers. They received $5 cash compensation for participation. 61% are female and 63% have purchased sustainable products in the past. Subjects were randomly and equally assigned to either a test (A) or control condition (B), described below. Table 5.2 summarizes subject demographic information by condition. Note that majority of the subjects are not students.

Table 5.2. Summary of demographic information of the subjects in each condition (N=19 per condition).

Age	Cond. A	Cond. B	Income	Cond. A	Cond. B	Education	Cond. A	Cond. B	Occupation	Cond. A	Cond. B
18-25	8	8	<25k	6	6	Some college	2	9	Student	8	8
26-35	6	7	25k- 50k	4	2	College degree	12	5	Non-student	11	11
36-45	1	0	50k-100k	4	2	Masters degree	4	5			
46-55	2	2	>100k	2	6	Doctoral degree	1	0			
56+	2	2	No answer	3	3						

5.3.2. Experiment Design and Procedures

Subjects were exposed to toasters with ST features in condition A and no ST features (control) in condition B. Stimulus design is discussed in the next section (5.3.3). Table 5.3 lists the tasks that subjects have performed.

Table 5.3. Experiment flow.

Step	Experiment content
1	Choice task (3 choice sets)
2	Equal value task (2 choice sets)
3	Revealed information task (1 choice set)
4	Eye-tracking survey (4 toasters)
5	Attribute importance rating (9 attributes)
6	Trust rating (3 toasters)
7	Post-survey: demographics, purchasing habits, sustainability awareness, etc.

In Step 1, subjects were shown two physical prototypes at a time, each with a corresponding information card (see Figure 5.3 for an example). They were asked to make a purchase decision between the two toasters presented. This was repeated for three pairs of toasters, for a total of three purchase decisions.

Pair 1

Toaster A		Toaster B	
Bagel function :	No bagel function available	Bagel function :	Can toast bagels
Defrost function :	Defrost function available	Defrost function :	No defrost function available
Energy per toast :	Fourteen watt-hours / toast	Energy per toast :	Sixteen watt-hours/ toast
Dial shape :	Cylindrical dial	Dial shape :	Tapered dial
Dial metric :	Measured in colors	Dial metric :	Measured in numbers
Activation lever :	One per slot pair	Activation lever :	One per slot pair
Exterior case :	Cool touch exterior	Exterior case :	Cool touch exterior
Toasting slots :	Self-centering	Toasting slots :	Not self-centering
Extra lift :	Extra lift function available	Extra lift :	No extra lift function available
Cord storage :	No excess cord storage	Cord storage :	Can store excess cord
Shipping method :	Shipped by boat	Shipping method :	Shipped by plane
Customer review :	Three out of five stars	Customer review :	Four out of five stars
Country of origin :	Made in China	Country of origin :	Made in China
Price :	$14.99	Price :	$16.99

Figure 5.3. Example information cards.

In Step 2, subjects completed an equal value task, writing-in a missing price for a toaster so that the two toasters presented were equally appealing. One toaster had a price of $15.99, and the other had an area to write-in-price. The equal value task was performed twice. Subjects were asked to name a price for a sustainable toaster in one pair (where the "normal" toaster had a price of $15.99), and a "normal" toaster in the other (where the sustainable toaster had a price of $15.99).

In Step 3, subjects completed a revealed information task. Subjects were again asked to make a purchase decision between two toasters. Some attributes cannot be obtained directly from visual inspection of the prototypes (see six attributes in italics in

Table 5.4), such as customer rating and energy usage. In Step 3, the configuration of these attributes was concealed under strips of paper on an information card, see an illustration in Figure 5.4. Subjects were asked to rank their desire to see these attribute configurations from most to least. Then, they were shown their top-three picks and made a purchase decision based on the information revealed about the two toasters, along with what they could see on the physical prototypes.

Toaster K	Toaster L		Toaster K		Toaster L
Extra lift			Extra lift		
Cord storage			Cord storage		
Toasting slots (self-centering or not)			Toasting slots (self-centering or not)		
Customer review			Three out of five stars		Four out of five stars
Energy usage per toast			Eighteen watt-hours / toast		Sixteen watt-hours/ toast
Shipping method			Shipping method		
Country of origin			Country of origin		
Price			$14.99		$16.99

(i) Attributes configurations are concealed	(ii) Top three attribute configurations are revealed

Figure 5.4. An illustration for Step 3: (i) The attribute information of a pair that cannot be obtained directly by visual inspection of the physical prototypes are concealed under strips of paper. (ii) After a subject ranks the attributes, the first three attributes in the subject's rank are revealed.

