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Enabling Design in Frontier Contexts: A Contextual Needs Assessment Method with Humanitarian Applications

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Enabling Design in Frontier Contexts:
A Contextual Needs Assessment Method with Humanitarian Applications

by

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Dedication

This work is dedicated to those in our world with urgent needs that remain unmet. I have been given much in this life; this is a humble step towards sharing what I have received.

Acknowledgements

I thank my Creator, the omniscient designer, for giving me the desire, the ability, and the grace to work towards applying engineering to humanitarian needs.

I thank my delightful wife Jennifer, my encourager, supporter, and best friend, for nourishing me with her food, love, and encouragement. She has kept me in the dissertation marathon to the finish line, and I know there will be many more marathons to run together as partners.

Throughout my life, many fine teachers have skillfully invested their time and knowledge in me. In many respects, my achievements are dividends of their investments. A few of these teachers have exemplified education at its finest, laying the foundation for my own path as an educator. I am especially grateful to my advisor, Dr. Kristin Wood for his encouragement and mentoring. He has had consistent faith in me far beyond my own. My co-advisor Dr. Carolyn Seepersad has been another answer to prayer, quickly learning my topic and providing invaluable perspective and encouragement. I thank my parents, who not only made my life possible, but who also taught me the path to a life of true eternal significance. For this path to life, I am eternally grateful to my Lord and Savior Jesus Christ, who is the Master Teacher[1].

My colleague and friend Julie Linsey faithfully served as a reliable (and frank) sounding board. Junjay Tan expertly performed significant portions of the empirical product study and helped write the conference paper. George Malinoff assisted with the PersonaWarmth design process. Uma Namasivayam and Abiola Ajetunmobi created and skillfully role-played the part of the rural villagers for students to interview. Jennifer Porlier provided excellent assistance with food boiling product video and product choice interviews. Dozens of graduate and undergraduate students volunteered their time and

[1] Bartlett (2002) gives an inspiring comparison of engineering education best practices with Jesus Christ's teaching.

valuable insights by participating in the case studies. My wife Jennifer endured countless product interviews before the fledgling method was fit to test on anyone else. The late John W. Jensen[2], my friend and classmate, was an avid outdoorsman and provided critical advice on mobile lighting product selection and customer needs.

I am deeply grateful for financial support from US taxpayers through the National Defense Science and Engineering Graduate (NDSEG) Fellowship. I would also like to express my sincere gratitude to Jack W. Walker for the Romans 8 Endowed Graduate Fellowship in Engineering, and to the College of Engineering for their financial and administrative support. Additionally, my advisor saw to it that I never went a semester without some form of funding.

[2] John died in an avalanche on March 6th, 2005. He has gone on to a better place, and he will be missed.

Enabling Design in Frontier Contexts: A Contextual Needs Assessment Method with Humanitarian Applications

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This dissertation provides foundational knowledge, methods, and tools to equip engineers in discovering, documenting, and acting upon contextual information important for successful product design. These contributions fill a gap in current design methodologies which inadequately support accounting for contextual information. Formally accounting for contextual information is especially challenging when the design context is frontier (unfamiliar) to the designers, as is often the case with high human-need projects.

A foundational framework is established for classifying contextual information. An empirical product study is conducted to explore the nature of context scenarios and in what way usage context factors influence customer product preferences. Based on the classification framework, literature search, and empirical study, a contextual needs assessment methodology is developed to assist the designer in discovering and documenting the "how," "where," and "who" factors of the context framework. An advanced extension of the methodology employs hierarchical clustering to increase the formality and repeatability of grouping context scenarios and factor values. Case studies provide quantitative and qualitative measures of the usability, usefulness, and designer

acceptance of the proposed contextual needs assessment method. The exciting results provide strong justification for the widespread dissemination of the methodology in education as well as in field practice. The proposed methodology and tools hold promise to enhance the success of any customer-driven design process, and especially those in frontier design contexts.

