The Thesis Committee for Matthew Nelson Saunders
Certifies that this is the approved version of the following thesis:

The Effects of Empathic Experience Design Techniques on Product Design Innovation

APPROVED BY
SUPERVISING COMMITTEE:

Supervisor: ______________________________
Carolyn C. Seepersad

____
Kristin Wood

The Effects of Empathic Experience Design Techniques on Product Design Innovation

by

Matthew Nelson Saunders, B.S.

Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

May 2010

Dedication

I would like to dedicate this work to my family for their constant support that has allowed me to pursue numerous opportunities throughout my life and to all of my friends and lab mates that have helped me throughout graduate school.

Acknowledgements

I would like to acknowledge first and foremost my graduate advisor, Dr. Carolyn C. Seepersad, whose guidance and encouragement has challenged me to new heights. I am also sincerely grateful for the help of Kristin Armstrong and Jessica Guzman, who performed undergraduate research and contributed greatly to the evolution of the project through performing experiments and creating outreach programs. The input and inspiration from Dr. Art Markman and Dr. Kristin Wood was also invaluable in organizing and performing all of the experiments.

I would also like to thank our collaborators at the University of Massachusetts at Darthmouth, Dr. Katja Hölttä-Otto, Ramesh Srivathsavai, and Nicole Genco, whose input on the project regularly added insights and new research avenues.

Finally, I would like to thank the National Science Foundation for supporting the grant that has funded this research. Without their support none of this would have been possible.

May 7, 2010

Abstract

The Effects of Empathic Experience Design Techniques on Product Design Innovation

Matthew Nelson Saunders, M.S.E.

The University of Texas at Austin, 2010

Supervisor: Carolyn C. Seepersad

The effects of empathic experience design (EED) on the product design process are investigated through a series of product redesign experimental studies. As defined, empathic experience design is the simulation of the experiences of a lead user, or someone who uses a product in an extreme condition. To better understand product innovation, the link between creativity in engineering design and commercial market success is explored through literature and a study of award-winning products is performed to analyze the current trends in innovation. The findings suggest that products are becoming increasingly more innovative in the ways in which they interact with users and their surroundings and that a gap exists between the current tools available for engineers to innovate and the types of innovations present in award-winning products. The application of EED to a concept generation study shows that empathic experiences while interacting with a prototype results in more innovative concepts over typical interactions. The experimental group also saw an increase in user interaction innovations and a decrease in technical feasibility. The application of EED to a customer needs study compares the effect of empathic experiences in an articulated use interview setting. The EED interviews discovered 2.5 times the number of latent customer needs than the control group. A slight decrease in the breadth of topics covered was also seen, but was compensated for when used in conjunction with categorical questioning. Overall the use of empathic experience design is shown to increase the level of innovation throughout the product design process.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Motivation

Depending upon the industry and level of innovation, new products are expected to fail 30-90% of the time [1-3]. To lower this failure rate, engineers need better techniques for creating breakthrough products.

Typically the most successful products are the products that exhibit a high level of customer satisfaction. From the perspective of a Kano diagram, Figure 1.1, the types of features present in a product can be related to a customer's satisfaction.

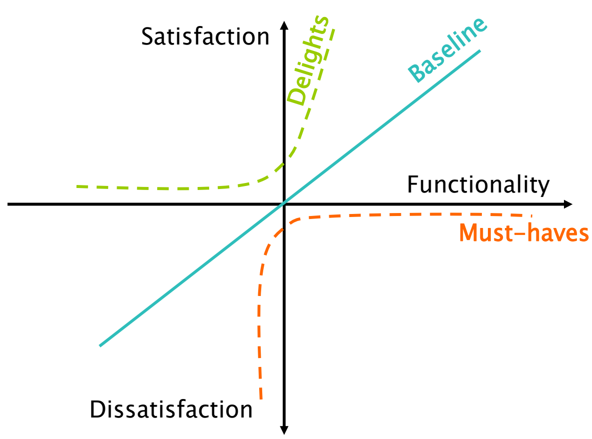

Figure 1.1: Kano Diagram[4]

Features that are mandatory are considered *Must-haves* and must be well implemented or will lead to customer disappointment. These features are so standard in the market that any execution less than high functionality is unacceptable. *Baseline* features are ones for which better implementation leads to a high level of customer satisfaction. *Delights* are known as features that are considered surprises. The difficulty with incorporating delightful features into a design is that they are difficult to discover using traditional customer needs analysis techniques. Although customers may appreciate the feature, they will rarely suggest the feature during an interview. If better techniques were available to help discover these unarticulated, or latent, customer needs, then products could potentially become more successful.

One of the current approaches to generate latent needs is to focus on the product's interactions with the user. For example, Von Hippel conducts customer interviews with *lead users*—customers who push a product to its limits—as a source of ideation [5-7]. These customers are said to experience needs prior to the general population and because they benefit significantly from having those needs fulfilled, will usually innovate or modify the existing product to solve their specific problem. Essentially lead users are ripe with ideas that could delight the rest of the populace, or at least segments or sub-markets of a populace. Lead users may also be identified according to a product adoption curve representing the acceptance of a given product over time as seen in Figure 1.2.

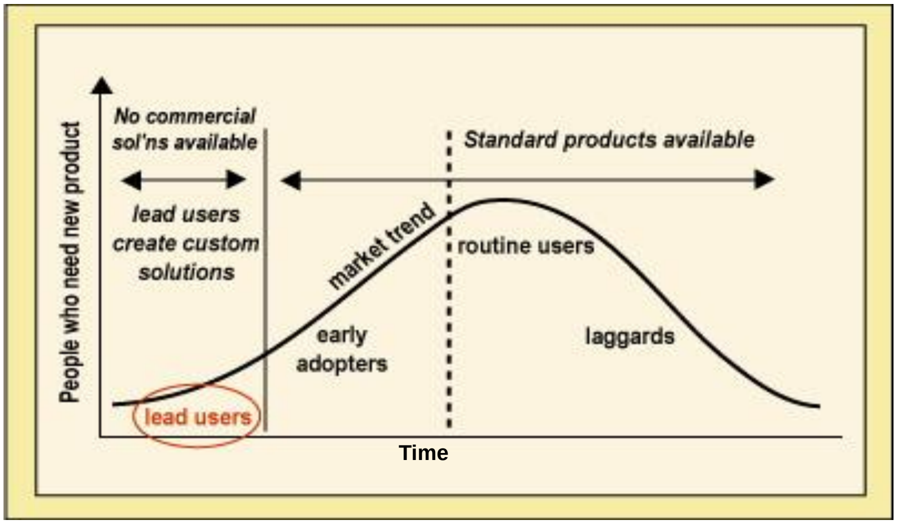

Figure 1.2: Identification of Lead User [8]

While the lead user technique has shown that it can produce innovative solutions, it can be difficult and expensive to isolate lead users because of their low numbers [6]. In related work, Hannukainen and Hölttä-Otto [9] and Lin and Seepersad [10] have developed techniques for helping ordinary customers serve as lead users by interacting with a product under extreme conditions. Both studies illustrated that customers experienced the customer needs of a lead user when placed in an experience that defined the lead user. For example, Hannukainen and Hölttä-Otto compared the communication needs exhibited by deaf and blind users to the needs expressed by typical users placed in a dark room or loud ambient environment to simulate the experience of being deaf or blind. It was demonstrated that the ordinary customers were situationally the same as the lead users and exhibited the same customer needs. The potential use of simulating lead users with average customers as lead users could yield the same innovation results as lead users themselves. This effect could even be magnified by transforming an engineer with a wealth of design knowledge into a lead user. The substitution of a simulated lead user has been labeled as empathic experience design (EED). This study will explore the effects of empathic experience design on the product design process to evaluate whether the technique could be used as a source of innovation.

1.2 Empathic Experience Design

Empathic experience design (EED), as proposed by Lin and Seepersad, is illustrated in Figure 1.3 [10].

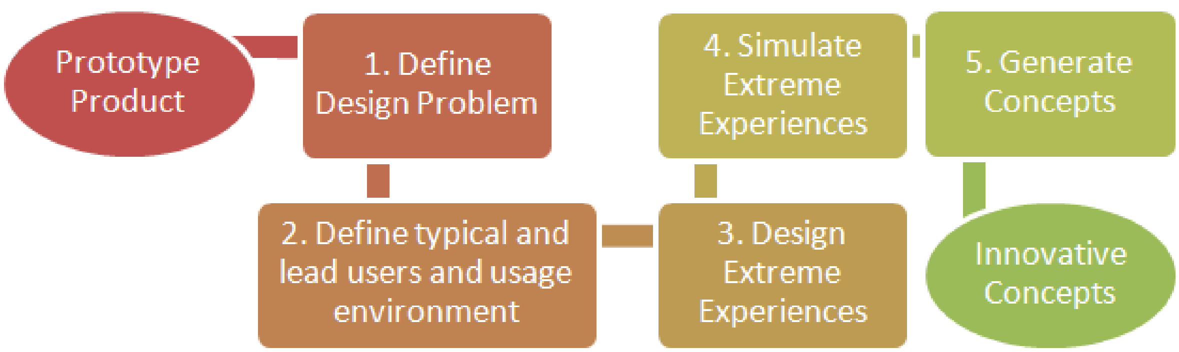

Figure 1.3: Empathic Experience Design (EED) Method [10]

The process begins by selecting a product to be redesigned and outlining the scope of the design problem. The characteristics of the typical and lead users are identified, including uses and context. Based upon the differences between the typical and lead users, experiments can be developed to simulate the lead user empathically. Next, the simulations are performed and the participants are asked to generate concepts. At this stage traditional customer needs analysis techniques may also be performed in place of the concept generation. Finally the innovative concepts can be extracted from the concepts. A similar process may also be performed for customer needs analysis in which a customer needs interview is carried out instead of concept generation, and innovative design avenues are identified from the derived customer needs. A more detailed procedure will be illustrated in the application of the technique to concept generation (Chapter 4) and customer needs analysis (Chapter 5).

1.3 Current Use of Empathic Experience Design

Since 1999 Ford Motor Company has been using their "Third Age Suit" [11] and Birthways, Inc.'s "Empathy Belly" [12] to help designers simulate the experience of some of their most extreme users and redesign the customer's interactions. The "Third Age Suit," developed in-house by Ford, helps their young engineers understand the challenges faced by older drivers. The suit adds weight and bulk to the body and joints to restrict motion and flexibility. The suit also includes goggles with changeable lens to add cataracts to vision, ear plugs to limit hearing, and gloves to limit the sense of touch and dexterity.

Figure 1.4 Ford Motor Company's "Third Age Suit" [11]

The "Empathy Belly" simulates the experience of pregnancy by adding bulk and weight in positions similar to carrying a third trimester fetus, which limits dexterity and changes a user's center of gravity. The suit also restricts lung capacity with a tight strap and has a water bladder to reduce a user's balance.

Figure 1.5 Birthways Inc. "The Empathy Belly" [12]

Through the use of these suits, Ford has acknowledged numerous innovations including wider opening doors and raised seat heights for ease of entry and exit of the vehicle as well as strap-like door handles to transfer the action of opening a door from the fingers and wrist, which are commonly most prone to arthritis, to the larger muscles of the arm. Another innovation present in the Ford Taurus X and directly claimed to be derived from the inspiration of the suits is a wide flip-down mirror located in the roof console that allows the driver to maintain visual contact with passengers in the second and third row of seating without turning his or her head [13, 14]. Additional features also include counter-weighted folding seats with pop-up headrests that allow for seat rearrangement with one hand available in the Mercury Monterey and Ford Freestar minivans [13].

Although Ford is a pioneer in simulating lead users for product redesign, no research has been carried out to evaluate the effectiveness of this technique. The features that have been developed already have illustrated a level of user centered innovation, which could have potential to delight customers. Unfortunately, little public knowledge is available concerning Ford's procedural use of these suits and experiments and other techniques they have tried during the development and evolution of the suit.

Other techniques, such as empathic design [15], in which researchers observe a user interact with a product in a traditional environment; articulated use [16], in which customers are allowed to interact with a product during a formal interview; and bodystorming [17], in which designers act out normal use in front of their peers, are also aimed at helping designers better understand, or even experience, how customers interact with products. These methods have also been reflected in universal design studies that encourage designers to target broader sections of the population [18, 19]. Since it is important to consider how a product interacts with the user, its surrounding environment, and neighboring products [20], it appears that these types of techniques may become increasingly important. While universal design typically focuses on designing for either elderly or impaired users, empathic experience design focuses on the interactions of anyone who challenges the designed boundaries of the product.

1.4 Research Opportunities

The focus of this research is to evaluate the impact of empathic experiences on the product design process and, specifically, the customer needs analysis and concept generation stages of design.

Before the effectiveness of the empathic experience design (EED) method was investigated, award-winning innovative products were studied to investigate the need for more interaction-based techniques. The product analysis suggests that there is a gap between traditional design techniques and the form of innovation currently exhibited by products, and more interaction-based approaches may be needed.

Two studies were designed and implemented to investigate the effectiveness of EED in the product redesign process. First, the EED technique was applied to a concept generation study, in which participants engaged in empathic experiences with a product prior to developing concepts. The empathic experiences were predicted to cause an increase in the level of innovation with a slight decrease in the level of technical feasibility in the generated concepts. A second study applied the EED technique to customer needs analysis, in which participants engaged in empathic experiences during an articulated use interview. The empathic experiences were predicted to cause a significant increase in the rate of discovery of latent customer needs, relative to traditional articulated use interviews.

Chapter 2

Literature Review

2.1 Examining the Relationship between Innovation and Market Success

The goal of every product development process is to ultimately create a commercially successful product. The common belief is that this objective can only be accomplished through product innovation, but numerous underlying factors can influence the success of a product. Cooper [21] classified these factors into the following categories: market, synergy of product and firm's skills, characteristics of the product venture, execution of development, the product itself, and information found during development. Within these categories, 18 dimensions of success were identified from related literature. The same list has been modified and supported by numerous studies [22-25], and similar lists have been suggested by additional studies [26-29]. Despite the abundance of supporting research, however, the categories may not be universally applicable to different markets and cultures. Mishra [30] found that the application of Cooper's dimensions, which had been studied in Canada [21] and China [25], did not correlate to similar results in a study of Korean innovation. Cooper and de Brentani [22] argued that success factors may be ranked differently for products outside of the manufacturing sector, such as financial service products.

These studies and the majority of related research suggest that innovation and competitive advantage are leading factors in product success [21-23, 25, 27, 31], but there may be too many market factors to draw a linear relationship between technical innovation and success. For example, the research of Kleinschmidt and Cooper [23] suggested that while highly innovative products and products with a relatively low level of innovation find commercial success, products of moderate levels of innovation are less likely to find success. A high level of technical innovation is encouraged, but innovation alone will not necessitate market success. Due to the multitude of determinants of success, an innovative product was defined, for the sake of this study, as a product that changes or has the potential to change the nature of the marketplace by satisfying a new (or latent) customer need or by satisfying customer needs in a significantly new way. In contrast, a breakthrough product was defined as an innovative product that had *already* experienced commercial success in the context of numerous market and business influences.

The difficulty of creating innovative products is further exacerbated by apparent differences in customer evaluation and acceptance of innovative products based on their similarity to related products [32, 33]. The more successful products seem to be difficult for customers to categorize because they do not fit neatly into preexisting product categories. Customers spend more time analyzing innovative products, and cannot make quick decisions based on previous experiences. . Customers' evaluations of innovative products often demonstrate lack of familiarity, irrationality, user-product interaction problems, uncertainty, compatibility, aesthetics, and fixation on seemingly trivial details of the product [34]. These non-function, as viewed from a consumers perspective of not adding functions, related product components that also include the emotional design branch of industrial engineering are important to the customer's purchase decision, but are also difficult to evaluate at the engineering level early in development because of the required consumer research into potential behavior and responses to the design [35].

To further increase the difficulty of developing innovative products, several studies support that the development and management of products differ greatly based on the level of innovation [31, 36-41]. For an engineer tasked with designing an innovative product, it is difficult to characterize the appropriate target level of innovation. In a comparison of innovation factors cited in the literature, Garcia and Calantone [42] identified more than 15 constructs of innovation with 51 attributes. They distinguished incremental, really new, and radical forms of innovation to clarify and unify the theories of innovation by merging existing terminology. Incremental innovation is the classical approach of utilizing customer needs analysis to create slight generational improvements to an existing product. Radical innovations cause disruption of the marketplace by introducing a breakthrough technology. Really new innovation can be any combination of factors between incremental and radical. These classifications are supported with s-curves [43, 44], in which products experience slow evolution in their initial development, followed by an accelerated series of improvements, only to level off into a final period of slow development. In this way, the evolution of a product follows an "S" shaped pattern of improvement on a plot of quality over time.

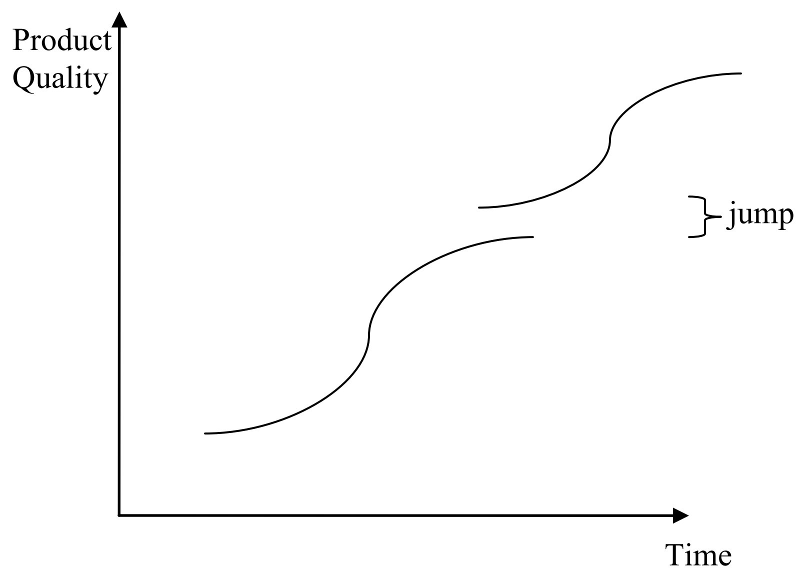

Figure 2.1: S-Curve Innovation

Discontinuities in improvement, or jumps, create new curves of higher quality. It was suggested that the market of a product also follows an s-curve and that radical innovation is defined by causing jumps on both a product's technology and market curves. Really new innovation is characterized by a jump in either curve, but not both. Incremental innovation is classified as movement along existing curves. Innovation should therefore be viewed as a relative property as suggested by Dewar and Dutton [45] because it is inherently based on the degree to which one product distinguishes itself from preceding and competing products. Based on these classifications, the literature suggests that radical innovation is rare and occurs in less than 20% of innovations, while incremental innovation is much more widespread [42].