In Step 4, subjects worked on an eye tracker/computer screen that recorded participants' eye movements. Subjects wrote-in the cost of a toaster. On one stimulus screen, they saw an image of a toaster on the left, while text descriptions on the right. On a following question screen, they wrote-in how much it cost. Four sets of stimulus and question screens were shown. Price was removed on all the stimulus screens, and ST features were added only to the first two toasters shown in the test condition in the eye-tracking survey. The four toasters from Pairs 2 and 3 used in Step 1 (see Table 5.5 in Section 5.3.3 for details) were photographed and made into on-screen stimuli for the

eye-tracking survey. Energy usage and shipping method were randomly positioned in the list of attributes for all four toasters, with restriction that these attributes did not appear in the first or last two rows. In the survey process, subjects' eye movements were recorded by Tobii Studio software. Due to computer issues, four subjects did not take the eye-tracking survey, which resulted in 17 subjects in each condition for this step.

In Step 5, subjects rated how important each attribute was in forming their decisions in the survey thus far, from 1 (not important at all) to 5 (very important). To keep consistent in both conditions, the ST features (visible on the prototypes) were not included in this rating.

In Step 6, a trust rating task captured how subjects perceived the actual sustainability of a toaster. Toaster (i) from Pair 1, (ii) from Pair 2, and (ii) from Pair 3 in Table 5.5 of Section 5.3.3 were selected as stimuli for the trust-rating task. Subjects were provided with three toaster images online (with all attributes included), each with a randomly assigned set of ST features, see an example stimulus in Figure 5.5. As people are usually serious about recommendations, the trust-rating question was framed as below:

"Imagine one of your friends is actively seeking out a low-environmental-impact toaster to buy and use. How confident are you in introducing this toaster to him/her as a low-environmental-impact toaster?

Please indicate your confidence level for each toaster from 0% to 100%, where,
0%- Not confident at all in introducing it as a low-environmental impact toaster.
100% - Definitely confident in introducing it as a low-environmental impact toaster."

Figure 5.5. Screenshot for a trust-rating task.

Lastly, in Step 7, subjects finished a post-experiment survey about their demographics, purchasing habits, sustainability awareness, and so forth.

5.3.3. Stimulus Preparation

Selection of Toaster Attributes and Levels

Consistent with Study 1 and Study 2, toasters were selected as the case product; all toaster prototypes were in black color, of non-specific brand, and had two slots. Customer interviews and web research identified a list of basic attributes and sustainable attributes. All of the ST features prototyped in the work in Chapter 4 were included in this study, except for slot covers, which were perceived as another part that is easily broken, as reported by some subjects in Study 2. All of the attributes are reported in Table 5.4, with attributes in rows and attribute levels (configurations) in columns.

Table 5.4. Attributes and levels selected.

Group	Attribute		Level 1	Level 2	Level 3
I Basic & II ST	Bagel function	:	Can toast bagels	No bagel function available	
	Defrost function	:	Defrost function available	No defrost function available	
	Dial shape	:	Cylindrical dial	Tapered dial	
	Dial metric	:	Measured in numbers	Measured in colors	**Measured in watts**
	Activation lever	:	One per slot pair	**One per slot**	
	Exterior case	:	Cool touch	Cool touch, **with leaf pattern**	
	Toasting slots	:	*Self-centering*	*Not self-centering*	
	Extra lift	:	*Extra lift function available*	*No extra lift function available*	
	Cord storage	:	*Can store excess cord*	*No excess cord storage*	
	Customer review	:	*Four out of five stars*	*Three out of five stars*	
	Country of origin	:	*Made in China*		
	Price	:	*$14.99*	*$15.99*	*$ 16.99*
	Power save	:	**Power save function available**		
III Sust.	*Energy per toast*	:	*Fourteen watt-hours*	*Sixteen watt-hours*	*Eighteen watt-hours*
	Shipping method	:	*Shipped by boat*	*Shipped by plane*	

-    **Bolded: ST features/levels**
-    *Italic: Attributes that are only presented on information cards in written words*

There were three types of attributes: basic, ST features, and sustainable attributes. Basic attributes were included to create a variety of toaster profiles, and most importantly "hide" the sustainable attributes in a long list of attributes. They also increased the challenge of decision-making. They were: bagel, defrost, dial shape, dial metric, number of activation levers, exterior case, self-centering slots, extra lift, cord storage, customer review, country of origin, and price. The ST features were only included in the test condition. They were: two activation levers—one for each piece of bread, power save function, embossed leaf pattern, and dial metric measured with power levels (See Figure 4.2, Chapter 4, Features B, C, D, and E). Sustainable attributes were included in both conditions, included as indicators for actual sustainability of a toaster, as pre-tested with some subjects in Pilot Study 2. They were: energy usage per toast (14 watts-hours/ 16 watts-hours/ 18 watts-hours) and shipping method (shipped by boat/ shipped by plane). "Watts-hours" is abbreviated to "WH" here and throughout the

chapter. A toaster with a lower energy usage and/or shipped by boat is a sustainable toaster as pretested in the next section.