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Chapter 1: The Need for Contextual Information Accounting in Product Design

The central objective of this dissertation is to develop the foundational understanding, methods, and tools to equip engineers in discovering, documenting, and acting upon contextual information important for successful product design. The central hypothesis is that *engineers equipped with methods and tools for contextual design will show a measurable improvement in contextual understanding of design problems outside their experience and expertise*. This chapter sets the stage with a discussion of the concept of *context* in relation to the product design process, and why improved methods for handling contextual information in design are needed. Properly handling contextual information is especially challenging when the design context is frontier (unfamiliar) to the designers, as is often the case with high human-need projects. With this motivation in mind, a *product design context* framework for handling contextual information is presented as a foundation to the following chapters. This chapter concludes with a dissertation roadmap of the objectives laid out towards the goal of developing and delivering improved methods and tools for contextual design. These methods and tools will enhance the success of any customer-driven design process, and especially those in frontier design contexts.

1.1 CONTEXT DEFINITIONS

In language, context adds to meaning. Elementary language arts curricula teach young readers the life-long skill of exploiting "context clues" in order to determine the meaning of new, foreign-looking words. Context also adds to the "meaning" or value a user perceives in a designed product or system[3]. From the perspective of customer satisfaction, possible implications of a product include: delight, satisfaction, indifference, or disgust on the part of the user. The varying levels of customer satisfaction depend upon the value or utility of a product's attributes, and value or utility depends in part

[3] "product or system" is simplified to "product" from this point forward to enhance readability

upon the context[4]. Since product designers rarely dictate the context surrounding products, it is necessary to understand and account for context in the design process.

The following definitions provide insight into defining context:

> ***Context***: *That which surrounds, and gives meaning to, something else.*[5]
>
> ***Context*** *(a) The part of a text or statement that surrounds a particular word or passage and determines its meaning. (b) The circumstances in which an event occurs; a setting.*[6]
>
> ***Context*** *(a): the parts of a discourse that surround a word or passage and can throw light on its meaning. (b) the interrelated conditions in which something exists or occurs: Environment, Setting*[7]
>
> ***Environment*** *(a): the circumstances, objects, or conditions by which one is surrounded*[7]

The first definition of context includes both surroundings and provision of meaning as elements of the definition. The second two definitions divide these elements of surroundings and meaning provision into separate definition parts, thus distinguishing a context definition very similar to “environment” from a context definition which carries linguistic implications. The word “environment” was originally considered for this research; however context is purposefully chosen here to capture both the reference to surroundings as well as the acknowledgement that these surroundings have an important role in contributing to meaning or value. The definition of *context* used throughout this dissertation is a blend of the four above:

Context – the circumstances or setting in which an object occurs, and which influences its value.

In addition to the definition of context above, the definitions shown in Table 1.1 are also important in the discussion that follows.

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[4] Formally, Product Utility = f(product attributes, context factors) where f() is a model of user preferences.
[5] http://www.swif.uniba.it/lei/foldop/foldoc.cgi?context Free On Line Dictionary Of Philosophy 3.0
[6] The American Heritage® Dictionary of the English Language, 4th Ed. 2000, Houghton Mifflin.
[7] http://www.m-w.com/cgi-bin/dictionary

Table 1.1: Context Related Definitions

- *Product attribute(s)* – important product characteristics such as volume, mass, operating cost, and convenience (characteristics often included in product specifications or a customer requirements list).
- *Customer [product] attribute preferences* – The customer's preferences for product attribute values; e.g. a strong preference for mass ≤ 1kg.
- *Product [design] context* – the collection of factors influencing customer attribute preferences including: product usage context, customer context, and market context.
- *[Product] usage context* (PUC) – the application and environment in which a product will be used that may significantly influence customer attribute preferences.
- *Context factor* – a single characteristic of a product's usage context. For example, "usage frequency" or "product surroundings."
- *Context scenario* – a set of specific values for a set of context factors.

1.2 A Case for Design Context: Mobility Enabling Products

Healthwrights and the Hesperian Foundation have worked for years to improve the quality of life for persons with disabilities in developing countries. As part of this effort they have published extensive self-help guides for community workers and those they serve with prolific illustrations to transcend language and literacy barriers (Werner, 1987; Werner, 1998). One of the books in this series (Werner, 1998) notes that wheelchairs exported from wealthy nations are often not appropriate in the foreign contexts of developing countries. As a result, the failure to satisfy customer needs often leads to abandonment (Figure 1.1). Table 1.2 summarizes four examples from around the world which require a specific mobility product to fit the context. The left column pictures a unique aspect of each context, and the right column pictures a mobility enabling product appropriate for each context. As shown in the table, none of the solutions are the same as wheelchairs commonly seen in the United States.