2.2 AN EVALUATION OF ENGINEERING INNOVATION TOOLS

While numerous factors influence the success of a product, only a product's innovation is affected directly at the engineering level and the product design stage. Designers are currently told to innovate, but few tools are provided to help a designer maximize the likelihood of product success. Should the designer add an additional function, reduce product size, make the product easier to use, or pursue other options? What is it that makes a product stand out from the competition? It has been shown that factors such as having a good design process with reviews, clear strategy, and willingness to take risks and enter new markets [46] contribute to good business performance from the management point of view, but what can the design engineer do during the design process? In some instances, engineers are tasked with incorporating design requirements forced upon the product from large retailers just to get the product on the shelf [47]. These tradeoffs in a design not only hinder potential innovation, but also may lead to decreased commercial success [48].

The dilemma begins with the difficulty of gathering customer needs to create innovative products. Several sources suggest that the creation of highly innovative or breakthrough products is not likely with traditional customer needs analysis because the needs are latent, or not yet articulated [6, 29, 32, 49, 50]. Some customer analysis tools, such as voice of the customer (VOC) [51] and the lead user method [6], claim to result in more successful products than other methods; however, product success is far from guaranteed. Additionally, benchmarking the competition [16, 52] is an important part of the House of Quality [51] for comparing a product to leading competitors and connecting customer needs with engineering specifications; however, this tool, as well as adaptations of it [53], may suffer from the challenges of extracting customer needs effectively and moving beyond incremental innovation.

Despite all of the research on innovation, the engineer is still left with very little guidance on the engineering-level characteristics of innovative products. The current product attribute checklists available to designers, including categories for decomposing product specifications and checklists for embodying concepts [16, 54, 55], do not directly encourage innovation for the sake of potential market success. These lists are normally used throughout the design process to ensure that all aspects of a product's development cycle are considered, but they do not provide guidance for competitive advantage or innovation. They do not help differentiate and distinguish one concept from another at the state of ideation, which according to Goldberg [28] is a promising time to evaluate concepts for potential innovation and success.

Some tools are available for this critical early stage of development. The creation of a project mission statement [16], for example, encourages designers to identify potential areas of innovation at the beginning of a design project, but no guidelines are provided to examine potential areas thoroughly. Also, there are many creativity and brainstorming tools that help the designer create as many ideas as possible. Examples include 6-3-5 [55, 56], C-sketch [57], TRIZ [58], Design by Analogy [59], Design Through Transformation [60], and Biomimetic Concept Generation [61]. Similarly, there are numerous tools for selecting the concept that best meets customer requirements (e.g., [62-64]). Interestingly however, Cooper finds that many concept selection methods are designed to select mediocre concepts, because the methods do not use “product superiority” as a criterion [46] and therefore do not lead to breakthrough products.

The aforementioned tools are available to all designers, but somehow only a fraction of products can truly claim to be breakthrough products. It is important to remember that tools exist throughout the entire product design process and many have been shown to lead to innovations. Before creating additional tools, such as empathic experience design, a better understanding of product innovation is needed in order to set the benchmark for innovation success. Towards this goal, a systematic study of award-winning products was performed, as described in the following chapter.

Chapter 3

Defining Innovation: A Motivating Product Study

3.1 Motivation

It is not easy to design an innovative product that delights customers. Current engineering design methods provide help in designing a good product, but the designer lacks tools that help him or her create a truly innovative, successful product. By comparing the ways in which award-winning products are more innovative than their market competition, overall conclusions on the current trends in product innovation can be made. The research study described in this chapter focuses on identifying the engineering-level characteristics that appear most often in award-winning innovative products. Armed with the knowledge of the engineering-level characteristics that make many products successful, a designer will be better equipped to realize the next breakthrough innovation.

3.2 Research Methodology

A research methodology was developed to establish a set of engineering-level characteristics of innovative products and to use those characteristics for analyzing trends among award-winning, innovative products. The research proceeded in a series of three steps: (1) developing a comprehensive list of engineering-level characteristics of innovation, (2) selecting innovative products to be analyzed, and (3) analyzing the products with respect to the characteristics identified in the first step. A subsection is devoted to describing each of the steps.

3.2.1 Developing a Set of Engineering-Level Characteristics of Innovation

The goal of this step was to compile a set of engineering-level characteristics that describe innovative products. Engineering-level characteristics are those that describe observable features of the product itself, such as architecture or functionality, rather than enterprise- or market-level characteristics such as market share or profitability. The engineering-level characteristics are selected to be *domain-independent, comprehensive,* and *mutually independent*. A *domain-independent* characteristic can be used to describe various types of products, rather than a specific product (e.g., material flow versus gallons per mile). The characteristics in a *mutually independent* set should not overlap; in other words, it should be possible to identify a product that exhibits one specific characteristic without exhibiting the remaining characteristics. A *comprehensive* set of characteristics should be sufficient for describing any innovation in the domain of interest. The electro-mechanical domain was the focus of this study; innovations that are purely chemical, electrical, or materials-related, without a mechanical component, were not considered in the study.

With these features in mind, the characteristics of innovative products were compiled by reviewing a variety of innovative products. While reviewing each product, the researchers asked, “What features made the product more innovative than competing products at the time of its release?" The review was conducted from the perspective of the customer, rather than the manufacturer or the designer. For example, customers cite a product's compact size as innovative, rather than the advances in material processing and manufacturing that enabled it; therefore, improved size is a potential characteristic of innovative products. Characteristics were added to the set as necessary to accurately describe the differences between products. The set was refined for comprehensiveness, mutual independence, and domain-independence. For validation purposes, characteristics were developed independently by two of the authors and then critically evaluated and merged into a unified set. Also, the final set was compared with other lists of product criteria, such as the requirements list checklist provided by Pahl and Beitz [42] to verify its completeness.

As shown in Table 3.1, five important categories of innovation were identified: Functionality, Architecture, Environmental Interactions, User Interactions, and Cost. The first category is used to evaluate whether the breakthrough product offers a significant new function, relative to competitive products. The functionality must allow the user to solve a new problem or perform a new function. Functionality is evaluated from the perspective of the user rather than the perspective of the engineer and his/her knowledge of the inner workings of the product. The second category is used to evaluate whether there are any architectural innovations (related to size, layout, or usage context) in the breakthrough products that are not generally found in competitive products. The environmental interactions category addresses modified flows of material, energy, or information into or out of a functional model [46] of the product. A modification includes a change in the type of flow (e.g., electrical energy replaced by solar energy in a solar-powered device) or in the magnitude of the flow (e.g., a more fuel-efficient vehicle). The environmental interactions category also includes product interactions with pre-existing infrastructure, such as data formats, standardized connectors, or other types of pre-existing hardware, software, services, or networks. The user interactions category is used to evaluate whether the innovative products are more user-friendly than competitive products. For example, the physical demands characteristic refers to innovations that make the product easier to use under various physical conditions, including permanent or temporary physical disabilities. The sensory demands characteristic includes innovations that enhance ease of use for sensory-impaired persons or persons with temporary sensory impairment (e.g., a cell phone user at a loud concert). The modified cognitive demand characteristic refers to innovations that make it easier to understand a product, including its assembly, operation, and/or inputs/outputs. Finally, cost is included as a secondary characteristic that sometimes accompanies other characteristics (e.g., a change in design enables both modified material flows and reduced operating costs).

Table 3.1: Characteristics of Innovation

Functionality

- *Additional Function*- Allows the user to solve a new problem or perform a new function while still performing the function of the comparison product.

Architecture

- *Modified Size*- The physical dimensions during operation or storage have changed in expansion or compaction beyond subtle or incremental differences.
- *Modified Physical Layout*- The same elements of the product are still present, but the physical architecture has changed.
- *Expanded Usage Physical Environment*- The product can now be used in more usage environments with different resource availability or different physical characteristics.

Environmental Interactions

- *Modified Material Flow*- Accepts or creates different materials or uses materials in new ways.
- *Modified Energy Flow*- Utilizes new sources of energy or converts to a different form of energy than previously used.
- *Modified Information Flow*- Different types or amounts of information are being gathered, processed, or output/displayed.
- *Interaction with Infrastructure*- The product interacts with previously owned infrastructure.

User Interactions

- *Modified Physical Demands*- The product is easier to use physically beyond subtle or incremental differences.
- *Modified Sensory Demands*- The product is easier to use from a sensory stand point beyond subtle or incremental differences.
- *Modified Mental Demands*- The product is easier to use mentally beyond subtle or incremental differences.

Cost (Secondary Characteristic)

- *Purchase Cost*- Purchase cost is **significantly** different.
- *Operating Cost* – Operating and/or maintenance costs are **significantly** different.

The sample products in Table 3.2 illustrate several of the innovation characteristics. The Vicks Forehead Thermometer, illustrated in Figure 3.1, is a thermometer designed to eliminate the difficulty of taking a child's temperature by accurately measuring temperature from the forehead rather than the standard mouth, ear, rectal, or armpit methods. It also displays a background color based on the grade of the fever, ranging from green for no fever to red for high fever. Relative to competing, home-use thermometers, the color-coded display increases the amount of information displayed, as recorded in the "Modified Information Flow" column of Table 3.2. It also makes it easier for the user to determine if a fever exists without having to memorize appropriate temperature ranges, as classified by the "Modified Cognitive Demands" column in Table 3.2. The thermometer also embodies "Modified Physical Demands" because it is physically easier to measure a child's temperature on the forehead, relative to other locations.

Figure 3.1: Vicks Forehead Thermometer [65]

Figure 3.2: Nike+ Apple iPod Pedometer Attachment [66]

Table 3.2: Sample Products that Illustrate Characteristics of Innovation

Product	Vicks Forehead Thermometer	Nike+	Oliso Frisper
Comparative Product	children digital thermometer	running pedometer	home vacuum sealer
Function			
Additional Function		x	
Architecture			
Modified Size		x	x
Modified Physical Layout		x	
Expanded Usage Environment	x		
Environmental Interactions			
Modified Material Flow			
Modified Energy Flow		x	x
Modified Information Flow	x	x	
Interaction with Infrastructure		x	x
User Interactions			
Modified Physical Demands	x		
Modified Sensory Demands		x	
Modified Cognitive Demands	x		
Cost			
Purchase			
Maintenance			x

The Nike+, Figure 3.2, is a jogging pedometer attachment for Apple iPod digital music players. A small piezoelectric measuring unit placed in or on a jogger's shoe collects pace data, and communicates it wirelessly to an iPod attachment, which broadcasts current and average workout pace through the iPod headphones. When connected to a computer, the device sends data from previous workouts to an online account that helps runners track their distance, pace, and running routes. These features justify marks in the "Additional Function" and "Modified Information Flow" columns in Table 3.2. The connection between the pedometer and an iPod and a computer is an advantageous "Interaction with Infrastructure." In this sense, the infrastructure interaction is manifested both geometrically, by attaching to the iPod, and digitally, by exchanging data between the shoe-based module and the iPod. Compared to competing, one-piece pedometers, the Nike+ is both smaller in size ("Modified Size") and modular ("Modified Physical Layout"). The use of a piezoelectric accelerometer in the foot unit is considered a "Modified Energy Flow" because competing products used springs and lever arms at the time of its release, which require more energy. The Nike+ also provides "Modified Sensory Demands" by allowing users to hear their data over the iPod headphones in addition to tracking it visually.

Figure 3.3: Oliso Frisper Home Vacuum Sealer [67]

The Oliso Frisper, Figure 3.3, is a home vacuum sealer that punctures a tiny hole in any closable plastic bag, removes the air, and then heat-seals the hole to ensure a vacuum. As opposed to traditional vacuum sealers that require specialized bags, this method of sealing allows a variety of bags to be continually reused, and it is not required to span the full length of the bag to operate properly. The puncturing and resealing mechanism is considered a "Modified Energy Flow," and it allows the Oliso Frisper to be considerably more compact than the competition, as recorded in the "Modified Size" column in Table 3.2. The Oliso Frisper also exhibits improved "Interaction with Infrastructure" because it can be used with existing household sealable bags. The product also earns a reduced "Cost" designation because the customer can use any sealable plastic bag (rather than expensive, specialized bags) and reuse the original bag countless times without function loss.

3.2.2 Selecting Innovative Products for Analysis

Products were selected from three published lists of innovative products: Time magazine's Inventions of the Year, Popular Science's Best of What's New, and Industrial Designers Society of America's (IDSA) International Design Excellence Awards (IDEA). Products were selected from these lists, rather than personal research by the authors, to avoid any researcher bias in the selection of products. The lists also provided a wide assortment of products to support a relatively broad analysis of innovation, with Time's list oriented towards the general public, Popular Science towards scientific-minded readers, and IDEA towards industrial designers and other professionals.

As shown in Table 3.3, a set of criteria was developed for selecting products from the published lists. Since the purpose of this study was to investigate mechanical innovation, products with no significant mechanical component were eliminated (e.g., new software, materials, or chemicals). The innovation also needed to be function-related, rather than a purely cosmetic or aesthetic change. This criterion eliminated fashion and most clothing, except for a few that demonstrated mechanical innovation. Also, products were required to be commercially available; prototypes were eliminated to ensure design feasibility. Only end consumer products were considered, rather than components (e.g., engines, transmissions). Since products were evaluated from a consumer perspective, it was difficult to evaluate components that were isolated from a parent product. The ability of a product to change or potentially change a marketplace was a significant criterion. This criterion eliminated useless innovation or innovation for the sake of innovation (e.g., a combination pen/fingernail clipper/money clip). Finally, it was necessary for the product to be relevant to the United States market, rather than international markets, so that the U.S.-based researchers could evaluate the product relative to competing products.

Table 3.3: Product Selection Criteria

- The innovative product must be electro-mechanical or hardware-related.
- The innovation must be related to the functionality of the product, rather than its aesthetics alone.
- The product must be successful or potentially successful in the marketplace.
- The product must be available in the marketplace (i.e., no prototypes).
- The product must be an end consumer product, rather than a component.
- The product must have changed or have the potential to change the marketplace.
- The product must be relevant to the US market.

The selection criteria were used to extract products from the published parent lists. After analyzing the 2003-2008 editions of each parent list, 197 products were obtained. Although additional products could be obtained from earlier editions of the lists, the product count was hypothesized to be large enough to provide significant insights on innovation. (This hypothesis is revisited in Section 4.) Overall 45, 104, and 80 products were extracted from the Time, Popular Science, and IDSA lists, respectively, with 29 of those products receiving awards from multiple lists.

3.2.3 Analyzing Innovative Products

Each of the 197 products was analyzed with respect to the innovation characteristics in Table 3.1. A sample analysis is illustrated in Table 3.2. Analysis was based on the description of the product in the award list. Each product was analyzed with respect to a comparative product. The comparative product was selected by identifying the product class likely to be most competitive with the innovative product at the point of purchase. The comparative product should be the product class that a customer would most likely consider purchasing, instead of the innovative product. For example, an iPod® would be compared to other digital music players, rather than a compact disc player.

As the products were analyzed, the repeatability of the study was investigated. Repeatability was assessed with inter-rater agreement, which measures the degree to which two judges assign the same ratings to each alternative [68]. Specifically, Cohen's [69] kappa coefficient, K, and standard percent agreement were used to calculate inter-rater agreement, as defined in Equations 3.1 to 3.4.

$$K = \frac{percent\ agreement - chance\ agreement}{1 - chance\ agreement} \tag{3.1}$$

$$percent\ agreement = \frac{number\ of\ total\ agreements}{number\ of\ possible\ agreements} \tag{3.2}$$

$$chance\ agreement = P(Rater\ 1) * P(Rater\ 2) + \left(1 - P(Rater\ 1)\right) * (1 - P(Rater\ 2)) \tag{3.3}$$

$$P(rater\ x) = \frac{number\ of\ assignments\ by\ rater\ x}{number\ of\ possible\ assignments} \tag{3.4}$$

Coefficient values can range from 0, which represents agreement equivalent to expected chance agreement, to 1, which represents perfect agreement. Generally, inter-rater agreement of 0.40 or less is considered "poor" agreement; 0.4 to 0.75 is considered "fair to good" agreement; and 0.75 and above is considered "excellent" [70, 71]. Percent agreement was calculated as the direct proportion of agreements to the total possible number of agreements. Lists of approximately 10 sample products were evaluated by two of the authors independently. Then, differences were discussed, and the procedure was repeated, as a means of training the judges, until an acceptable level of inter-rater agreement was achieved for the sample products. In this evaluation, judges were considered to agree if both indicated that a product satisfied (or did not satisfy) an innovation characteristic. Initial inter-rater agreement fell in the 0.65 *K*, or 85%, range between authors, but discussion and modification of the innovation characteristics and their definitions raised the level to 0.75 *K,* or 90%, for new samples of independently analyzed products. Forty-nine products, or 25% of the total number of products, were analyzed in total by multiple authors. Not only was a high inter-rater agreement seen in the form of Cohen's kappa and percent agreement, 0.68 and 88%, respectively, but the differences in analysis by innovation categories varied by less than 8%.