Profile Design

Using basic attributes and sustainable attributes, the author constructed a set of profiles and revised them based on three runs of pilot studies. Six pairs of toaster profiles were finally selected, according to the following criteria: (1) To make the decision challenging, one toaster is not obviously better than the other within each pair; (2) To make two toasters distinguishable on their actual sustainability, energy usage within a pair must be different; when shipping methods within a pair are different, the lower-energy-usage toaster must be shipped by boat.

Pilot study 1 tested descriptions of all the attributes and levels with four native English speakers, and edited them until confusions and inappropriateness were resolved, as listed in Table 5.4. Pilot study 2 asked 20 subjects to cluster toasters into groups based on their overall preference, then rank each group as a whole from the most preferred group to the least preferred group. An initial test showed eighteen toasters with written descriptions of all attributes (10 subjects). It was found that too many profiles with too much information on each card made the task too difficult for subjects to work on within ten minutes. Thus, a modified study was conducted with another 10 subjects, using the same method, but reducing the number of profiles to nine, and deleting attributes that do not change in the control condition, such as activation lever, and attributes that are relatively trivial, such as dial shape and dial metric. Frequency of a pair that appeared in a group, and average group ranking for each toaster were calculated. Combining these

two measures while considering the necessary restrictions for each pair, the author selected six pairs of toasters. These toaster pairs were not meant to be really equal, but to make the choice within each pair more challenging, and thus to stimulate subjects to think about it carefully. From talking to the subjects, it was found that most subjects viewed a lower-energy usage toaster as more sustainable, and more than half of them also associated being shipped by boat with sustainability. Further, using a $1 increment in price made decisions challenging enough: subjects considered price, but did not sort toasters mainly based on price. With this price differential, they considered functions first, and then made tradeoffs for price. Pilot study 3 confirmed "equal" pairs with six subjects by using physical prototypes and full information cards. Subjects were asked to select a toaster to buy within each pair, and distribute 100 points between the two. The choice data showed that the pairs were challenging enough to use for the full study. Table 5.5 summarizes toaster stimuli shown in each step.

Table 5.5. Toasters, ST features, and sustainable attributes presented in each step.

Step	Task	Pairs of/ individual toasters	ST features added in the test condition	Sustainable Attributes for Toaster (i) and (ii) in Pair
1	Choice task (3 choice sets)	Pair 1	Power save function	(i): 14 WH, boat (ii): 16 WH, plane
		Pair 2	Two levers+wattage	(i): 18 WH, plane (ii): 16 WH, boat
		Pair 3	Leaf pattern+wattage	(i): 18 WH, plane (ii): 14 WH, boat
2	Equal value task (2 choice sets)	Pair 4	Power save function	(i): 14 WH, boat (ii): 18 WH, plane
		Pair 5	Two levers+wattage	(i): 16 WH, boat (ii): 14 WH, boat
3	Revealed information task (1 choice set)	Pair 6	Power save function	(i): 18 WH, plane (ii): 16 WH, boat
4	Eye-tracking survey (4 toasters)	Toaster 1	Two levers+wattage	18 WH, plane
		Toaster 2	Leaf pattern+wattage	18 WH, plane
		Toaster 3	N/A	16 WH, boat
		Toaster 4	N/A	14 WH, boat
5	Attribute importance rating	N/A	N/A	N/A
6	Trust rating (3 toasters)	Toaster a	Three sets of ST features were randomly added to Toasters a, b, and c.	14 WH, boat
		Toaster b		16 WH, boat
		Toaster c		14 WH, boat
7	Post-survey	N/A	N/A	N/A

Then the final stimuli were prepared. Each pair had two versions, one for the control condition and one for the test condition, with the same ST features added to both toasters within one pair. Toasters with sustainable attributes presented in each step, and ST features added in the test condition are summarized in Table 5.5.

5.3.4. Measures

Step 1 measures subjects' final decisions, while Step 2 to Step 6 explore underlying reasons for the decisions by measuring willingness to pay for a sustainable toaster, ranking and importance of, attention attracted by sustainable attributes, and trust on a toaster's sustainability. For statistical analysis, raw data in each step was coded and processed as below. Names of processed data are shown in *Italics.*

Choice: Choice data from Step 1 were coded for each pair: coded as "1" if a sustainable toaster was selected, otherwise, coded as "0."

Δ*WTP:* Willingness to pay (WTP) was tested using the write-in-price data from Step 2. Average Delta WTP *(ΔWTP)* was calculated across two pairs by averaging difference between the two toaster prices within each pair (one fixed at $15.99).

Ranking: Step 3 data was used to calculate average ranking for the two sustainable attributes: energy usage and shipping method, within the revealed information task, on a per-subject basis.

FT% and *FC%:* In Step 4, gaze data were collected by the Tobii Studio software. An area of interest (AOI) was manually created for each sustainable attribute of the toaster and the overall text area, as shown in Figure 5.6. After AOIs (energy usage, shipping method, and the overall text area) were created for each stimulus, gaze

data were exported for further analysis, including: fixation time and fixation count on energy usage, shipping method, and the overall text area. As subjects read text at different speeds, all gaze data on sustainable attributes were normalized as percentages. For example, percentage fixation time on energy usage was calculated by dividing the fixation time spent on the energy usage AOI by the fixation time spent on the whole text area. The subject-level measure of fixation time on sustainable attributes was calculated by summing percentage fixation time on energy usage and shipping method per screen, then averaging sums across the four stimulus screens, represented as *FT%*. The subject-level measure of fixation count on sustainable attributes was calculated in a similar way (*FC%*).
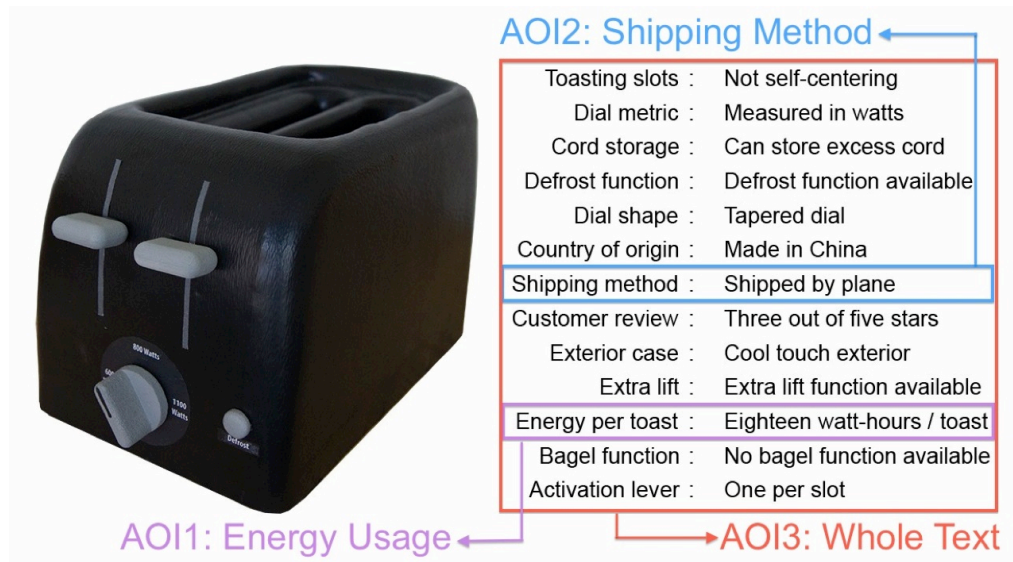

Figure 5.6. An example of the AOIs generated for a stimulus.

Δ*Importance:* Importance of sustainable attributes relative to non-sustainable ones was used as an aggregate level measure, per subject. It was obtained from data

collected in Step 5, by subtracting average importance rating for all non-sustainable attributes from the averaged importance of energy usage and shipping method.

Trust: Mean trust rating was calculated for each subject across the three toasters evaluated in Step 6.

5.4. Results

5.4.1. Overview

Data analysis was conducted in two parts. First, to test hypotheses, all measures were analyzed at an aggregated level, as reported in Section 5.4.2. Then, Section 5.4.3 details disaggregated results to examine potential variance sources for the test, namely, choice results within each pair in Step 1, and various results on individual sustainable attributes, including ranking in Step 3, attention (reflected on gaze data) in Step 4, and importance rating in Step 5. Table 5.6 summarizes the hypothesis testing, with the aggregated results on each measure in Table 5.7.

Table 5.6. Summary of hypothesis testing.

Hypothesis	Sig. Level	Measures Related	Evidence Presented In
1: The presence of ST features increases choice for a sustainable product.	$P<0.1$.	*Choice*	Table 5.7, Fig. 5.6
2: The presence of ST features increases the difference in WTP between sustainable and "normal" products.	$P>0.1$	*ΔWTP*	Table 5.7
3: The presence of ST features increases ranking of sustainable attributes in the list of attributes to know.	$P<0.05*$	*Ranking*	Table 5.7, Fig. 5.7
4a: When subjects review products on the screen, the presence of ST features increases percentage fixation time on sustainable attributes.	$P<0.1$.	*%FT*	Table 5.7, Fig. 5.7
4b: When subjects review products on the screen, the presence of ST features increases percentage fixation count on sustainable attributes.	$P<0.05*$	*%FC*	Table 5.7, Fig. 5.7
5: The presence of ST features increases the importance of a product's sustainability in choices.	$P<0.05*$	*ΔImportance*	Table 5.7 Fig. 5.7
6: The presence of ST features increases trust of a product's sustainability.	$P>0.1$	*Trust*	Table 5.7

Table 5.7. Aggregated results on measures ("*" p<0.05, "." p<0.1, compared to the control condition, "^" smaller value indicates higher ranking).