3.3 RESULTS

After all of the products were evaluated, the results were analyzed by characteristics and overarching categories as shown in Table 3.4. The first column lists all of the characteristics of innovation identified in Section 3.3, with category headings highlighted in bold. The second column indicates the percentage of products that displayed each characteristic. The third column indicates the percentage of products with at least one characteristic in each category. For example, 60.9% of the products exhibited at least one characteristic in the architecture category.

Table 3.4 Product Analysis by Innovation Characteristics and Categories

	Percent of products with each criteria (%)	Percent of products with at least 1 criterion for each category (%)
Function	-	38.1
Additional Function	38.1	
Architecture	-	60.9
Modified Size	23.4	
Modified Physical Layout	36.0	
Expanded Usage Environment	26.9	
Environmental Interactions	-	80.2
Modified Material Flow	10.2	
Modified Energy Flow	41.6	
Modified Information Flow	34.5	
Interaction with Infrastructure	20.8	
User Interactions	-	68.5
Modified Physical Demands	48.7	
Modified Sensory Demands	14.2	
Modified Cognitive Demands	15.7	
Cost	-	9.1
Purchase	2.5	
Maintenance	7.1	

Modified Physical Demands and Modified Energy Flow were the most frequently displayed characteristics, with 48.7 and 41.6% of products surveyed, respectively. Similarly, their parent categories, User Interactions and Environmental Interactions, were the most frequently cited categories, with 68.5% and 80.2% of products, respectively, exhibiting at least one characteristic in each category. In contrast, the percentage of products that granted the user an additional function was much lower at 38.1%. Since mechanical designers often associate innovation with functionality and technical superiority, this result is somewhat surprising. There are at least two different explanations for this difference. First, the results suggest that mechanical innovation may be more closely associated with a product's environmental and user interactions than with additional functionality alone, at least from the customer's perspective. Second, the environmental and user interaction categories are quite broad, as indicated by the number of characteristics associated with them. The breakdown in characteristics may also encourage the researcher to think more carefully about these categories and thereby identify more products that exhibit them.

Overall, neither the average number of characteristics per product nor the distribution of characteristics across categories differed substantially when compared across award lists or award list years. For example, the IDEA products were expected to display more User Interaction characteristics than the other award lists based on IDSA's origins in industrial engineering, but this hypothesis proved not to be the case.

As shown in Table 3.5, products were also analyzed by the type and quantity of awards received.

Table 3.5 Product Analysis by Number and Type of Awards

	# of Products	Average # of Characteristics	Standard Deviation
Overall	197	3.21	1.17
Multiple Awards			
One	168	3.08	1.08
Two	26	3.69	1.26
Three	3	5.33	4.45
Level of IDEA Award			
Bronze	24	3.16	1.43
Silver	28	3.51	1.32
Gold	20	3.36	1.16
Level of Popular Science Award			
Regular	89	3.28	1.15
Grand	15	3.76	2.89

As recorded in the first row of the table, the 197 products in the study averaged approximately three innovation characteristics per product. This result suggests that innovative products often exhibit numerous innovative advantages over comparative products. The relatively substantial standard deviation of this statistic suggests that many products are viewed as innovative with only one or two innovative characteristics, but there are just as many with four or more criteria.

The remaining rows of Table 3.5 display the average number of characteristics per product as a function of the type or number of awards. Only subtle differences were observed in the average number of characteristics per product, when compared across award levels. For example, IDEA offers bronze, silver, and gold awards, while Popular Science offers regular and grand awards. As shown in Table 3.5, the average number of characteristics for the gold and silver IDEA award winners were slightly more than the bronze level award winners, but the silver was also higher than the gold award winners. Similarly, Popular Science grand award winners display, on average, approximately one half more characteristic than the regular award winners.

The results also suggest that products that win more awards exhibit a higher average number of innovation characteristics. As shown in Table 3.5, twenty-six products appeared on two award lists, and three products appeared on all three of the lists (the One Laptop Per Child XO laptop, the Apple iPhone, and the Shift Tricycle). The triple award-winning products displayed approximately two more characteristics per product than the single award-winning products. These results have some interesting implications. First, they appear to validate the hypothesis that the innovation characteristics accurately describe product innovation, because products with higher level awards exhibit more characteristics on average. Second, the trend suggests that innovators may be wise to focus on *multiple* innovation characteristics, when attempting to design breakthrough products.

Although trends are visible in the data in Table 3.5, it should be noted that increasing the sample size of multiple award-winning products would probably still not enhance the statistical significance of the data. As seen in Table 3.6, expanding the sample size from the original study of products from 2006, 2007, and 2008 award lists to include 2003, 2004, and 2005 products had little effect on the standard deviation of the average number of characteristics of innovation per product.

Table 3.6: Effect of increasing sample size on statistical Significance

	Number of Products from Years in Study		Standard Deviation of # of Characteristics	
	Products from 2006-2008	Products from 2003-2008	Products from 2006-2008	Products from 2003-2008
Overall	95	197	1.24	1.17
Multiple Awards				
Single	82	168	1.12	1.08
Two	11	26	1.29	1.26
Three	2	3	2.83	4.45
Level of IDEA Award				
Bronze	13	24	1.54	1.43
Silver	10	28	0.57	1.32
Gold	8	20	2.62	1.16
Level of Popular Science Award				
Regular	40	89	1.25	1.15
Grand	10	15	1.79	2.89

More than doubling the size of the study had little effect on the statistical significance of the trends; accordingly, it is unlikely that additional data would improve the statistical significance of the award level comparisons.

3.4 Study Conclusions

The empirical product study identified the types of engineering-level characteristics that describe a set of award-winning, innovative products. One of the most interesting outcomes of the study was the frequency with which different types of innovations were exhibited. Of the products analyzed in the study, 68.5% and 80.2% had an increase in user and environment interactions, respectively, compared to 38.1% with additional functions and 60.9% with innovative architectures. Based on these results, it appears that a customer may choose one product over another based on its environmental and user interactions more than any other trait. These modified or additional interactions seem to act as the delighters in the Kano diagram. They typically do not involve high functionality, but result in great satisfaction. This finding stresses the need for engineering design methodologies that help designers improve product interactions. Tools are available for considering function, architecture, and environmental interactions during the design process. These tools include an abundance of recent research on functional modeling, product architecture, and green design. While more research and industrial applications are certainly needed in those areas, there appears to be a significant gap between current design methodology and the need to incorporate innovative user interaction features as part of many successful products.

As previously mentioned, there are several emerging engineering design techniques, such as empathic experience design, that focus on customer interactions with a product, as a source of innovations. Based on the results of this study as well as literature that suggests a design shift towards a product's interactions [20], it appears that these types of techniques may become increasingly important. The effectiveness of EED to aid designers in creating user-focused innovation during the product design process was explored through two exploratory studies in the following chapters.

Chapter 4

The Application of EED to a Concept Generation Study

4.1 Motivation

Although the correlation between empathic experiences and customer needs analysis has been investigated in the past [9, 10], the effects of such experiences on concept generation activities have not been studied formally. By studying how design engineers interact with prototypes in a product redesign environment, a concept design methodology could be established that better stimulates the innovation of breakthrough products. This study investigates the impact of having an empathic experience prototype interaction while redesigning a product and the effectiveness of the technique in helping designers generate more innovative ideas than traditional interactions.

4.2 Experimental Setup

The current study investigates the application of the empathic experience technique as a concept generation aid. The specific application is the redesign of alarm clocks. The study was conducted in collaboration between The University of Texas at Austin and the University of Massachusetts-Dartmouth campuses to increase the sample size and diversity of the project. Groups of undergraduate mechanical engineering students at both schools were asked to interact with several alarm clocks with or without empathic experiences and then asked to generate concepts. The findings presented here represent preliminary results for the UT-Austin campus that have been analyzed according to selected novelty and feasibility metrics.

4.2.1 Selection of Product

Before beginning the experiments, the product to be used was carefully chosen. To narrow the search for an acceptable product, several screening requirements were created, as outlined in Table 4.1.

Table 4.1: Product Selection Criteria

Mechanically or Electro-mechanically based-Since the participants were mechanical engineering students, the product needed to be within the scope of design abilities of the participants.
Medium to light complexity-A product of medium to light complexity based on easily understood principles with ample room for improvements was preferred to allow for a quick redesign and variety of solutions.
Product familiar to wide range of participants-The product needed to be familiar to a wide range of students to help turn the average user into a lead user.
Possible interaction based improvements-The team desired a product that could have interaction based improvements that would not be easily suggested in the control group. This objective sets up the potential for differentiation in the results to statistically test the effect of the empathic experiences. Products with known, if not widely known, interaction based improvements were favored.
Experimental conditions capable of leading to interaction improvements-The experimental conditions capable of encouraging the improvements were considered in the process as well. Since the experiment represented the initial full-scale testing of the procedure, easily controllable conditions were desired.
Cost-It was desired to perform experiments in classroom setting for under $100, which included multiple products and experimental conditions.
A non-camping related product category-Finally, the team sought products that were in consumer categories beyond camping and outdoor equipment since the previous related study [10] used a camping tent. This restriction would help illustrate the wide number of applications of the technique.

Ultimately, the team decided upon the use of an alarm clock in the study. Alarm clocks typically perform little function beyond interaction with the user, and it was hypothesized that by altering the way a user interacted with the alarm clock, participants would generate innovative suggestions. While most people use alarm clocks on a daily basis, few users know of the more creative ones on the market such as ones that utilize vibration pads or move around the room. Alarm clocks also seemed to epitomize the use of limiting senses and suggest that users might suggest non-traditional modes of alarm.

Multiple alarm clocks were considered for use as prototypes, but the most basic digital and mechanical alarm clocks found were used to provide participants with only standard features. The alarm clocks, as seen in Figure 4.1, were bought at Wal-Mart for approximately \$5.99 and \$7.99 respectively. The digital clock has an LED display; buttons for time, alarm, hour, and minute; a switch to turn the alarm on/off; a display for the on or off status of the alarm; a power cord; a backup 9V battery; and a snooze function. The analog clock has glow-in-the-dark arms; a display for time in hours, minutes, and seconds; a display for alarm time; a dial for time setting; a dial for alarm setting; a switch for alarm on/off; and a power cord.

Figure 4.1: Alarm clocks used in experiments

To ensure that the same alarm clocks were used at both campuses all clocks were bought in Austin, TX and half were shipped to Dartmouth, MA.

Multiple products were considered during the organization of the current studies and could potentially be used in future testing. Since the technique generally focuses on user interactions, universal design product award lists were considered for possible products and could still be used as an excellent source of ideas. For example, Doro Electronics produces a home phone with pictures in the place of speed dial so that elderly users do not have to remember numbers or names. They can simply press the inserted photograph of the person they wish to call. Looking through other lists of award winning products may also help find an innovative product that has less innovative or common counterparts to be used in experiments. Other products that have been considered for use in testing are common medical devices (eg. Thermometers), small kitchen appliances (eg. Blenders), umbrellas, coolers, backpacks, office equipment (eg. Paper shredders), and athletic equipment.

4.2.2 Selection of Experimental conditions

As previously mentioned, experimental conditions were considered when selecting the product. Since alarm clocks typically rely upon the sense of sound as a mode of alarm, the experimental conditions were designed to limit the participants' senses to encourage creative solutions. A combination of three experimental conditions were used, as seen in Figure 4.2, including a blindfold created from a folded bandana to limit sight; head phones to reduce hearing; and oven mitts to reduce dexterity and sense of touch.

Figure 4.2: Experimental conditions

While the experimental conditions should reflect the desired goal and be unique to each product, there are some general conditions that could be applied to a variety of products. The conditions are designed to limit the user's interaction in some manner, so any form of limitation can be used as a condition. Table 4.2 provides a general list of potential empathic experiences and how they could be achieved in an experimental setting. The experiences for the alarm clock were selected from this list to simulate the sight, hearing, touch, and dexterity limitations. The only remaining limitation relevant to the alarm clocks was the mental category, but the researchers desired to leave this category for future research.

Table 4.2: Potential experimental conditions

Limitation	Level of limitation	Experimental Condition
Sight	Reduce	lab goggles with fine grid on transparency paper (*allows for variability of levels)
		low quality welding goggles
	Reduce scope	blinders on side of glasses, holes in restrictive sheet
	Blind	Completely dark room
		Blindfold
		enclose product in dark container with hand holes
Hearing	Deaf	ear plugs
		ear protection headphones used during gun shooting
		headphones with sound louder than ambient noise
Touch	Reduce	add layer between user and prototype (gloves)
Taste	Ability to distinguish tastes	consume more of a certain flavor prior to consumption (bitter, salty, sour, sweet, savory)
	Reduce	reduce or eliminate sense of smell
Smell	Eliminate	close nose (clip)
		isolate nose (snorkel goggles)
	Reduce	smell stronger smell prior
	Heighten	breathe strips to open nostrils
Dexterity	Hand	oven mittens, gloves, mittens
		tape fingers together with medical tape
	Arm	one hand behind back
		carrying weight or bulk with one hand
	Body	jumpsuit adding bulk, weight, joint padding
		wear protective equipment (hockey/football pads)
Mental	Multitask	recite information (phone number, alphabet backwards)
		read off prompter, talk on phone/carrying conversation
		answer questions/simple math problems every 15-30 seconds
		play a game while interacting
		could add incentive/reward to encourage performance
Environment	Night	dark room with light source (flashlight reflecting off wall, projector with dark screen/tape on lens)
	Rain	mounted sprinkler under canopy
	Temperature	change room temperature
	Location	add rocks/sticks on floor
		confine space in small or low ceiling room

4.2.3 Selection of Participants

Experiments were performed at both The University of Texas at Austin and University of Massachusetts at Dartmouth campuses. Each school approached recruitment in similar fashions, but could not perform identical procedures due to differences in IRB protocol. Potential participants at The University of Texas at Austin were recruited from the senior level mechanical engineering design class, ME366J. The rationale for using these students was that they have a strong and consistent educational exposure to mechanical engineering design.

Students were given the incentive of extra credit for participating and other forms of extra credit were presented so there was no pressure to participate. The identity of the participating students remained anonymous from the teaching professor. Students were referred to only by provided participant numbers, and the professor was given a list of names for extra credit with the source of extra credit disguised from the professor. In Fall 2009, students signed up for 2 hour time slots covering a two week period. Groups of six students were randomly created with mutual availability and notified of their session details. A total of 46 students participated in the study in this manner. In Spring 2010, experiments were performed during lecture time and students were given the option to either participate in the experiment or work on other material. Each lecture section was assigned to be either control or experimental. Students were counted off and organized into as many groups of 6 students as possible with remaining students forming groups of at least 4 students. A total of 65 students participated in the study in this manner. Experiments were run in the lecture format at UMass-Dartmouth over the course of three semesters. Only the results of the Fall 2009 participants from UT-Austin are included in this analysis.

4.3 Experimental Procedure

Before beginning, students were briefed in the procedure and consent was obtained. Participant groups were asked to simply generate three alarm clock concepts after a brief period of interaction with alarm clocks. Students were asked to interact with the digital and mechanical alarm clocks in small groups for 15 minutes before performing the concept generation. Interaction was defined as any typical use including setting the time and alarm, turning off the alarm, changing the time and alarm, and using the snooze function for both clocks. Students were instructed to perform these actions and watch another person perform them. While the control group received no extra stimulus, the experimental groups were given the same instructions but asked to also use the experimental conditions of headphones, bandanas, and oven mitts. Students were allowed to use the conditions in any order or combination, but were asked to try each condition separately and to combine them all together.

Both groups performed a round of modified 6-3-5 [55, 56], or C-sketch [57], concept generation technique. This technique consists of a small group of participants rotating individually generated concepts and commenting through the use of sketches and phrases. Each student was asked to draw/sketch 3 concepts for an alarm clock on separate pieces of paper using phrases or comments to help convey his or her ideas. After 15 minutes, each person passed their sketches to another member of the group to expand and make comments on the ideas. Comments were tracked by providing each student a different colored marker and labeling the original concept by participant number. Each subsequent rotation was 6 minutes until each person had a chance to comment and make suggestions on every other concept. During the lecture based format, as many commentary rounds as possible were performed in the allotted lecture time, which was typically 4 rounds.

4.4 METHOD OF ANALYSIS

The generated concepts from the 6-3-5 session were compared and analyzed between the control and experimental groups according to a set of metrics. Since 6-3-5 was used to generate concepts, students occasionally made features or evolved the design in a manner that contradicted previous versions of the design. A concept was defined for the sake of analysis as the "general direction" of the design, or the design with a feature set that was most congruent with the perceived agreement of the group. If the main idea branched or encompassed two separate substantial ideas, then each idea was considered a concept and analyzed as such. Additionally, students occasionally created an entirely new concept on purpose.

Before applying metrics at the feature level, features were categorized into descriptive bins for use in analysis. The alarm clocks were broken into 6 basic and 3 additional features, as seen in Table 4.3, including the basic features of mode of alarm, display, information shown, user input, energy source, and snooze. Additional features included alternative use, music, and shape/layout.

Table 4.3: Alarm clock feature definitions

Mode of Alarm- Any feature that is used to wake a user up. This also applies to any feature that forces the user to get out of bed including moving alarm clocks. Standard feature defined as the use of beeping or ringing sound.
Display Type- Any form of displaying information to the user. Standard feature defined as basic analog, LED, or digital display.
Information Shown- The type and amount of information displayed to the user. Standard feature considered current time, alarm time (analog clocks), am/pm, and alarm on/off.
User Input- Any method of input or interaction between the user and clock including setting the clock or turning the alarm on/off. Standard features include buttons and/or dials.
Energy source- Any feature that supplies power to the clock. Stand features defined as power cord and/or battery.
Snooze- Any feature that describes whether an alarm clock has snooze capabilities and how to activate the function. Standard features include buttons for digital clocks and none for analog clocks.
Music Player- Any feature that describes the existence of type of music playing capabilities. Standard feature implies no music playing capabilities. Music is separate from additional uses because of the prevalence of music playing functionality.
Additional Uses- Describes any additional functions performed by the alarm clock beyond traditional and music playing capabilities. Standard feature implies no additional functions.
Shape/layout- Describes the architecture, outward appearance, or theme of the clock frame. Standard implies no unique characteristics of the shape or layout.