Condition	Measures						
	Sum of *Choice*	ΔWTP	*Ranking*^	*%FT*	*%FC*	$\Delta Importance$	*Trust*
Test A	33.	0.6	5.1*	18.9% .	19.4%*	-0.26*	61.7
Control B	23	0.7	5.9	16.3%	16.3%	-0.93	64.8

5.4.2. Aggregated Results

A nominal logistic regression was applied to *Choice*, with condition as an independent variable. It indicates that considering all three pairs, subjects are more likely to choose a sustainable toaster in the test condition than in the control condition (33 vs. 23, p<0.1), which marginally supports H1, as depicted in Figure 5.7.
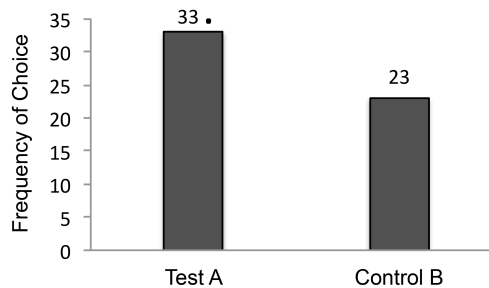

Figure 5.7. Sustainable toasters are more likely to be selected in the test condition, i.e., H1 is marginally supported (p<0.1, compare test A to control B).

ANOVAs were applied to ΔWTP, *Ranking, FT%, FC%,* $\Delta Importance$, and *Trust* separately. As shown in Figure 5.8, *Ranking* (test vs. control: 5.1 vs. 5.9, p<0.05), *FC%* (test vs. control: 19.4% vs. 16.3%, p<0.05), and $\Delta Importance$ (test vs. control: -0.26 vs. -0.93, p<0.05) are tested to be significantly different between test A and control. Thus H3, H4b, and H5 are strongly supported. *FT%* in the test condition is significantly greater than that in the control condition at 0.1 level (18.9% vs. 16.3%, p<0.1), which marginally supports H4a.
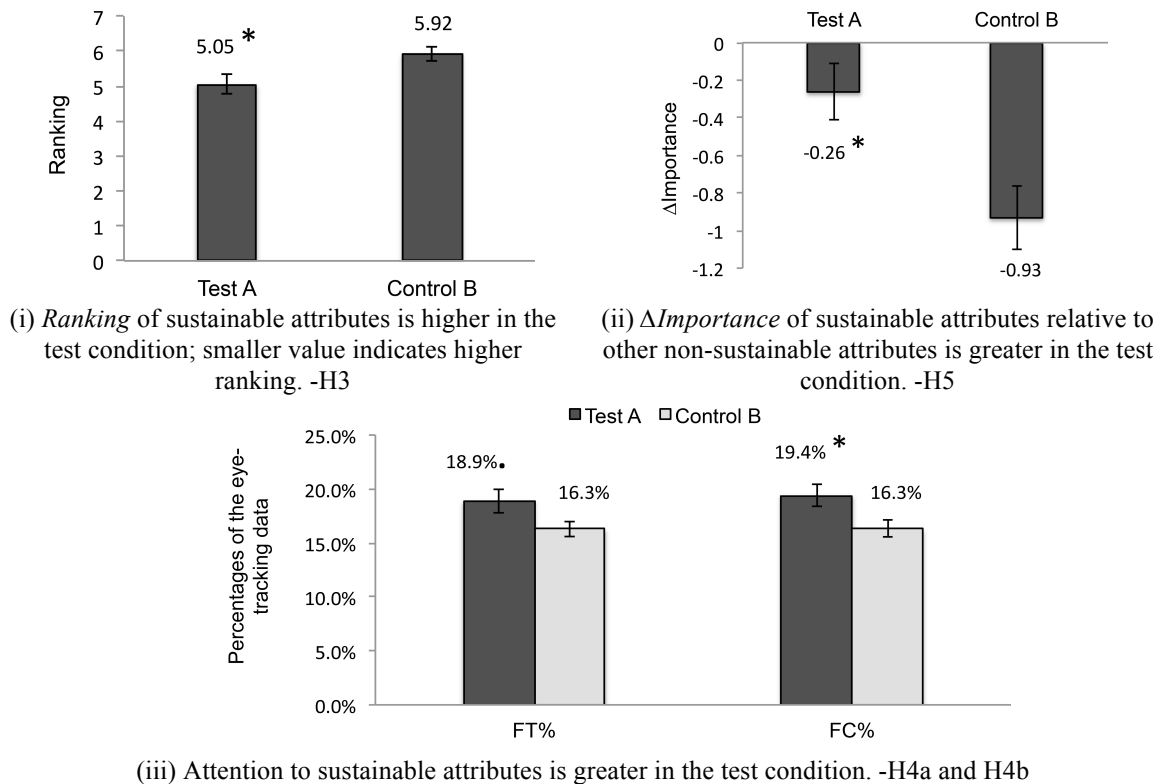
(i) *Ranking* of sustainable attributes is higher in the test condition; smaller value indicates higher ranking. -H3

(ii) Δ*Importance* of sustainable attributes relative to other non-sustainable attributes is greater in the test condition. -H5

(iii) Attention to sustainable attributes is greater in the test condition. -H4a and H4b

Figure 5.8. The presence of ST features increases ranking of, importance of, and attention to sustainable attributes ("." $p<0.1$, "*" $p<0.05$, compare test A to control B; error bars show ±1 standard error).

The other hypotheses are not supported: the presence of ST features does not increase the difference in Δ*WTP* between a sustainable and "normal" toaster (H2), and the trust of a toaster's sustainability (H6).

5.4.3. Disaggregated Results

Nominal logistic regressions were applied to *Choice* for each pair separately. Figure 5.9 depicts frequency of a sustainable toaster being selected, and statistical significance, for each pair. It shows that H1 is strongly supported by the results from Pair 3, which has a larger energy usage difference of 4 WH, vs. 2 WH in the other pairs.
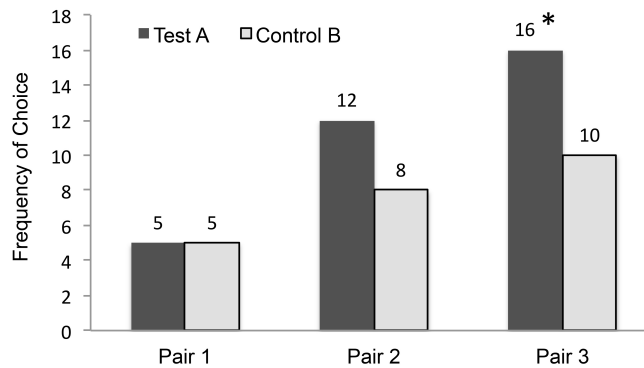
Figure 5.9. Nominal logistic regressions reveal that hypothesis H1 is strongly supported by choice in pair 3 ("*" $p<0.05$).

To check if ST features lead to differences of *Ranking, ΔImportance*, and attention (*FT%* and *FC%*) on individual sustainable attributes, detailed ANOVAs were conducted on energy usage and shipping method, without aggregation across the two attributes. For *Ranking*, shipping method is ranked higher (lower value indicates higher ranking) in test (test vs. control: 6.4 vs. 7.3, $p<0.05$), while energy usage is not (test vs. control: 3.7 vs. 4.6, $p>0.1$). *ΔImportance* is tested to be larger in the test condition only on energy usage (test vs. control: 0.13 vs. 0.11, $p<0.05$). For gaze data, only shipping method attracts significantly more attention in test than in control *(%FT*: 7.9% vs. 6.3%, $p<0.1$; *%FC*: 8.3% vs. 6.3%, $p<0.05$).

5.5. Discussion

The experiment supports hypotheses H1, H3, H4a, H4b, and H5: sustainability-triggering features increase choices of a sustainable product, mean ranking of sustainable attributes in the list of desired attributes to be revealed, gaze attention to sustainable attributes, and importance of a product's sustainability in choices. Note that hypotheses

H1 and H4a are only marginally supported at p<0.1 level. As the overall trends in the data leaned towards the support of the hypotheses, it is possible that with the collection of more data, stronger statistical significance could have been reached. Hypotheses H2 and H6 were not supported: there was no difference in WTP or trust in sustainability claims seen with the inclusion of ST features.

Results on H1 suggest that ST features altered subjects' choices towards more sustainable products weakly, but might get stronger when the difference in actual sustainability is larger. It is likely that even though ST features trigger customers to think about sustainability, whether or not this ultimately affects choice is highly sensitive to the context and details of the choice at-hand. The significance in Pair 3, which has larger difference in actual sustainability, might also be due to burn-in effect; i.e., without randomization of orders presented, the frequency of seeing ST features is increasing, and the triggering of sustainability considerations might get stronger and stronger.

Positive results on H3 and H5 partially explain why the alteration in choices happens: ST features increase importance of a product's sustainability in choices, and lead subjects to seek information on sustainable attributes. In addition, the analysis on gaze data corroborates the subjective importance rating and ranking, and demonstrates that subjects in the test condition did pay more attention to sustainable attributes, in terms of percentage fixation time (H4a) and percentage fixation count (H4b). The disaggregated analysis of *Ranking*, Δ*Importance*, and gaze data (*FT%* and *FC%*) varies: all of them show significant increase either on shipping method or energy usage, but not on both. It indicates a potential opportunity to research how ST features affect customer

evaluations on different types of actual sustainable attributes, such as sustainable attributes that are in line with customers' benefits (e.g., lower energy usage), and those that bring inconvenience to customers (e.g., being shipped by boat). Combining results from information search (*Ranking*) in Step 3, tracking eye movements on a survey (*FT% and FC%*) in Step 4, and attribute importance rating *(ΔImportance*) in Step 5 provides a preliminary understanding about how subjects evaluate sustainable attributes differently when ST features present or not.