A standard feature was considered to be any feature similar to or equivalent to the features present in the provided prototypes, such as basic beeping or ringing noise as a mode of alarm. If a feature was not specified in a particular concept, then standard features were assumed. Each feature was assigned into a bin to accurately describe the present feature and new bins were created as needed while analyzing. For example, a design that automatically set the current time by means of satellite or radio waves was classified as “Automatic” and a design that allowed the user to turn off the alarm by verbal command was classified as “Voice Activated.” Since the User Input feature encompassed both setting the clock and turning off the alarm, it was possible that a design could have both of the previously mentioned classifications, in which case the design would be categorized as “Automatic + Voice Activated.” Combination bins were treated as their own unique bins to allow for accurate representation of the design and were necessary due to the broad feature definitions. A complete list of bins for each feature may be viewed in Appendix A.

4.4.1 METRICS

Numerous metrics were used including standard techniques suggested by Shah[72, 73], Linsey[74] , and Srivathsavai [75] as well as experimental metrics developed during the innovative product study. Multiple metrics were used to evaluate the same principle or idea to evaluate the ability of the metrics to measure the idea. For example, seven different metrics and variations of metrics were used to quantify the idea of “creativity/innovation.” Designs were analyzed at either the feature level, concept level or both, depending upon which was appropriate for the application.

At the feature level, values were assigned for each feature independently of the other features. Concepts were evaluated according to the previously defined boundaries of concepts. Note that capitalized or lower case variables correspond to concept or feature levels, respectively.

Novelty

The novelty of a design was evaluated relative to all other designs at both the concept and feature level according to Shah [72, 73]. At the concept level, the novelty of a concept was measured by grouping it with other concepts with similar ideas. The size of that group relative to the overall set of concepts was used to calculate novelty as follows:

$$S_{Novelty} = \frac{T-C}{T} * 10 \quad (4.1)$$

where T is equal to the total number of designs in the set and C is the number of designs with similar ideas. The value was multiplied by 10 to scale the value similarly to other metrics.

The values at the feature level were assigned through a similar process by comparing the number of concepts assigned to the concept's bin for a given feature to the total number concepts, as follows:

$$s_{Novelty} = \frac{T-c}{T} * 10 \quad (4.2)$$

where c represents the number of designs that belonged in the same bin for a particular feature. The average value of the assigned feature level novelty scores for each design was also calculated by summing the novelty scores for each of the features in a single design and dividing by the total number of features, as follows:

$$s_{Novelty\_avg} = \frac{\Sigma(s_{Novelty})}{\#\, of\, features} \tag{4.3}$$

Since designs and products are frequently defined by a single distinguishing characteristic or dimension, the maximum assigned novelty score at the feature level was also recorded for comparison.

$$s_{Novelty\_max} = \max\,(s_{Novelty}) \tag{4.4}$$

<u>Originality</u>

As an alternative to the novelty metric, originality was assessed at the feature and concept level as defined by Gulliford [76]. A value was assigned on a four point interval scale, as seen in Table 4.4, based upon the evaluator's opinion of which word better described the design or feature.

Table 4.4: Originality descriptions and corresponding scores

Description	**Originality** ($S_{originality}, s_{originality}$)
Common	0
Interesting	4
Exceptional	7
Genius	10

Although the originality metric developed by Gulliford utilized an 11 point scale, repeatability studies performed at UM-Dartmouth[75] suggested that the most repeatable results were achieved with the use of a four point scale. Similar to the novelty metric, the average and maximum of the feature level scores were recorded. The average feature score was taken by summing the originality scores for each feature of a particular design over the number of features.

$$s_{originality\_avg} = \frac{\sum s_{originality}}{\#\, of\ features} \quad (4.5)$$

$$s_{originality\_max} = \max\left(s_{originality}\right) \quad (4.6)$$

Number of innovative characteristics

The characteristics of innovative products developed in the previous product study (Chapter 3) were adapted as an experimental method of analyzing the level of innovation present in concepts. Concepts were analyzed in the same fashion as products in the product study. To compare the concepts to the market, a list of features present in the top 20 bestselling alarm clocks at Wal-Mart, Target, Buy.com, and Amazon were collected (Appendix B). The number of innovation characteristics displayed by a design was used to determine the Empathic Experience Design (EED) metric, as follows:

$$S_{EED} = N_{characteristics} \quad (4.7)$$

where $N_{characteristics}$ represents the number of characteristics of innovation assigned to a concept. This analysis was also used to help break down the types of innovation, such as differentiating between function-based and user interaction-based innovations, exhibited between the control and experimental groups.

Feasibility/Quality

The technical feasibility, or quality, was assessed at both the concept and feature level based upon Shah[72] and the modified version suggested by Linsey [74]. The following flow chart was used in order to evaluate the designs at the concept level.

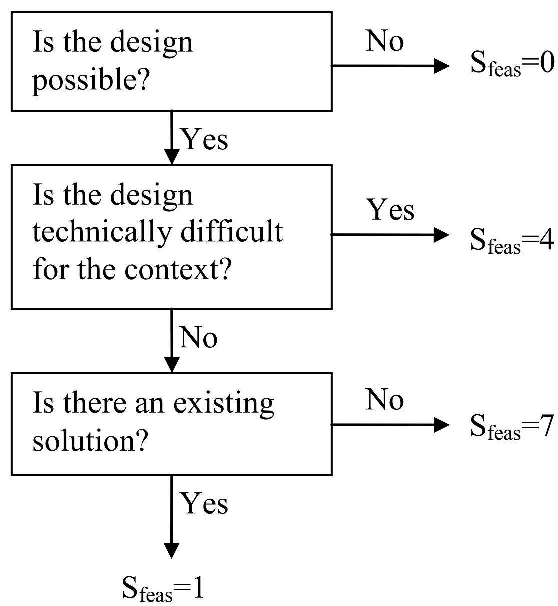

Figure 4.3: Flow chart for assigning feasibility scores

For the sake of analysis, a solution was said to exist if similar or analogous subsystems were on the market. For example, if an alarm clock turns on a television or video screen to wake up a user, then it would be said to leverage an existing solution because most televisions have a timer feature to turn off the television even though few if any alarm clocks incorporate that technology. The manufacturer could buy the subsystems and assemble them relatively easily.

The same procedure was repeated for each feature and the average of the scores was taken. The average feature score was taken by summing the feasibility scores for each feature of a particular design over the number of features, as follows:

$$s_{feasibility\_avg} = \frac{\sum s_{feasibility}}{\#\ of\ features} \tag{4.8}$$

Since a design is only as feasible as its least feasible feature, the minimum feasibility score at the feature level was also recorded.

$$s_{feasibility\_min} = \min\left(s_{feasibility}\right) \tag{4.9}$$

<u>Design Fixation</u>

The approximate level of design fixation, or similarity to the prototypes, was assessed as the percentage of features that were considered the same as those in the experiment prototype.

$$S_{fixation} = \frac{N_{standard}}{\#\ of\ features} \tag{4.10}$$

where $N_{standard}$ represents the number of "Standard" features.

4.5 Evaluation of Metrics

Before analyzing the data between the control and experimental groups, the metrics were compared against each other to determine the most fitting metrics for use in the current and future data analysis. All of the data was averaged for each group of participants, and the scores for each of the eleven metrics were compared.

4.5.1 Evaluation of creativity metrics

The effectiveness of the seven metrics used to evaluate the level of creativity in the designs was analyzed by comparing the scores to each other. While the scales differ slightly between the metrics, the plot in Figure 4.4 shows how each metric handles different levels of creativity.

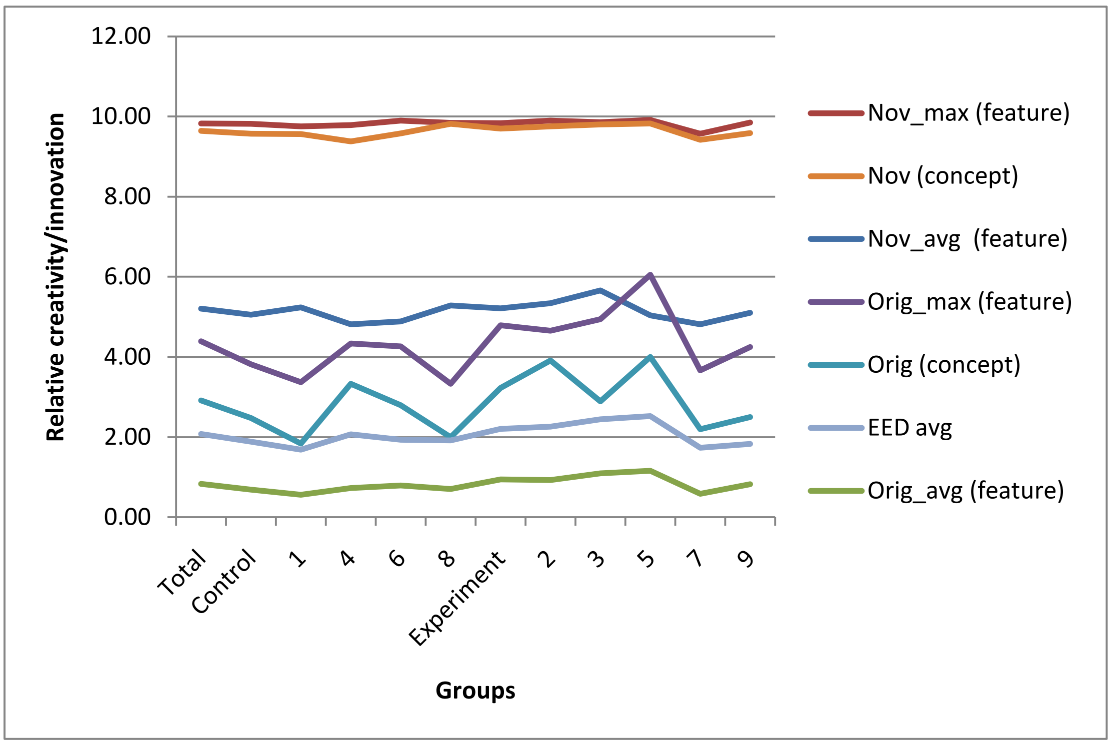

Figure 4.4: Comparison of relative creativity/innovation

As a whole, the novelty metric was not very effective at reflecting a design's level of creativity. The novelty values are inflated because of the wide variety of different features in the data set. While a certain feature, such as "Automatic" User Input, may have been seen numerous times, the creation of combination bins of format "User Input

Feature A + User Input Feature B" incorporating that feature with another created a large number of unique bins for sorting the concepts. Overall the novelty metric is strongly affected more by the granularity of the bins for each feature. Each bin can either be broad and risk accurately describing a feature or it can be specific and cause inflated values from the large number of unique combinations of features.

Also, at the concept level it is nearly impossible to group similar designs for evaluating novelty. The concept level analysis could be better applicable to simpler problems that do not have multiple functions and components. With alarm clocks that interact with a user in multiple ways for numerous functions, it is difficult to select a dimension for grouping the clocks. Should clocks be grouped according to common mode of alarm, the way in which the alarm is turned off, or both?

Furthermore, by just comparing designs within the data set, the metric does not capture whether a design is actually novel. The metric rewards designs or features that are exhibited fewer times in the data set, which treats extremely mundane solutions the same as highly unique solutions. If a student comments on a feature that is considered so obvious by the other participants that they would not even mention the feature, then the extremely mundane solution would appear only a few times in the data set and be rewarded as being innovative. Without a comparison to ideas outside of the data set, the metric becomes biased and unhelpful for an engineer evaluating whether to pursue one concept or another.

The metric is also ineffective in a rotational concept generation technique, such as the modified 6-3-5 used in this experiment. Students tend to repeat ideas and add the same feature to multiple alarm clocks, which causes a deflation of score. For example, one student added a helicopter feature to five designs regardless of the relevancy to the current design. By doing so, the once creative feature is now ordinary and repetitive. If the designs are compared against ideas outside of the data set, such as with the EED metrics, these repetition and technique-based biases are eliminated.

Overall, the originality metric was more responsive and reflected relative levels of creativity than the novelty metric. The originality metric showed higher fluctuations in the scores caused by the use of a four point interval scale and the comparison to external ideas. The maximum originality score at the feature level and the concept level score mirrored each other, which suggests that the prediction of creativity can be summarized by a single defining feature. The same effect can be seen with the novelty metric as well, but it is harder to see because there is less variance between novelty metrics. It should be noted that averaging at the feature level should not be done. Since most designs changed the prototype in only one or two dimensions, any creative feature is lost in the numerous ordinary features. The effect of averaging also changes based upon how many different features were chosen to analyze a product or design and creates a bias towards using a fewer number of features.

While the EED metric does not seem to capture the relative creativity between groups, it offers an in-depth breakdown of the types of innovation present in a set of designs. This information is unique to this metric and valuable for evaluating the effectiveness of the empathic experience technique as seen in Section 4.6.2.

4.5.2 Evaluation of feasibility metrics

As seen in Figure 4.5, a similar evaluation of metrics was performed with the three feasibility metrics to determine the most suitable metric for quantifying relative levels of technical feasibility.

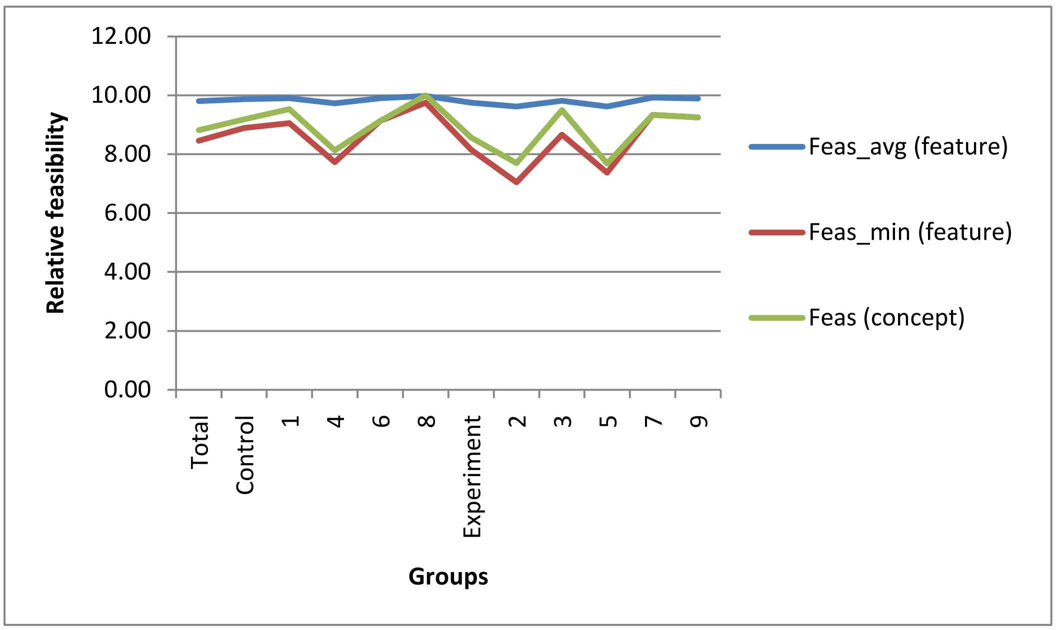

Figure 4.5: Comparison of relative feasibility

The plot illustrates once again that averaging masks the effect of a limiting feature and reduces the variation between groups. The minimum score at the feature level is especially limiting with feasibility because if one feature is technically difficult to implement, then the entire design is difficult to implement.

In future analysis only the maximum originality and minimum feasibility at the feature level and the EED analysis will be used to evaluate concepts. Although the data suggests that the minimum and maximum of the feature level scores mirror the trends at the concept level, higher repeatability between multiple evaluators has been demonstrated at the feature level [75].

4.6 RESULTS

4.6.1 Effect of Experimental Conditions

After ensuring that the appropriate metrics were used to study the data, the differences between the control and experimental groups were explored. The scores for each of the overall/total, control, and experimental groups as well as the individual design groups are compared in Figure 4.6 and Table 4.5.

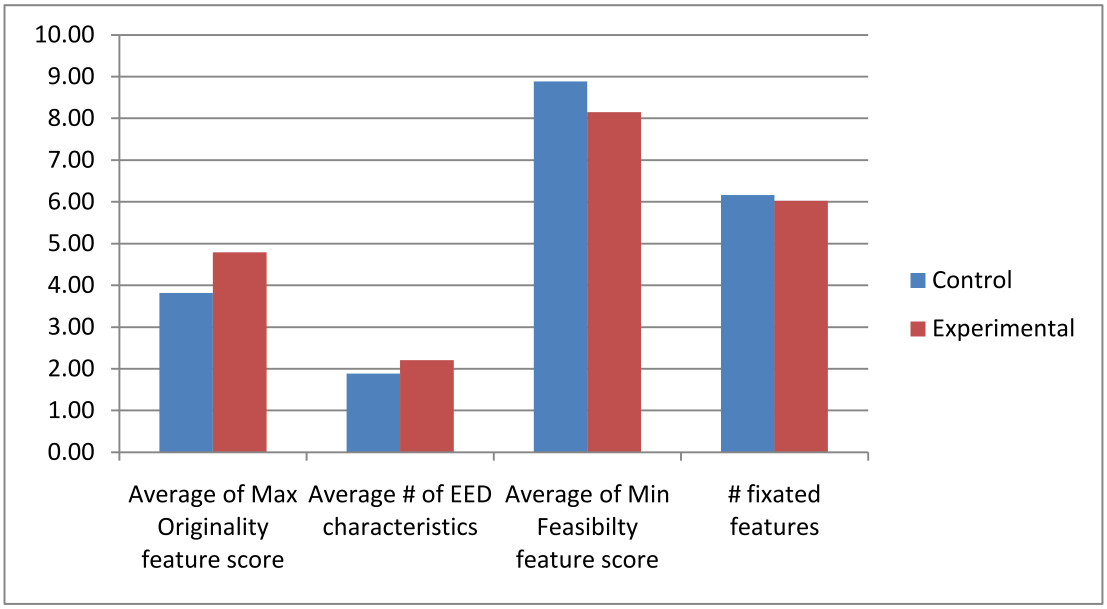

Figure 4.6: Comparison of control and experimental groups

Table 4.5: Comparison of control and experimental groups

	# of designs	Average of Max Originality feature score	Average of Min Feasibilty feature score	Average # of EED characteristics	% of design fixation
Total	148	4.39	8.45	2.07	67.57
Control	61	3.82	8.89	1.89	68.49
Group 1	19	3.37	9.05	1.68	69.01
Group 4	15	4.33	7.73	2.07	65.93
Group 6	15	4.27	9.13	1.93	73.33
Group 8	12	3.33	9.75	1.92	64.81
Experimental	87	4.79	8.15	2.21	66.92
Group 2	23	4.65	7.04	2.26	65.70
Group 3	18	4.94	8.67	2.44	58.02
Group 5	19	6.05	7.37	2.53	69.01
Group 7	15	3.67	9.33	1.73	75.56
Group 9	12	4.25	9.25	1.83	68.52

The experimental group experienced an increase both in the max originality score at the feature level and the average number of innovation characteristics. The experimental group also saw a decrease in the minimum feasibility score at the feature level and a slight decrease in the percent of design fixation. Based upon the disparity seen in the originality values, a larger divergence in the feasibility would be expected since the two metrics are often inversely related to one another. It is promising that the experimental group experienced a larger increase in innovation than decrease in feasibility, which might suggest the experimental group had more of the top designs.

The statistical significance of the differences between the mean metric values were evaluated using a one-sided t-test for unequal variances [77]. The null hypothesis was that the means of the metrics for control and experimental groups were equal. The p-values for originality, feasibility, and number of EED characteristics were 0.02, 0.05, and 0.12, respectively. Assuming a statistical significance level of 0.05, the mean values of originality and feasibility for the experimental group can be considered larger and smaller, respectively, than the mean values for the control group. Differences in the number of EED characteristics was not significant. Although the difference in the number of innovation characteristics is relatively small between the groups, less than half a characteristic difference, the scale of the metric is considerably lower than for originality or feasibility. While products or designs could theoretically be innovative in 13 different characteristic, in practice and observation few designs ever have more than 5 characteristics with the average being lower.

Comparing the individual groups within the control and experiment sets against each other, the existence of outlier groups can be seen. For example, group 7 had significantly lower innovation and higher feasibility ratings than the rest of the experimental groups. With the addition of more data the effect of these types of underperforming groups will hopefully be lessened.

It can also be noted that the number of designs present in each group are not multiples of three, which would be expected with three designs per participant. These values are different because some groups generated more than three concepts per person as the 6-3-5 progressed. Concept boundaries were defined in Section 4.4. There was no evidence to suggest a significant difference in the number of concepts generated by the experimental and control groups, although the experiment was not designed to evaluate the quantity of concepts produced by each group.

The level of design fixation was also calculated, but was determined to not be as meaningful as the other metrics. This metric is biased by the number of features used for analysis. The fewer features used in analysis; the more likely the values would be inflated. Since the granularity of the features used in this analysis were fairly broad, the statistic was not effective at conveying the differences between the data sets. While little variation was seen between the groups, the metric could be useful for comparing to future data sets and will be monitored.

4.6.2 Analysis of types of innovation

The characteristics of innovation created in the earlier product study were used to break down the types of innovation present in the designs. The following tables represent the percentage of the designs in the control and experimental sets that exhibited each category or characteristic with major differences highlighted.

Table 4.6: Analysis by characteristics of innovation

		Percentage of designs with each characteristic		P-value
	Characteristic of innovation	**Control**	**Experimental**	
Function	Additional Function	0.13	0.20	0.0043
Architecture	Modified Size	0.02	0.02	0.0639
	Modified Layout	0.26	0.34	0.0002
	Expanded Usage Environment	0.08	0.09	0.0647
Environmental Interactions	Modified Material Flow	0.10	0.11	0.0213
	Modified Energy Flow	0.39	0.33	0.2962
	Modified Info Flow	0.23	0.24	0.0039
	Interaction with Infrastructure	0.30	0.29	0.1332
User Interactions	Modified Physical Demands	0.11	0.10	0.3791
	Modified Sensory Demands	0.16	0.39	0.0001
	Modified Cognitive Demands	0.10	0.08	0.1651
Cost	Cost	0.00	0.00	-
	Avg. # of Characteristics	**1.89**	**2.21**	

Although the two groups performed equivalently for several categories, the experimental group experienced a higher percentage of designs for three of the innovation characteristics, as highlighted in Table 4.6. The largest difference seen was the increase in Modified Sensory Demands in the experimental group. This result is promising since the experimental conditions focused on altering a user's sensory interaction with the prototypes. A common feature in the experimental set was the use of open-faced analog clocks so that users could feel the position of the clock hands to set or read the time. The inclusion of Braille or engraved controls was also prevalent to help users distinguish between the buttons or knobs. The experimental group also saw unexpected increases in the frequency of designs exhibiting Modified Layouts and Additional Functions. Some of the common features for Modified Layout included clocks that were wearable or interfaced with a user's bed, while Additional Function included designs that performed normal morning chores such as making coffee. The experimental group did see a noticeable decrease in designs with Modified Energy Flows, such as clocks that required a user to pull a cord to turn off the alarm or that moved around the room. No designs showed a significant reduction in cost, but this result was expected since most changes in cost in the earlier product study were from the elimination of a consumable needed for operation, which few if any alarm clocks require.

Statistical significance was calculated by averaging the number of characteristics exhibited by each design group. The p-value represents the significance that the existence of a difference between the average group for experimental and control. All of the major differences were statistically significant, while the smaller differences were not.

Breaking the analysis down to the categories of innovation level provides similar results at a different granularity. The values present in Table 4.7 represent the percentage of the designs that had at least one characteristic for the given category. For example, 30% of the control set exhibited a change in at least one of the characteristics within the architecture category.

Table 4.7 Analysis by categories of innovation

	Function	Architecture	Environmental Interaction	User Interactions	Cost
Control	0.13	0.30	0.61	0.36	0.00
Experimental	0.20	0.37	0.67	0.54	0.00
P-values	0.0043	0.0003	0.0033	0.0001	-
Results from Current Study	0.17	0.34	0.64	0.47	0.00
Results from Product Study	0.38	0.61	0.80	0.69	0.09

When broken down by categories, the experimental group saw a statistically significant increase in all categories over the control group. As could be predicted based upon the previous analysis by characteristics, the largest difference by category was seen in the user interactions. Although the experimental set had a higher average number of characteristics per design, it was not expected that the experimental would have higher percentages across all of the categories.

One of the surprising findings is that the trends are similar to those of the product study in Chapter 3. The most frequently displayed innovation category was Environmental Interactions, followed by User Interactions, Architecture, Function, and finally cost. This effect was not expected but could offer further support of them as a tool for measuring innovation. The similarities could also be caused by the definitions of the characteristics themselves. Further research would be needed to evaluate these claims.

4.6.3 Analysis of top designs

An alternative approach to analyzing or studying the data is to look at the top designs from the data set because companies often only care about the best ideas present in a sample. Based upon the previous product study, it was shown that innovative products exhibit three innovative characteristics on average. For the sake of this analysis, an alarm clock design was said to be innovative if it embodied three or more characteristics of innovation. The percentage of designs for each group that had high levels of originality, evaluated by scores of 7 or 10 for maximum originality at the feature level, and low feasibility, evaluated by scores of 4 or 0 for minimum feasibility at the feature level, were used to breakdown the top designs. The results are provided in Table 4.8.

Table 4.8: Breakdown of top designs

	% of Designs with a “high” (3+) # of EED characteristics	% of Designs with a "high" (7 or 10) max originality score	% of Designs with a "low" (4 or 0) feasibility
Control	32.8	23.0	9.8
Experimental	34.5	36.8	21.8

As shown, there is very little difference between the control and experimental groups in terms of the number of EED innovation characteristics exhibited. This result is slightly unexpected given the difference in the average number of characteristics per design in favor of the experimental group. In terms of high originality, however, the experimental group was considerably more likely to have a high originality rating.

Unfortunately the experimental group was also twice as likely to have a low feasibility score, which suggests a tradeoff between the two metrics. In an actual engineering design process, the designs with high originality and high feasibility would be ideal candidates for further development. The experimental group had a higher frequency of these designs with 20% of the group, compared to 15% for the control group, exhibiting high levels of both originality and feasibility.

4.7 Conclusions

Overall, the experimental group exhibited slightly higher creativity and innovation and lower technical feasibility than the control group. These differences were shown to be statistically significant and suggest that the use of empathic experience techniques will lead to better designs. The breakdown of results according to the characteristics of innovation is very promising. The experimental groups saw a significant increase in User Interactions and specifically Modified Sensory Demands. Since the experimental conditions were designed around altering a user's sensory interaction with the prototype, these results support that the technique can increase innovation based upon the selected conditions. Furthermore, the experimental group had a higher percentage of products that were both high in originality and feasibility. It is important to remember that these are preliminary results and conclusions and significantly more data has yet to be analyzed.

4.7.1 Observations

After each group participated in the study they were asked several questions informally. Based upon the feedback from the participants several conclusions can be made. First, while the students liked the used of the empathic conditions, they thought that it made them fixate on designs meant just for physically handicapped users. Most students from both groups commented that the interaction with the alarm clocks was a good reminder of the elements of an alarm clock to include in their designs because they mainly use their cell phones as an alarm clock.

In hindsight, the choice of an alarm clock may not have been the best option to use in this study. The alarm clock is a high s-curve product that has experienced extensive evolution in the past leaving few design avenues unexplored. Additionally, many of the more exotic alarm clocks on the market are quite popular and have received attention in recent years. An ideal product would allow for ample room for improvements in a variety of different ways so that the effect of the empathic experience interactions could be clearly identified in the results.

While group based concept generation techniques such as 6-3-5 have been shown to generate more innovative ideas than other techniques [57], its use in the study may not have been the best option. It is suggested that instead of using 6-3-5 to generate concepts, allow the students to individually generate as many and as detailed designs as he or she desires in a given amount of time. By allowing the students to draw as many designs as possible, a more accurate comparison between the control and experimental designs could be achieved. It would not only allow for the use of additional metrics such as quantity and depth of concepts in analysis, but also reduce the effect of the students including clocks currently on the market. For example, numerous designs drawn by participants were identical in every feature to clocks found in the market, such as Nanda's Clocky seen in Figure 4.7, which rolls away from the user using randomly generated motions.

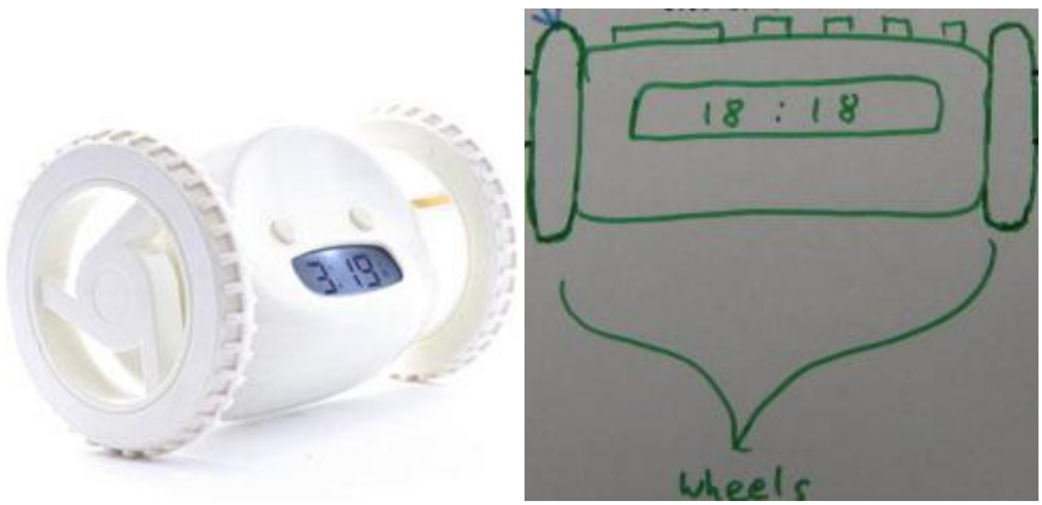

Figure 4.7 Clocky [78] and Clocky-based design

If those students were allowed to draw as many ideas as possible, then the impact from drawing current market clocks on the relative levels of innovation when compared to ideas outside of the data set could potentially be reduced with the wealth of other ideas.

As previously mentioned during the evaluation of metrics, students frequently added the same features to multiple designs within the group or added features that were contradictory to the current concept causing difficulty in determining which features should be considered for analysis. The metrics developed by Shah [72] were designed to be used on individual-based concept generation techniques, which may be one of the reasons why they performed poorly in this study. Similarly, a recent study [75] suggests that the results of Shah's metrics may not be easily repeatable for group concept generation.

Chapter 5

Application of EED to a Customer Needs Analysis Study

5.1 Overview

In conjunction with the application of empathic experience design to concept generation, the broader ranging impacts of empathic experience design were evaluated using a customer needs study. Since the proposed positioning of the technique in the product design process is between customer needs and concept generation, it makes logical sense to explore the effects in both areas. Whereas the concept generation study focused on actually generating innovative ideas, the customer needs study investigates the rate of discovery of latent needs that could lead to an innovative design. The study investigates whether customers that have an empathic experience interaction with a prototype during customer needs interviews will suggest more latent customer needs than they would otherwise generate with typical prototype interaction.

5.1.1 Motivation

The study is based upon a previous study performed at the University of Texas at Austin for the Honors Thesis of Joseph Lin in 2007[10]. In the study, Lin compared the results of various customer needs techniques on the redesign of a two-person dome camping tent. The study consisted of verbal interviews in which participants were asked their thoughts on a tent, articulated use interviews in which participants constructed a tent while commenting, and empathic lead user interviews in which participants constructed a tent under extreme conditions, in the dark with oven mitts on their hands, while commenting. Each of the three types of interviews had a free speech portion, in which participants were prompted to discuss characteristics of their ideal tent, and a categorical questioning portion, in which a series of open-ended questions were asked. He found that while the extreme conditions helped discover five times as many latent needs as the articulated use interviews, the empathic lead user interviews saw a decrease in the breadth of categories mentioned during the interview.

Although the study performed by Lin had intriguing results, there were numerous opportunities for improving the experimental procedure. The current study represents an expansion and slight modification of the experiment to validate the previous conclusions. It is important to note that the results and conclusions presented here represent preliminary findings. This project is an ongoing study and the statistical significance of the results will continue to grow as more interviews are performed. By studying how customers interact with prototypes in a customer needs analysis setting for product redesign, it can be discovered whether different types of interactions lead to a greater rate of discovery of latent customer needs that are difficult for customers to articulate.

5.2 Experimental Methodology

The main alteration made to the previous study revolved around procedural changes. In the previous study, the three customer needs analysis techniques were not investigated independently of each other. Half of the participants performed an articulated use interview followed by the empathic lead user interview and the other half participated in all three of the interviews. No one participated exclusively in the empathic lead user interview, and the empathic interview was always performed last. While insights were drawn, a direct correlation between the rate of latent needs discovery and the use of a specific technique was not fully validated. The questions asked during categorical questioning were also modified slightly based upon changes made to the categories used in analysis. The current study tries to correct the procedure and increase the sample size to strengthen the overall results.

5.2.1 Selection of Participants

To simulate the diverse customer feedback typically seen in industry, a wide variety of participants was desired, with different genders and different disciplines, designated as engineering and non-engineering. Participants were found using word-of-mouth and by recruiting volunteers at major areas around the UT-Austin campus. Students were offered the incentive of a variety of UT drinkware for participating in the study, which took around 40 minutes to perform. The only screening question for limiting participation was the requirement of having constructed a tent at least 5 times throughout his or her life. A basic knowledge of how to construct a tent was necessary so that the volunteers could focus on commenting on the tent rather than figuring out how to assemble it.

Basic demographic information including age, gender, major of study, and approximate tent building experience were collected prior to participating. An equal number of engineering and non-engineering majors was desired for both the control and experimental conditions. Gender was recorded only to ensure a relative balance in the data, but was not a major focus. Once an individual volunteered, the assignment of either control or experimental conditions was performed based upon the current balance of the demographic statistics. The availability of suitable locations to run experimental conditions was also taken into account. While control experiments could be run in a variety of locations, only select locations and rooms could achieve the level of darkness desired as an experimental condition. Preference was given to perform an experimental interview if one of the favored experimental locations was available. Although the final number of participants, which is expected to be approximately 40 participants, will be determined based upon reaching a level of statistical significance for the results and trends discovered, a total of 24 have taken part so far.

5.2.2 Interview procedure

After volunteering and being assigned conditions for the interview, participants were asked to come to a designated interview slot at a specific time and location. Before beginning the interview, consent was obtained and the participant was given a brief overview of the procedure. The anonymity of the participant was ensured at all times and names were never recorded.

Each interview was structured into two parts. First, a free-speech articulated use interview was performed in which the participant was asked to assemble, explore the interior, and disassemble the tent. Following the free-speech portion, a brief categorical questioning procedure was implemented. The participant was asked to provide comments throughout the process, such as likes and dislikes, or a comparison to the individual's theoretical ideal tent. An REI Camp 2 Dome tent, Figure 5.1, was used for the interviews. It is a two-person tent that uses two poles attached through a number of clips as a support frame. There is a large door on both of the long sides and windows on the shorter sides. A rain fly is supported by a third short pole and straps to the bottom of the two main poles to create a canopy over both entrances.