Section 5.4.1 suggests hypotheses related to willingness to pay and trust are not supported, i.e., when both toasters within a pair have ST features, no evidence shows that subjects are willing to pay more for a sustainable toaster or less for a "normal" toaster, or more likely to trust a toaster's sustainability. For willingness to pay, it is possible that ST features caused subjects to pay more attention to shipping method (ranking and eye-tracking data support this), and then they also took the actual transportation cost (e.g., being shipped by plane costs more than by boat) into consideration. Trust rating on sustainability does not show significant difference across conditions. It is not sound to simply stretch ST effect and state that ST features can increase trust of a toaster's sustainability. Unlike communication or thought trigger, trust is a complex construct that incorporates multiple dimensions, such as cognition, emotion, and behaviors [117]. Design for trust requires an understanding of social elements and human subtleties of trust perception [118]. More effort is needed on investigating design features to increase trust.

This study could be furthered by conducting a follow-up study on Amazon Mechanical Turk to test ST effect on choices with a wider range of customers. Two versions of a survey could be designed. The only difference between the two versions is that toaster images have ST features or no ST features. Similarly, energy usage and shipping method will be two sustainable attributes, together with other basic attributes, but energy usage will only include two levels, 14 watt-hours and 18 watt-hours, as reasoned in Section 5.5, paragraph 2. To reduce anchoring effect on known price, willingness to pay question will be presented as the first part of the survey, showing one toaster image with attribute information at a time. To reduce leverage of shipping cost on WTP, all toasters in this part are shipped by boat but vary on energy usage and other basic attributes. Next, subjects will be prompt to make purchase decisions. Six pairs of toasters will be provided instead of three, as it is difficult to find a pattern with three pairs as tested in Study 3 reported here. Part three will examine what information subjects would like to know for facilitating a purchase decision. A list of attributes will be provided and subjects will be asked to select all the attributes that they want to know to help them make a choice. Part four will repeat Step 6 on trust rating of Study 3 reported in this chapter. Finally, the same post-experiment survey, with new questions on subjects' perceptions of energy usage and shipping method regarding their desirability and sustainability, will end the study.

5.6. Summary

Chapter 5 shows that adding ST features increases choice for a sustainable product at a weakly significant level, but strongly increases the importance of a product's

sustainability in a purchase decision and leads subjects to search for information on sustainable attributes. In addition, eye-tracking data provides insights into how sustainable attributes are evaluated when ST features present or not. Percentage fixation time and fixation counts corroborate that subjects did pay more attention to a sustainability-related attribute, shipping method, in the presence of ST features. Note that generalizing focus on shipping method and energy usage to focus on sustainable attributes relies on a premise that subjects think shipping method affects a product's sustainability, although this is a common knowledge to engineers and tested as accurate in pilot studies.

This study indicates that communication features can cause customers to evaluate other product features, and change choices, and illustrates some of the user research methods being used to investigate this issue. The promising results demonstrate that engineers can do more by linking engineering to both economic profit and environmental impact, that is, design and engineering products in a way that could increase purchases and decrease environmental impact. It will also encourage engineering designers to design products not just for the customer's final choice, but also to shape decision context and the construction of preferences. A combination of different user research approaches used in this study enriches the ways in which engineer researchers can explore customer preferences during design.

6. CONCLUSION

6.1. Summary

This research offers a wide review of findings from related fields, such as customer decisions and product design, and three empirical studies that address sustainable design by accommodating construction of preference proactively: tailoring product features to trigger sustainable preference constructions and facilitate customers to make sustainable decisions. Researching on the interdisciplinary problem for increasing customer sustainability considerations via design, Chapter 2 conducts a review in four areas, including creative design methods for conceptual phase, commonly used sustainable design methods, priming and its application in design, and customer decision making, which provides a foundation for understanding the background of the three studies presented in the dissertation.

Study 1 in Chapter 3 investigates the priming effect on designing for sustainability communications. Two exercises for priming designers with heightened sensory perceptions and sustainability focus were introduced: in the form of a collage activity and in the form of a simple questionnaire. In the collage exercise, subjects (designers) arranged pictures of sponges on a two-axis diagram to indicate their preference and opinion about environmental impact of each product, and also matched 28 sensory words, such as bright, harsh, smoky, and bland, with the product images. In the simple questionnaire, subjects answered a short questionnaire to write about three examples of things they have done to reduce their environmental impact and describe the sponge or cloth they use at home to clean dishes using five senses. After priming, they

all worked on the idea generation task. The proposed priming stimuli and two benchmarks were compared to no priming stimulus. Results show that only collage significantly increased the number of effective features and effectiveness of features as judged by experts to trigger sustainability considerations. Furthermore, results rated by AMT judges only support that collage outperformed no priming stimulus in the number of effective features generated. Study 1 indicates that priming stimuli can be targeted to achieve specific goals in the design process, beyond increasing the sheer number and novelty of features. It is an effective way to attain a fast change in the frame of mind. Specifically tailored stimuli might have potential to address challenges found in academic and industrial situations.