Figure 5.1: REI Camp Dome 2 tent [79]

For the control conditions interviews, participants were simply asked to interact with the tent normally during the assembly. For empathic experience or experimental condition interviews, participants were asked to interact with the tent with oven mitts on their hands in a dark room. These conditions were chosen to simulate lead user conditions, such as arriving to a campsite late in cold weather with gloves, or extraordinary users, such as partially blind or arthritic. A level of light equivalent to a night with a partially full moon was desired, which was achieved by turning on a ceiling-mounted projector to a standard blue screen and taping a piece of paper folded into fourths over the lens. In addition to covering up any windows in the room, this procedure created a low amount of ambient light that allowed for the interviewee to distinguish shapes and outlines. Since most of the interviews were performed in small conference or classrooms, access to a projector was almost always possible.

Participants were allowed and encouraged to speak freely while assembling the tent. Involvement of the interviewer was kept at a minimum and any interactions were carefully calibrated to avoid biasing or encouraging one type of comment over another. If the participant was silent for several minutes, he or she was reminded to continue to comment. Guidance in the construction of the tent was only offered if the participant had failed several times on a particular step, which mainly happened with the attachment of the rain fly. Participants were asked to clarify or explain vague comments to ensure the proper context of the comment for deriving customer needs later. For example if participants stated, “This is hard,” they would be asked to explain, which resulted in comments such as, “It’s hard to insert the pole into the rain fly.”

Following the articulated use interview, categorical questioning was performed, covering the categories of size/shape, environmental interactions, safety, durability, aesthetics, costs, ergonomics of use, ergonomics of setup, and transporting the tent. The questions were structure to be as unbiased as possible, such as “What did you think of the setup process?” and “What do you think about the durability of the tent?”.

While the participant spoke, the researcher transcribed the comments. The interviews were also recorded using a tape player and microphone in case a comment was missed or clarification was needed. The tapes were erased as soon as a complete transcription was obtained.

5.2.3 Method of analysis

From a transcribed interview, the stream of remarks was broken down into thoughts or ideas representing a single comment. A thought was considered a statement or collection of information that could be grouped together pertaining to a similar specific subject. Each of these comments was numbered for analysis purposes. The list of comments was assessed on whether it generated a customer need and then classified into customer needs categories. Comments that did not result in a customer need or represented repeated customer needs statements were discarded and were not categorized. For example, if a participant mentioned the effectiveness of the rain fly at repelling rain, then further comments relating to the same topic would be discarded unless he or she added more details or information. A high level of precision for the formation and division of thoughts into comments was not required since the method of analyzing the comments focuses on deriving customer needs rather than dissecting the comments themselves.

The categories used to group the customer needs, shown in Table 5.1, are a modified list from the study performed by Lin and are based upon familiarity with the problem.

Table 5.1 Definitions of customer need categories

Geometry: Any need pertaining to the physical dimensions, volume, or shape of the tent during use. This category does not include storage, which is covered by the Transport category.
Environmental Interactions: Any need related to a location or place of use such as a campsite or backyard; a type of environmental factor such as weather, rocky, rainy, dark, sunny, or temperature; and the use of windows for light or ventilation.
Safety: Any mention of harm to either self or others in the area such as poking with poles or tripping on guide wires.
Durability: Any mention of the quality of construction or resistance to deterioration of quality or function including sturdiness, breaking, and tearing, time of ownership, long-lasting, or maintenance issues.
Aesthetics: Any mention of color, pattern, or other element that triggers an emotional response in the user. These needs should not be functionally based.
Cost: Any reference to money or expense of either purchase or maintenance repairs.
Ergonomics (Use): Any user interactions with the tent after it is assembled. Doors, zippers, pockets, and holding equipment are included, as well as needs relating to a user's comfort in use derived from floor material or size of the tent for multiple people (which would also be marked as Geometry).
Ergonomics (Setup): Any user interactions with the tent during the process of assembly and disassembly including reference to instructions, ease of construction, struts, grommets, poles, pole clips, rain fly, staking, and guide wires.
Transport: Any mention of the tent in its storage bag including weight, being portable, compact form, carrying bag, attachment to backpack, handle, tightening clips, or storage of tent.
Latent Needs: A latent need was defined as any customer need that suggests an unexpected change in the design, or requests features that are not present in commonly-available, related products. Latent needs also encompassed needs that do not fit into any other category. The classification as a latent need overrides all other categories.

It should be noted that latent customer needs were treated as their own category of needs. If a comment derived a latent need, as defined by the definition, then the comment was not classified into any other category regardless of whether the comment would typically be included in the domain of another category. For example, the suggestion to print the instructions of assembly onto the side of the tent so they are never lost was classified as a latent need rather than Ergonomics (setup) even though instructions are normally covered by Ergonomics (setup). This procedure was implemented to prevent latent needs from being double-counted in the analysis. Also, Ergonomics was divided into Setup and Use as separate categories to accommodate the large number of comments received in this area. While most of the categories could have been broken down into a finer granularity, doing so would not have contributed to the analysis as much as the separation of ergonomic comments did.

Although most comments were classified as only one category, it was not uncommon for comments to hit numerous categories or derive multiple customer needs. For example, the comment "I like how it is light weight and compact" would receive two transportation marks since "light weight" and "compactness" are two separate customer needs.

Since the interviews and accompanying analysis were performed by three separate researchers, agreement and reliability between them was ensured during the study. Several subsets of interview comments were categorized according to the prescribed procedure by all three researchers independently. The results were compared for interrater agreement and a percent agreement over 93% was achieved. Cohen's Kappa was not used in this instance because of the low frequency of classifications.

5.2.4 Metrics used in analysis

The resulting classification of customer needs was analyzed according to several basic metrics. The breadth of the customer needs was assessed by the number of categories hit by a given participant during the free speech portion of the interview. This metric was only applied to the free speech portion, since each category was revealed during the categorical questioning. The total number of derived customer needs, including latent needs, and the total number of latent needs discovered for the entire interview were also used for comparing the effects of the control and experimental conditions.

Although Lin[10] also measured depth of comments, this metric was not used because participants were asked to clarify vague statements to correctly assess the appropriate customer need.

5.3 RESULTS

5.3.1 The effect of empathic conditions

Overall, there was a slight difference in the average number of customer needs derived between the two groups, 29.8 and 27.1 for the control and experimental groups, respectively. This difference is not statistically significant, with a p-value of 0.264, so it can be assumed that the experimental conditions do not lower the number of derived customer needs.

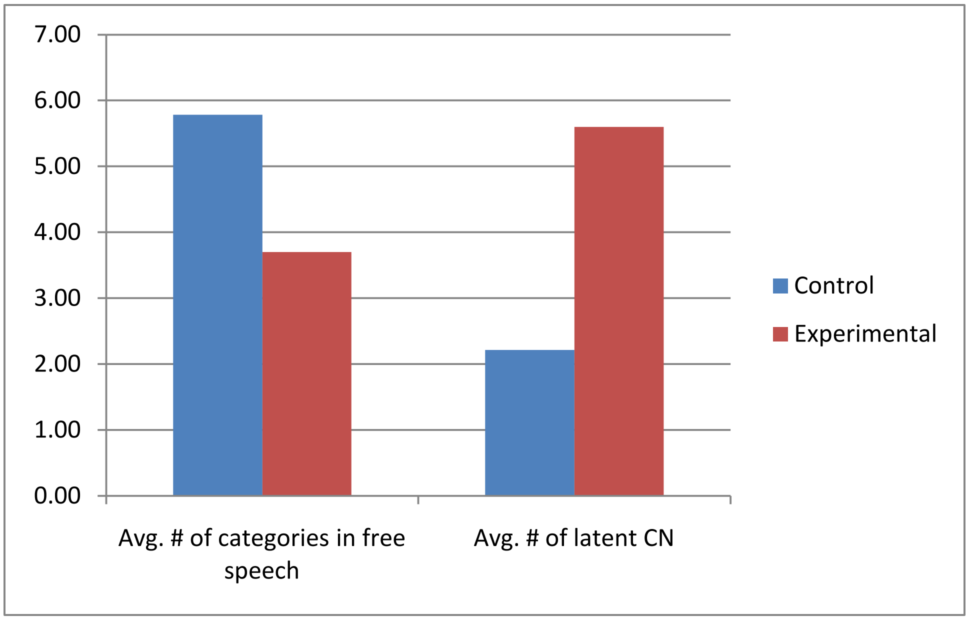

Figure 5.2: Effect of conditions on customer needs

The conditions did have a substantial difference on the types of customer needs, as seen in Figure 5.2. The experimental group experienced a decrease in the average number of customer needs categories mentioned by approximately a third and an increase of more than 2.5 times the number of latent needs discovered. Both of these trends were statistically significant with p values of 0.007 and 0.01 for the differences in number of categories and latent needs discovered, respectively. Although the trends follow those shown by Lin, the magnitudes of the differences are not as significant. Lin reported an increase of 5x production of latent needs. Since the samples are of comparable sizes, 20 and 24 for Lin and the current study, respectively, the difference in magnitude was probably caused by the changes in the interview procedure. Potential differences between the groups of participants could also have factored into the results.

Table 5.2: The average number of CN by categories touched during free speech

Category	Avg. # of CNs per categories-Control	Avg. # of CNs per categories-Experimental
Geometry	1.5	1.4
Environmental Interactions	3.1	1.7
Safety	0.4	0.2
Durability	1.1	0.1
Aesthetics	0.9	0.0
Cost	0.1	0.0
Ergonomics (Use)	2.0	1.5
Ergonomics (Setup)	5.1	4.3
Transport	1.9	0.9
Avg. # of categories	**5.8**	**3.7**

Not only did the control group mention more categories of customer needs during the free speech interview, but they also had a different distribution of the customer needs as seen in Table 5.2. The average number of customer needs followed the same trend for both groups, with Ergonomics (setup) occurring most frequently, followed by Environmental Interactions, Ergonomics (use), Geometry, and Transport. While the control group had more Setup Ergonomics and Environmental Interaction customer needs, these categories constituted the majority of the latent needs, which were counted separately. These results are not surprising given that free speech occurred while using the product. It would be expected that the majority of the comments would be related to the setup.

The main differences between the sets are the higher number of comments regarding transport, aesthetics, and durability from the control group. Since the experimental group experienced the tent in a dark room with limited visibility, those comments are expected to be more focused and to exclude comments concerning aesthetics. The participants did not see the tent constructed with proper light, which prevented them from noticing or commenting on smaller features of the tent. Participants also mentioned during categorical questioning that they could not assess the durability because of the limitations of the oven mitts and not being able to feel the tent material.

5.3.2 Effects of different interview styles

Since multiple interview techniques were used in the experiments, the effects of each were analyzed. The progression of the customer needs can also be seen in Figures 5.3 and 5.4.

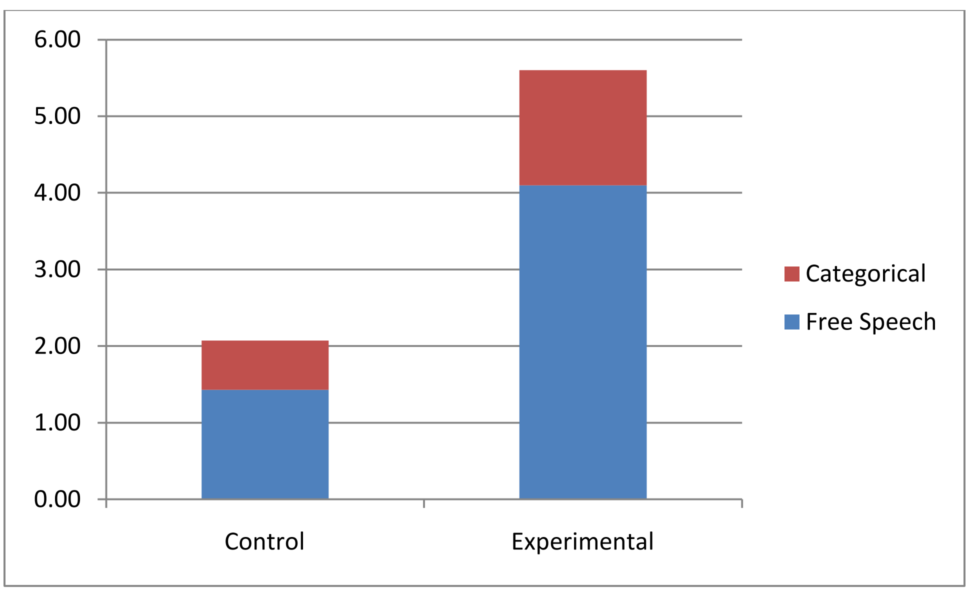

Figure 5.3: The progression of latent need discovery by interview type

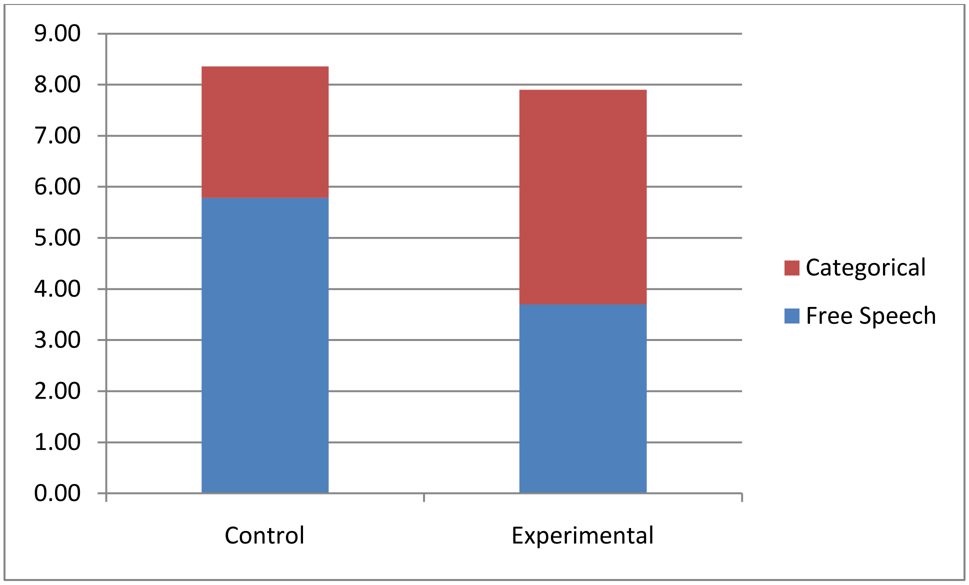

Figure 5.4: The progression of the number of categories by interview type

The comparison between the two interview techniques suggests that the categorical questioning following the articulated use interviews was very useful under both sets of conditions. The categorical questioning almost doubled the number of customer needs generated, increased the number of categories touched, and discovered additional latent needs. As expected, the categorical questioning helped the experimental group more than the control group by significantly increasing the number of overall categories mentioned, from 3.7 to 7.9 for the experimental compared to the 5.8 to 8.3 for the control group. The number of customer needs derived was relatively constant across each type of interview and experiment conditions.

Even though the same questions were asked to both groups during the categorical questioning, the experimental group outperformed the control group in latent needs discovery in both sections of the interview. This result is encouraging and suggests that the experience of empathic conditions allows the participants to think about the tent differently.

Although a question was asked covering all categories during the categorical questioning, on average the participants had no comments or only reiterated previous statements on approximately two categories. This trend is illustrated with the average number of categories mentioned during the categorical interviews of 6.7 and 6.9 respectively, even though questions covering all 9 categories were asked.

5.3.3 Effects of participant demographic

Although the study is ongoing, a total of 24 participants have been interviewed so far. As seen from Table 5.3, the desired diversity has been achieved. There are currently more males than females that have participated in the study, but no effect has been observed to suggest gender would influence any of the results.

Table 5.3 Participant demographics

		# of Participants
Conditions	Control	14
	Experimental	10
Major	Engineering	11
	Non-Engr	13
Gender	Male	16
	Female	8
	Total	23
	Avg. age	22.3
	Avg. tent experience	45.3

While the participant's discipline of study was not presumed to have an effect on the derivation of customer needs, this effect was monitored and analyzed. There was found to be a slight difference between the subjects with an engineering background and those with a non-engineering background. The results suggest that the control set of non-engineers have outperformed the control engineers, but the effect of the empathic conditions appears to benefit the engineers more. The trends are shown in Figures 5.5 to 5.7.

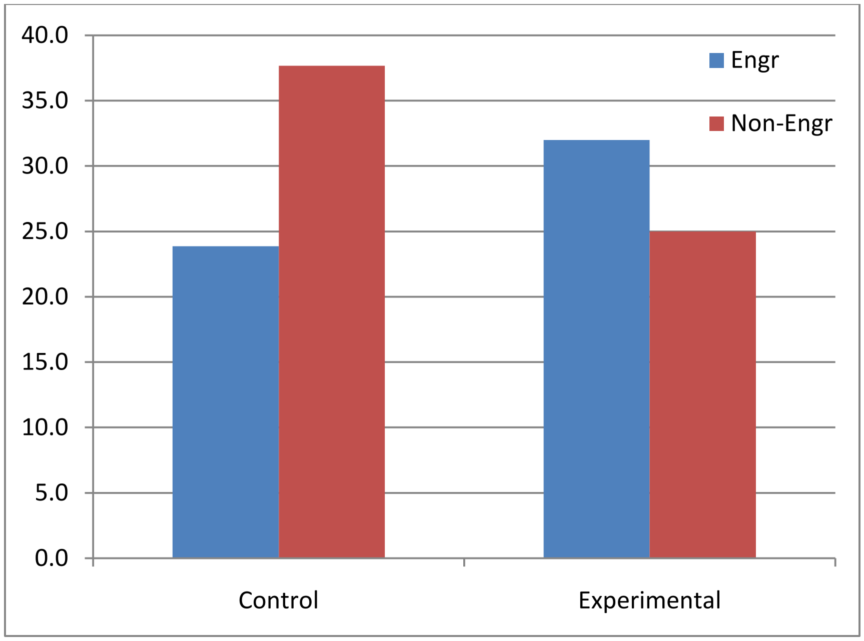

Figure 5.5: Effect of major of study on the total number of customer needs derived

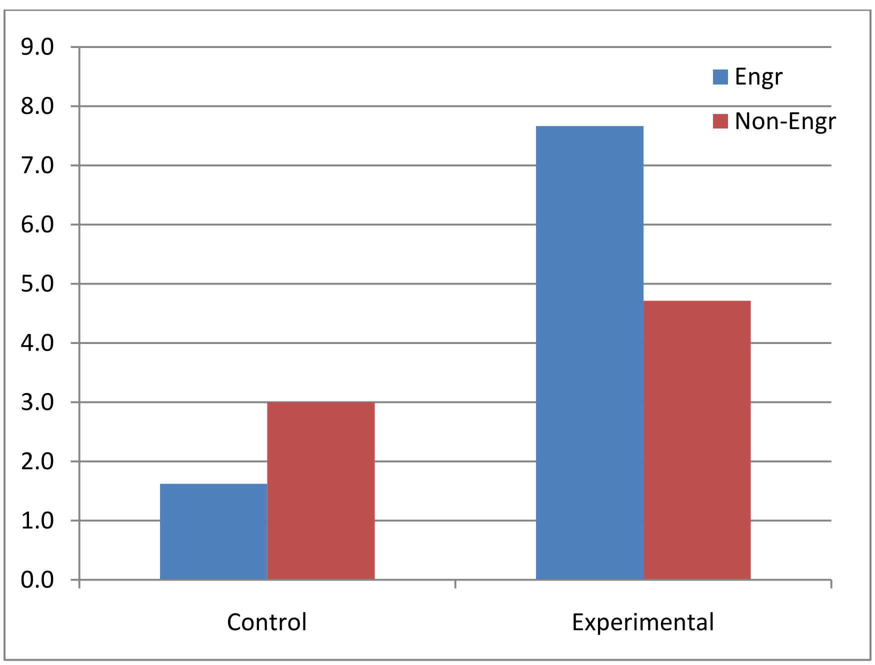

Figure 5.6: Effect of major of study on the average number of discovered latent needs

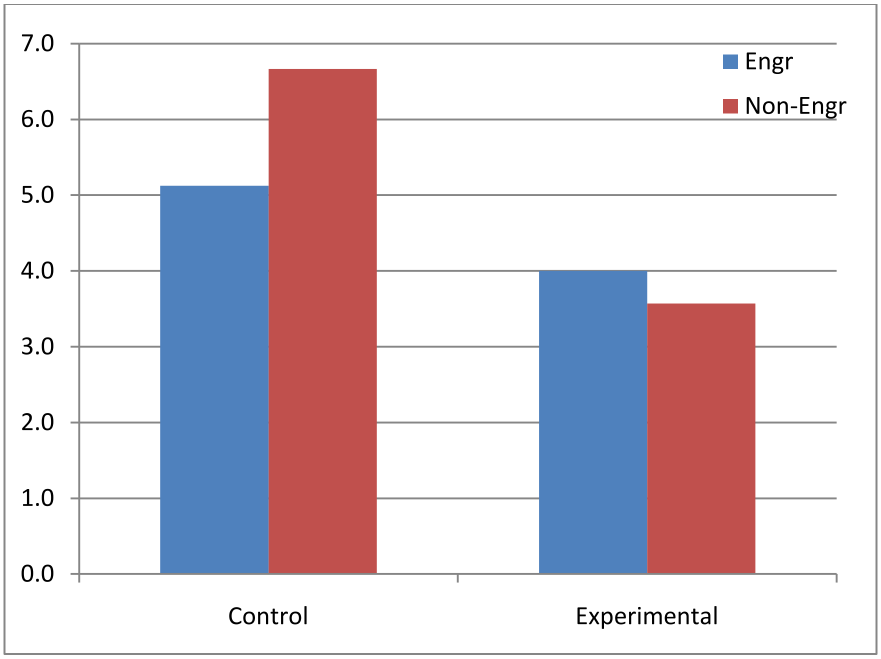

Figure 5.7: Effect of major of study on the average number of categories

Unfortunately, only a limited number of participants have performed at each combination of interview conditions and disciplines, and conclusions should not be drawn based upon only a couple of participants. Statistical significance was not calculated for these trends because the small sample size at each combination of demographic would have made the values irrelevant. These trends will be monitored in further research.

Based upon observations from early testing, the experience of the participant in building a tent was thought to have a factor in the derived customer needs. Participants claimed ranges of experience from five to upwards of a hundred builds in his or her lifetime. The distribution of experience between the control and experimental was fairly evenly dispersed allowing for an unbiased evaluation of the effect of the experience on the metrics.

Table 5.4: Effect of participant experience

Experience level (tent builds in life)	# of participants	Avg. # of CN	Avg. # of categories in free speech	Avg. # of latent CN
under 20	7	22.6	5.1	2.7
20 to 50	10	32.8	5.8	3.3
51 to 100+	7	28.9	3.4	5.0

The one obvious trend is the increase in the average number of latent customer needs discovered with an increase in experience, as shown in Table 5.4. This result is not surprising given that some of the more experienced tent builders could be considered lead users. Since this study is trying to simulate the experience of a lead user, it could be pertinent to define an experience upper limit for participation similar to the required minimal number of previous tent constructions. By establishing an upper limit, participants could be classified as lead users, and their ability to generate customer needs could be compared to those of participants with lower levels of experience who simulated lead user experiences.

The most productive group in terms of number and categories of customer needs was the medium experience group of 20 to 50 builds. This trend is not intuitive and could be caused from design fixation or acceptance of the current design of the more experienced participants. Several experienced participants would simply gloss over the features, accept the tent as a standard, and offer few comments.

In terms of the average number of customer needs or number of categories touched, the results could also depend on the individual participant regardless of experience. Some of the very experienced tent builders would draw upon their personal wealth of experiences and tell a story behind each of their comments, but similar stories also came from participants who claimed to have built a tent less than 10 times in their lives. The number and type of comments may also be correlated with the types of tents previously built. A good percentage of the comments were derived from comparison to other tents from previous experience.

5.6 Conclusions

The application of empathic experience techniques to customer needs analysis has been shown to increase the number of latent needs discovered by 2.5 times. By increasing the number of latent customer needs discovered, engineers are presented with a greater number and variety of innovative design avenues to create commercially successful products.

The empathic experiences did have a detrimental effect on the number of customer needs categories, with a decrease of a third in the number of categories touched by the average participant. The use of only empathic experience interviews may limit the breadth of gathered customer needs but increase the rate of discovery of latent needs based upon the conditions applied. On the other hand, a standard articulated use interview will cover a broad range of topics but is less likely to suggest innovative design avenues.

The tradeoff between breadth of categories and number of latent needs represents an ideal scenario for combining multiple customer needs techniques. As seen with the use of categorical questioning following the EED interview a wide breadth of comments comparable to traditional articulated use interviews could be achieved. Alternatively, multiple EED interviews with varying experimental conditions to cover all of the categories could be performed. For example, with this study a decrease in aesthetic and transport comments was seen between the two groups due to the limitations of dexterity and visibility as experimental conditions. An additional EED interview could be performed focusing on other limitations to encourage aesthetic and transport related comments to compensate for the fewer comments in the initial interview. By performing multiple empathic experience interviews, all categories of customer needs could be covered and a wide variety of latent needs discovered.

It is important to remember that these results are unique to the set of conditions used in the study and the latent needs and categories could change from empathic condition to condition. The selection of an experimental condition that allowed the participants to visually explore the tent more, instead of constructing the tent in a dark room, would probably not have led to a decrease in the number of customer needs categories touched during the free speech. Ultimately, the latent needs discovered correlated well with the applied empathic conditions. This stresses the importance of selecting appropriate limiting conditions for the empathic study. These conditions are currently selected based on the experience and creativity of the coordinator.

While the study suggests that the use of empathic experience techniques can be used to increase the number of latent needs discovered in a product redesign setting, restrictions on the types of experiences should be put in place to generate customer needs in the desired direction of redesign. Just because a latent need is identified, does not mean that pursuing it as a design avenue is worthwhile. Many of the discovered latent needs were unique only to the experimental group, which is encouraging because it illustrates that the experiences did have an effect on the customer needs. For example, only participants in the experimental group suggested glow-in-the dark or textured support pole clips to easily distinguish them from the fabric of the tent. Unfortunately, some of these latent needs may be too niche or specific for usefulness in the redesign process. The hope is that by increasing the number of latent needs discovered, a higher number of quality redesign avenues are presented to the engineer.

Chapter 6

Closure

6.1 Summary of Work

6.1.1 Summary of Innovative Product Study

As part of this research, 197 innovative, award-winning products were analyzed against their competition to identify what made those products stand out from the competition. The study focused on finding the types of engineering-level characteristics, specifically ones that the designer can influence directly during the design process, that make a product successful so that a designer can realize the next breakthrough innovation. Thirteen characteristics of innovation, divided into five categories, were created to describe the types of product innovations. It was found that the most innovative products were innovative in multiple categories. Overall, a vast majority (greater than 70%) of the award-winning products exhibited enhanced user interactions, with a similar percentage displaying enhanced environmental interactions, compared with approximately one-third of products offering an additional function and approximately half displaying innovative architectures. It was concluded that breakthrough or innovative products are becoming increasingly centered on user interactions and that engineers need better interaction-based methods, such empathic experience design, to design these products.

6.1.2 Summary of Concept Generation Study

The first application of empathic experience design to the product design process was as a pre-concept generation aid. Groups of undergraduate mechanical engineering students at The University of Texas at Austin and the University of Massachusetts-Dartmouth were asked to redesign alarm clocks. Students were allowed a brief interaction time with prototype alarm clocks with or without empathic experiences, which consisted of oven mitts, blindfolds, and head phones, and then asked to generate concepts. Results were analyzed for the level of originality, technical feasibility, and design fixation, and concepts were also evaluated with the engineering-level characteristics of innovation developed for the product study. An evaluation of current metrics used to analyze design concepts was also performed. Although this study is continuing, preliminary conclusions indicate that empathic experiences lead to a statistically significant increase in the originality of concepts with a corresponding decrease in feasibility.

6.1.3 Summary of Customer Needs Study

The second study applied the EED technique to customer needs analysis to determine if more latent needs can be generated over traditional approaches. This study was performed on the UT campus as an expansion of the former experiments performed by Lin and Seepersad [10]. Students of mixed majors and experience were asked to comment on a dome camping tent while they were constructing it under either typical conditions or empathic conditions (dark room with oven mitts) during an individual interview. Following the free speech construction, categorical questioning was also performed. From the comments, customer needs were derived, categorized, and evaluated based upon the number of latent needs discovered and the breadth of customer needs categories mentioned by the participants. Preliminary conclusions indicate that empathic experiences lead to statistically significant increases in the number of latent needs discovered by participants.

6.2 Conclusions on the use of EED in the product design process

6.2.1 Conclusions on the use of EED on concept generation

Although only preliminary results were presented, it was shown that empathic experiences can be used to generate more innovative solutions to a design problem, with a statistically significant increase in originality scores from the control to the experimental groups. When used in combination with other techniques, empathic design may aid in the development of better concepts that are more innovative with the same level of difficulty to implement. However, the empathic experiences led to a statistically significant decrease in feasibility. Fortunately, the increase in originality was greater than the decrease in feasibility and there were a greater percentage of products (20% to 15% of each group) that exhibited both high originality and feasibility.

The types of innovations exhibited by the control and experimental groups also differed with respect to the engineering-level characteristics of innovation developed for the product study. The experimental group was shown to produce a higher number of concepts with increases in customer-viewed functionality, modified layouts, and modified sensory demands. The relative frequencies at which designs exhibited different categories of product innovation were also similar to those observed in the product study. This finding was unexpected, but suggests that there may be a more universal trend with respect to the engineering-level characteristics that contribute to innovation.

The effectiveness of current metrics for measuring innovativeness and feasibility was also evaluated in the study. The investigation challenges the existing accepted procedure for analyzing design concepts and concludes with a seemingly better method of comparing generated concepts. The use of maximum originality score from a feature level analysis was shown to accurately represent relative levels of innovativeness better than the traditional novelty metric. The use of minimum feasibility score at a feature level analysis was shown to be a better approach than averaging the features across a design. Furthermore, the use of the characteristics of innovation developed during the study of innovative products as an analysis tool to breakdown the types of innovations present in a design or product was shown to offer a different level of depth than previous metrics.

6.2.2 Conclusions on the use of EED on customer needs analysis

The use of empathic experience interviews led to a statistically significant increase in the number of latent customer needs versus traditional articulated use interviews. By increasing the number of latent needs discovered, engineers are presented with more innovative design avenues to potentially create more commercially successful products.

The empathic experiences did led to a one-third decrease in the number of customer need categories mentioned by the participants. This finding suggests that the use of only empathic experience interviews may limit the breadth of gathered customer needs but increase the rate of discovery of latent needs based upon the conditions applied. Compared to a standard articulated use interview, EED interviews are more likely to generate latent customer needs, but will cover a narrower range of topics.

Due to the inherent trade-off in breadth versus latent needs discovery, the use of empathic experience interviews is best used in conjunction with other techniques to broaden the range of derived customer needs. The use of categorical questioning was seen to improve the breadth of needs discovery considerably, but other combinations such as running multiple EED interviews focusing on multiple dimensions of customer needs could also be tried to derive the benefits of both breadth of customer needs and sheer number of latent needs. Overall, the impact of empathic experiences suggests that the technique should be strongly considered in place of similar product design techniques.

While the effects of EED on concept generation were shown to have statistically significant, beneficial impacts, the use of empathic experiences for customer needs analysis could be an even better application. The customer needs study benefitted from fewer sources of noise because of the large diversity of participants and a more direct analytical approach. The process of measuring certain dimensions of a design, such as innovation and feasibility, in the concept generation study is relatively abstract and requires several assumptions. By contrast, the comments made during the customer needs interviews can be translated directly into customer needs according to well established procedures.

6.3 Future testing

6.3.1 Expansion of study of innovative products

In addition to the broad research opportunities motivated by this study, there are several opportunities for expanding and refining the study itself. For example, it would be helpful to define the innovation characteristics more carefully so that repeatable results can be obtained by new researchers with limited training. Also, some of the innovation characteristics could be broken down further, for example, to differentiate between changes in type and changes in magnitude of energy, material, and information flows. It would be interesting to investigate the impact of these fidelity changes on the results of the study. Real customer interviews could also be conducted to investigate their reasons for purchasing one product over the competition. Finally, the innovation characteristics developed in this study could be adapted as evaluation tools for analyzing the results of innovation studies. If the characteristics reflect the features of innovative products, then they should be useful as tools for predicting whether a product has the potential for innovative success.

6.3.2 Future testing for concept generation applications

Now that the impact of applying empathic lead user techniques on concept generation and customer needs has been studied, more opportunities are now available to refine and explore the limitations of the techniques. Similar experiments could be performed by varying the empathic conditions with the same product or applying the technique to a variety of products.

The data represented here only includes one semester's worth data from the University of Texas at Austin. The results have yet to be compared between semesters at UT Austin and between the UT Austin and UMass Dartmouth campuses. Future testing is already planned to expand into more product categories, including thermometers, with a similar experimental procedure.

6.3.3 Future testing for customer needs applications

This study represented the expansion and modification of the previous study performed by Lin and Seepersad [10], but numerous more opportunities are available for similar customer needs applications. The comparison of simulated lead users to actual lead users could also be done by defining lead users by a certain level experience in the domain. These types of experiments could help evaluate the effectiveness of the empathic lead user simulation. These types of distinctions of classifying individuals as lead users based upon the number of tent constructions may not be an accurate portrayal of a lead user since an individual may be a lead user in a variety of dimensions. An individual may have only constructed a tent several times, but each time was under exceptional conditions such as inclement environment or weather that would make him or her a lead user in a certain dimension. Conversely, just because a person has constructed a tent over 100 times does not mean that he or she has had any exceptional experiences. Increasing the number of times a person has assembled a tent just increases the probability of having had extreme experiences. Accordingly, it may be necessary to gather more information from the participant, such as background information on the extent to which they have pushed a product to its limits, before classifying him/her as a lead user.

Unfortunately, the simulation of the lead user will probably never eclipse the use of an actual lead user during interviews because it is impractical to simulate countless hours in and around a tent under a variety of conditions because of the time and expense. There are also limitations to the types of experiences that can be simulated. For example, it would be hazardous and difficult to simulate the experience of constructing or sleeping in a tent in near flooding conditions as one participant claimed to have done.

6.3.4 Adaptations of current experiments

There is a wealth of potential experiments possible to explore the impacts of empathic experiences on the product design process. Comparing the use of hypothetical empathic experience design, or asking an individual to think about the effect of the conditions on his or her current problem, to experimental empathic experience design could be very useful. These types of experiments could be implemented by asking participants to theorize about how interacting with the product would change from using it in extreme situations. For example, the participants in the customer needs study

(Chapter 5) could have been asked to imagine constructing the tent in the dark with gloves on their hands while they were actually constructing the tent. These results could then be compared to individuals who actually did those interactions. This application would also have the advantage of being able to simulate considerably more types of conditions, but the effect on discovery of latent needs may be reduced.

Similarly, one of the hardest steps in the empathic experience process is identifying potential lead users and the organization of the experiments depends greatly on the creativity of the researcher. The act of formulating the experiments causes the organizers to consider potential improvements participants could suggest and effectively could produce similar results to the hypothetical experiments previously discussed. If this is the case, then the need to actually implement the experiments is greatly reduced and similar results could be obtained by simply designing the product to include the projected customer needs. The greatest contribution of the EED process could simply be identifying outlier users and asking how they might use the product differently. Experiments could also be carried out in which students are provided with a product and asked to redesign the product after identifying lead users or potential extreme situations in which the product may be used.