Chapter 4 proposes Study 2 to examine the relationships between product feature design and customers' thinking upon interacting with the products during simulated purchasing tasks. Three approaches have been employed to elicit customer stated preferences, namely: make a consider-then-choose decision, write an email (or UDE), and be interviewed about additional information that they want to know. Two raters coded the email responses and interview data on if subjects mentioned ST features and if they mentioned sustainability-related information. Analysis on the coding data show that products with ST features could trigger customers to think about sustainability at the buying point, and prompt them to use sustainability as a purchase criterion. Study 2 exhibits that UDE is a useful approach to capture customers' thinking in reaching a choice, and the promising results provide a new perspective on engineering design:

tailoring design features not only for final choices, but also for changing customer thoughts and leading them to seek related information.

To go further step on how ST features affect individual choices, Study 3 in Chapter 5 addresses ST effect in a more realistic situation, where a list of attributes, including hidden information on actual sustainability, were provided along with physical prototypes. Subjects were randomly assigned to conditions with ST features present or not, while working on a list of tasks: make purchase choices, evaluate willingness to pay, indicate attributes to know, rate attribute importance and trust on sustainability, and answer surveys on an eye tracker, which captured how they focused on the sustainable attributes. The results are encouraging. Specially-designed ST features increased importance of a product's sustainability in purchasing choices and led customers to seek related information, although the final choices were weakly altered to sustainable options. The analysis on eye-tracking data supported that subjects spent more time on and more frequently looked at sustainable attributes, which corroborated the prediction: ST features caused subjects to pay attention to sustainability-related information. Chapter 5 demonstrates potential marketing value of trigger features: communication features can cause customers to evaluate related product attributes and change choices; and illustrates some of the user research tools and methods being used to investigate this issue, which are new to the engineering design community.

These chapters serve as an attempt of incorporating constructions of preferences in engineering design, with demonstrated studies in the sustainable product design field, where customer preferences are complex and difficult to capture. The promising results

from this research will encourage engineering designers to design products not just for customer final choice, but also for changing their decision context, and thus contribute on shifting customer decisions to a socially desired direction, and bridging the gap between engineering and marketing regarding product development. The work also exemplifies the usefulness of a number of human-subject experimental approaches in engineering design research.

6.2. Open Questions

A number of open questions are suggested throughout the dissertation for future work. Chapter 3 identified and tested priming as a useful technique to support designers in communicating sustainability. Potentials to improve and enhance this technique are interesting work for future. Positive affective priming showed a trend to help sustainability communication. It is possible that combining the proposed priming with positive affective priming in certain ways could pose bigger lift in ideation for communication purpose. Designers tested in this dissertation are all engineering students, who are relatively novice designers, without knowing the purpose of the priming activities. In real design activities, designers are sure to know the purpose of each method or technique they use. How to use priming stimulus purposefully and apply the priming technique tested in the lab environment to real industrial design remains a challenge. Research on how to adapt one stimulus to another for different communication purposes, such as communicate safety or luxury, would enhance power and flexibility of this technique.

Chapter 4 tested that ST features triggered subjects to think about sustainability by pooling possible and definite sustainability mentions as judged by two coders. Sustainability mentions, both mentions of ST features or non-ST features, were significantly increased. In future, the author will extend Study 2 to investigate modeling customer decision rules on using these ST features and sustainable attributes with consider-then-choose task. A wide range of product attributes will be combined into large number of profiles with a balanced orthogonal experimental design. Hundreds of subjects from different backgrounds will be recruited. The population of current study is limited to a small town in US, where most people have higher education, with relatively higher sustainability awareness. The population and sample size limited the generalization of the findings from this study. Decision making rules as discussed in Section 2.5.2 will be modeled on the data.

The main contribution of this dissertation is to link engineering design with consumer research by three successive empirical studies. However, the last two studies regarding customer decisions were still conducted by collecting stated preferences in lab environment. In future, the author plans to conduct field studies and further test the effect of ST features with revealed customer preferences. Cooperating with entrepreneurs, the author will manufacture commercial products with ST features, and sell them in real market. How to trigger sustainability considerations is a factor of interest, which will be tested with three levels (conditions): marketing messages to advertise sustainability, ST features manufactured on products, and none. Several retail

stores in different cities will be randomly assigned to one of the three conditions. By analyzing seasonal selling records, ST effects in real market might be supported.

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