6.3.5 Design Fixation Studies

Although the impact of design fixation was not the focus of these studies, the experiments could easily be reformulated to evaluate the effect of EED on design fixation. The effect of the inclusion of a prototype in a redesign setting has been the subject of a limited number of studies [80, 81], which have hinted at design fixation. Namely, the use of a prototype causes a designer to subconsciously develop similar designs. Experiments could be organized to investigate the effect of including a prototype during a concept generation study. This type of experiment could vary the levels of detail provided to the participants on a spectrum between the physical use of a prototype and the hypothetical use of the prototype. Groups of students could be given various ranges of details of existing solutions from actual products, pictures of products, rough outlines of product functions, or no material. These types of experiments could help benchmark the amount of design fixation seen at various levels of prototype interactions, and through a comparison to the results of empathic experience studies, the effect of the empathic conditions in terms of breaking or causing design fixation could be measured.

Appendix A: Bins by feature used in alarm clock analysis

Mode of alarm: "standard" – (beep and common sounds)
vibrating, electric, air, water, bed vibration, pillow vibration
flashing, glow, room light
special sounds, speakers, video (TV), music box, recordable
remove covers, deflate, poke, temperature
jump, roll, crawl, fly, extend, tread, restricted movement, catapult, avoids hand

Display: "standard" – (LED, digital, basic)
LCD, projector, audio, feel, dials
Multiple, large, color, lit, glow-in-dark

Info shown: "standard" – (time)
calendar (events), day (date/day of week), news, traffic, weather, temperature, quote
Battery charge, music, alarm time, time left
Weight, phone, wireless strength, tv info

User input: "standard" – (buttons, dials)
motion sensor, voice, touch screen, keypad, auto
Braille (textures/raised), open face, feedback, large
Pull, twist, crank, shake, location changing, lift, water
Puzzle (password), flipover, standing (weight)

Energy source: "standard" – (battery, power cord, both)
Crank, shake, wind, solar, detachable cord, retractable cord

Snooze: "standard" – (buttons, dial, touch screen)
Multiple, large, location changing, variable (time), voice, snooze, limited

Music "none"
Radio, personal

Alternative use:
picture frame, charge, phone, lamp, TV, power strip, tv remote, music remote, universal remote
lego, storage, remote, pill box, cup holder, contact case, mirror, bottle opener
coffee, toast, shower (turns on), flashlight, scale (weight), fan, watch, mask

Shape/layout: "standard" – (prototype)

Travel, folding, lamp, coffee maker, scale (stand on), clock on track (controlled movement),
modular, base/charger, wall panel, band, watch, mask, pillow, remote, phone, watch
music note, person, car, grandfather, rubix cube, sphere, shapes, hamster ball
bed, picture frame, lease, clocky, leash bed, music, wall clock, boombox, pyramid, cube, helicopter, purse, circle

Appendix B: Features in best selling alarm clocks

The features present in the top 20 selling alarm clocks at Walmart, Target, Buy.com, and Amazon retailers.

Display Related Features
backlit display, color display, large display, LCD screen, projector

Displayed Information
phone information, humidity, calendar, travel type/folding, automatically set date/year, gradually gets louder, panel layout, weather, light level outside, display brightness control, time spoken, temperature spoken, display indoor temperature, outdoor temperature (with wireless communication), display music info

Mode of Input/Alarm Related Features
daily alarm, talking, voice activated, volume control, remote, dual alarm, variable snooze, natural sounds, timer, automatic time set, set & forget (turn off alarm after certain time), vibration pad

Additional Functionality
play iPod, CD player, radio, play mp3s, nightlight, flashlight, home phone, Charge iPod

Architectural Features
moving with wheels, runs away from you, stereo, expanding architecture for iPod docking, multiple docks, Disney theme, princess/heart theme, Hello Kitty theme

References

[1] Berkowitz, D., Wren, B. and Grant, S., 2007, "Predicting New Product Success or Failure: A Comparison of U.S. and U.K. Practices (Report)," Journal of Comparative International Management, (June 2007).

[2] Lori, D., 2002, "Learning from Failure: Knowing What Went Wrong in Past Product Launches Can Be Key to Future Success," Stagnito's New Products Magazine, **2** (3), p. 18.

[3] *Prescription for New Product Success*, 1984, Association of National Advertisers, New York.

[4] Kano, N., 1984, "Attractive Quality and Must-Be Quality," The Journal of the Japanese Society for Quality Control, (April), pp. 39-48.

[5] Lettl, C., 2007, "User Involvement Competence for Radical Innovation," Journal of Engineering Technology Management, **24** (1), pp. 53-75.

[6] Von Hippel, E., 1986, "Lead Users: A Source of Novel Product Concepts," Management Science, **32** (7), pp. 791-805.

[7] Von Hippel, E., 2005, *Democratizing Innovation*, MIT Press, Cambridge, MA.

[8] 2004, Von Hippel, E. http://ocw.mit.edu/OcwWeb/Sloan-Schoolof-Management/15-356Spring2004/CourseHome/index.htm.

[9] Hannukainen, P., and Hölttä-Otto, K., 2006, "Identifying Customer Needs -- Disabled Persons as Lead Users," ASME DETC Design Theory and Methodology Conference, Las Vegas, NV, Paper Number: DETC2006-99043.

[10] Lin, J., and Seepersad, C., 2007, "Empathic Lead Users: The Effects of Extraordinary User Experiences on Customer Needs Analysis and Product Redesign," ASME DETC Design Theory and Methodology Conference, Las Vegas, NV, Paper Number: DETC2007-35302.

[11] Ford Drives a Mile in an Older Person's Suit, 2002, The Center for Universal Design, NC State University, Raleigh, NC, http://www.design.ncsu.edu/cud/projserv_ps/projects/case_studies/ford.htm.

[12] 2010, Birthways Childbirth Resource Center Inc., The Empathy Belly Pregnancy Simulator, http://www.empathybelly.org/home.html.

[13] 2003, Ford Ford Engineers Use Creative Tools to Better Understand the Vehicle Needs of Customers, http://media.ford.com/article_display.cfm?article_id=16406.

[14] Buss, D. Safety Tips: Designing Better Cars for Senior Drivers, http://www.edmunds.com/ownership/safety/articles/121492/article.html.

[15] Leonard, D., and Rayport, J., 1997, "Sparking Innovation through Empathic Design," Harvard Business Review, pp. 102-113.

[16] Otto, K., and Wood, K., 2001, *Product Design: Techniques in Reverse Engineering: Systematic Design, and New Product Development*, Prentice-Hall, New York.

[17] Kelley, T., 2001, *The Art of Innovation*, Profile Books Ltd., New York.

[18] Preiser, W., and Ostroff, E., 2001, *Universal Design Handbook*, McGraw-Hill Professional, New York.

[19] Story, M., Mueller, J. and Mace, R., 1998, *The Universal Design File: Designing for People of All Ages & Abilities*, The Center for Universal Design, NC State University, Raleigh, NC.

[20] Redström, J., 2006, "Towards user design? On the Shift From Object to User as the Subject of Design," Design Studies, **27** (2), pp. 123-139.

[21] Cooper, R., 1979, "The Dimensions of Industrial New Product Success and Failure," Journal of Marketing, **43** (August), pp. 93-103.

[22] Cooper, R., and de Brentani, U., 1991, "New Industrial Financial Services: What Distinguishes the Winners," Journal of Product Innovation Management, **8** (2), pp. 75-90.

[23] Kleinschmidt, E., and Cooper, R., 1991, "The Impact of Product Innovation on Performance," Journal of Product Innovation Management, **8** (4), pp. 240-251.

[24] Parry, M., and Song, X., 1994, "Identifying New Product Successes in China," Journal of Product Innovation Management Science, **11** (1), pp. 15-30.

[25] Song, X., and Parry, M., 1994, "The Dimensions of Industrial New Product Success and Failure in State Enterprises in the People's Republic of China," Journal of Product Innovation Management, **11** (2), pp. 105-118.

[26] Ali, A., Krapfel, R. and LaBahn, D., 1995, "Product Innovativeness and Entry Strategy: Impact on Cycle Time and Break-even Time," Journal of Product Innovation Management, **12** (1), pp. 54-69.

[27] Astebro, T., and Michela, J., 2005, "Predictors of the Survival of Innovations," Journal of Product Innovation Management, **22** (4), pp. 322-335.

[28] Goldenberg, J., Lehmann, D., and Mazursky, D., 1999, "The Primacy of the Idea Itself as a Predictor of New Product Success," Marketing Science Institute Working Paper.

[29] Lynn, G., Morone, J. and Paulson, A., 1996, "Marketing and Discontinuous Innovation: The Probe and Learn Process," California Management Review, **38** (3), pp. 8-37.

[30] Mishra, S., Kim, D. and Lee, D., 1996, "Factors Affecting New Product Success: Cross Country Comparisons," Journal of Product Innovation Management, **13** (6), pp. 530-550.

[31] Souder, W., and Song, M., 1997, "Contingent Product Design, and Marketing Strategies Influencing New Product Success, and Failure in US, and Japanese Electronic Firms," Journal of Product Innovation Management, **14** (1), pp. 21-34.

[32] Deszca, G., Munro, H. and Noori, H., 1991, "Developing Breakthrough Products: Challenges and Options for Market Assessment," Journal of Operations Management, **17** (6), pp. 613-630.

[33] Olshavsky, R., and Sprend, R., 1996, "An Exploratory Study of the Innovation Evaluation Process," Journal of Product Innovation Management, **13** (6), pp. 512-529.

[34] Veryzer, R., 1998, "Key Factors Affecting Customer Evaluation of Discontinuous New Products," Journal of Product Innovation Management, **15** (2), pp. 136-150.

[35] Crilly, N., J. Moultrie, and Clarkson, P., 2009, "Shaping things: intended consumer response and the other determinants of product form," Design Studies, **30** (3), pp. 224-254.

[36] Lawton, L., and Parasuraman, A., 1980, "The Impact of the Marketing Concept on New Product Planning," Journal of Marketing, **44** (1), pp. 19-25.

[37] Lee, M., and Na, D., 1994, "Determinants of Technical Success in Product Development When Innovative Radicalness is Considered," Journal of Product Innovation Management, **11** (1), pp. 62-68.

[38] More, R., 1982, "Risk Factors in Accepted and Rejected New Industrial Products," Industrial Marketing Management, **11**, pp. 9-15.

[39] Olson, E., Walker, O. and Ruekert, R., 1995, "Organizing for Effective New Product Development: the Moderating Role of Product Innovativeness," Journal of Marketing, **59** (1), pp. 48-62.

[40] Schmidt, J., and Calantone, R., 1998, "Are Really New Product Development Projects Harder to Shut Down?" Journal of Product Innovation Management, **15** (2), pp. 111-123.

[41] Song, M., and Montoya-Weiss, M., 1998, "Critical Development Activities for Really New Versus Incremental Products," Journal of Product Innovation Management, **15** (2), pp. 124-135.

[42] Garcia, R., and Calantone, R., 2002, "A Critical Look at Technological Innovation Typology and Innovativeness Terminology: A Literature Review," Journal of Product Innovation Management, **19** (2), pp. 110-132.

[43] Betz, F., 1993, *Strategic Technology Management*, McGraw-Hill, New York.

[44] Foster, R., 1986, *Innovation, the Attacker's Advantage*, Summit, New York.

[45] Dewar, R., and Dutton, J., 1986, "The Adoption of Radical and Incremental Innovations: An Empirical Analysis," Management Science, **32** (11), pp. 1422-1433.

[46] Cooper, R., 2005, *Product Leadership*, Basic Books, New York.

[47] Williams, N., S. Azarm, and Kannan, P., 2008, "Engineering Product Design Optimization for Retail Channel Acceptance," Journal of Mechanical Design, **130** (6), p. 081010.

[48] Michalek, J., O. Ceryan, P. Papalambros, and Koren, Y., 2006, "Balancing Marketing and Manufacturing Objectives in Product Line Design," Journal of Mechanical Design, **128** (6), pp. 1196-1204.

[49] Colarelli O' Connor, G., 1998, "Market Learning and Radical Innovation: A Cross Case Comparison of Eight Radical Innovation Projects," Journal of Product Innovation Management, **15** (2), pp. 151-166.

[50] Song, X., and Parry, M., 1999, "Challenges of Managing the Development of Breakthrough Products in Japan," Journal of Operations Management, **17** (6), pp. 665-688.

[51] Hauser, J., and Clausing, D., 1988, "The House of Quality," Harvard Business Review, pp. 63-73.

[52] Thevenot, H., and Simpson, T., 2009, "A Product Dissection-Based Methodology to Benchmark Product Family Design Alternatives," Journal of Mechanical Design, **131** (4), p. 041002.

[53] Leary, M., and Burvil, C., 2007, "Enhancing the Quality Function Deployment Conceptual Design Tool," Journal of Mechanical Design, **129** (7), pp. 701-708.

[54] Franke, H., 1975, "Methodische Schritte beim Klaren konstruktiver Aufgabenstellugen," Konstruktion, **27**, pp. 395-402.

[55] Pahl, G., and Beitz, W., 1996, *Engineering Design: A Systematic Approach*, Springer-Verlag, New York.

[56] Rohrbach, B., 1969, "Kreativ Nach Regeln -- Methode 635, Eine Neue Technik Zum Losen Von Problemen," Absatzwirtschaft, **12**, pp. 73-75.

[57] Shah, J., 1998, "Experimental Investigation of Progressive Idea Generation Techniques in Engineering Design," ASME DETC Design Theory and Methodology Conference, Atlanta, GA,

[58] Altshuller, G. S., 1984, *Creativity as an Exact Science*, Gordon and Breach, Luxembourg.

[59] Linsey, J., Murphy, J., Wood, K., Kortoglu, T. and Markman, A., 2006, "Representing Analogies: Increasing the Probability of Innovation," ASME DETC Design Theory and Methodology Conference, Philadelphia, PA, Paper Number: DETC2006-99383.

[60] Singh, V., Skiles, S., Krager, J., Wood, K., Jensen, D., and Sierakowski, R., 2009, "Innovations in Design Through Transformation: A Fundamental Study of Transformation Principles," Journal of Mechanical Design, **131** (8), p. 081010.

[61] Chiu, I., and Shu, L. H., 2007, "Biomimetic Design through Natural Language Analysis to Facilitate Cross-Domain Information Retrieval," Artificial Intelligence for Engineering Design, Analysis, and Manufacturing, **21** (1), pp. 45-59.

[62] Keeney, R., and Raiffa, H., 1976, *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, John Wiley and Sons, New York.

[63] Pugh, S., 1990, *Total Design*, Addison-Wesley, New York.

[64] Saaty, T., 1980, *The Analytical Hierarchy Process*, McGraw-Hill, New York.

[65] 2008, I. D. E. A. Vicks Forehead Thermometer, http://www.idsa.org/IDEA_Awards/gallery/2008/award_details.asp?ID=686.

[66] 2006, Popular Science Best of What's New. Recreation: Nike+iPod Sports Kit, http://www.popsci.com/popsci/flat/bown/2006/product_101.html.

[67] 2007, Popular Science Best of What's New. Home Tech: Oliso Frisper, http://www.popsci.com/popsci/flat/bown/2007/hometech/item_78.html.

[68] Tinsley, H., and Weiss, D., 2000, "Interrater Reliability and Agreement," *Handbook of Applied Multivariate Statistics and Mathematical Modeling*, Academic Press, New York.

[69] Cohen, J., 1960, "A Coefficient of Agreement for Nominal Scales," Educational and Psychological Measurement, **20** (1), pp. 37-46.

[70] Fleiss, J., 1981, *Statistical Methods for Rates and Proportions*, John Wiley and Sons, New York.

[71] Landis, J., and Koch, G., 1977, "The Measurement of Observer Agreement for Categorical Data," Biometrics, **33** (1), pp. 159-174.

[72] Shah, J., Vargas-Hernandez, N., and Smith, S., 2003, "Metrics for Measuring Ideation Effectiveness," Design Studies, **24** (2), pp. 111-134.

[73] Shah, J., Vargas-Hernandez, N., and Kulkarni, S., 2000, "Evaluation of Idea Generation Methods for Conceptual Design: Effectiveness Metrics and Design of Experiments," Journal of Mechanical Design, **122** (4), pp. 377-384.

[74] Linsey, J., 2007, *Design-by-Analogy and Representation in Innovative Engineering Concept Generation*, Unpublished Dissertation, Mechanical Engineering Department, University of Texas at Austin.

[75] Srivathsavai, R., Genco, N., Holtta-Otto, K., and C. Seepersad, 2010, "Study of Existing Metrics Used in Measurement of Ideation Effectiveness," ASME DETC Design Theory and Methodology Conference, Montreal, Quebec, Canada, Paper Number: DETC2010-28802.

[76] Gulliford, J., 1984, "Varieties of divergent production," Journal of Creative Behaviour, **18** (1), pp. 1-10.

[77] Montgomery, D., 1997, *Design and Analysis of Experiments*, John Wiley & Sons, New York.

[78] 2010, Nanda Clocky, http://www.nandahome.com/products/clocky/.

[79] 2010, REI Camping & Hiking, REI Camp Dome 2 Tent, http://www.rei.com/product/731378.

[80] Cardoso, C., Badke-Schaub, P., and Luz, A., 2009, "Design Fixation on Non-Verbal Stimuli: The Influence of Simple vs. Rich Pictorial Information on Design Problem-Solving," ASME DETC Design Theory and Methodology Conference, San Diego, CA, Paper Number: DETC2009-86826.

[81] Christensen, B. T., and Schunn, C.D., 2007, "The Relationship of Inventive Structure: The Case of Engineering Design," Memory & Cognition, **35** (1), pp. 29-38.

Vita

Matthew Nelson Saunders was born in Dallas, TX to Nancy and Jerry Saunders. He attended Garland High School in Garland, TX where he participated in the International Baccalaureate program. He attended Trinity University in San Antonio, TX and graduated in 2008 with a Bachelor of Science degree in Engineering Science with a minor in Mathematics. While at Trinity, Matthew was president of Trinity Engineers, swam on the Men's Swimming and Diving Team, and played on the Men's Water Polo Team. He began his graduate studies at the University of Texas at Austin in August 2008.

Permanent address: 3607 Lily Lane, Rowlett, TX 75089

This thesis was typed by the author.