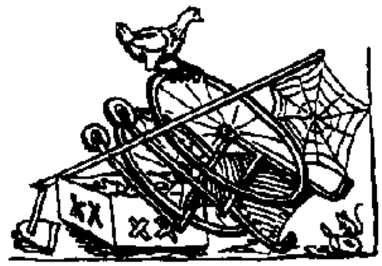
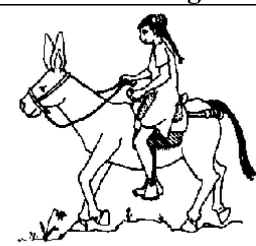
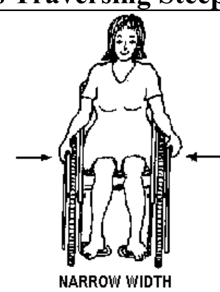
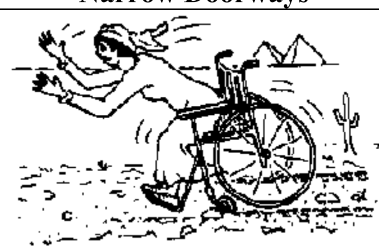
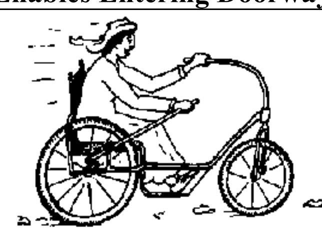


Figure 1.1: Wheelchairs Must Fit the Context to be Satisfactory (Werner, 1998)[8]

[8] This book encourages distribution: "Any parts of this book … may be copied … without permission from the author or publisher … [if] distributed free or at cost …"

Table 1.2: Different Mobility Products for Different Contexts (Werner, 1998)[8]

Design Need Context	Context-Appropriate Product
 Meals Cooked Low to the Ground	 Enables Reaching the Pot
 Steep, Hilly Terrain	 Enables Traversing Steep Terrain
 Narrow Doorways	 Enables Entering Doorways
 Rocky Terrain	 Enables Traversing Rocky Terrain

1.3 A 2ND CASE FOR DESIGN CONTEXT: IMPROVED VILLAGE COOKING SYSTEMS

The importance of design context is evidenced both in successful products with attributes that match context, as well as in failed products which did not address critical context factors. Table 1.3 is based on data from a World Bank review of numerous programs to introduce improved village cooking systems in countries around the world

(Barnes, et al., 2002). Out of 16 major reasons commonly causing the failure (or success) of a stove program, 8 of the reasons[9] appear to be directly tied to how well context is understood and addressed. The importance of accounting for context is evident from the report text, as shown in the following quote (Barnes, et al., 2002 p. 28):

> For assessing consumer needs … determine the existing patterns of stove use, the factors people consider when purchasing new stoves, the person who makes the decision to purchase a stove, and whether income and fuel savings will provide adequate incentives … stoves should be designed around the utensils used and food dishes typically prepared. … They should also be modified or redesigned to meet regional requirements.

Table 1.3: Historical Reasons for Failure of Improved Village Cooking Systems
Data from (Barnes, et al., 2002)

Causes of Failure	Contextual Information Required for Success
The new cooking system does not:	
… account for actual conditions of use and is therefore uneconomical and inconvenient.	What are actual conditions of use?
… resemble the traditional cooking system.	What is the traditional cooking system?
… accommodate large pieces of wood.	What size and types of fuel are available?
… improve a fuel supply problem.	What size and types of fuel are available?
… improve a smoke problem due to low-ventilation.	What is location and ventilation available?
… accommodate design for manufacture needs of local artisans.	What are local manufacturing practices?
… use locally available materials (increases cost).	What are locally available materials?
… utilize mass-production of critical components.	What local mass-production or import capabilities are available?

1.4 CUSTOMER SATISFACTION IS CONTEXT DEPENDENT

Customer satisfaction with *product attributes* depends in part on context: how, where, and by whom the product will be used. For this reason, a customer-driven product

[9] Example reasons not counted as contextual include: "Major results expected in less than 3 years," "Planned & managed by outsiders," and "Government involvement in production."

design process must account for context in order to reliably maximize customer satisfaction. The Kano model of customer satisfaction is shown in Figure 1.2, illustrating that the absence or implementation of a function may influence customer satisfaction in three different ways. Each is represented as a different curve: “delighted”, “expected” (also called “linear”), and “basic.” The diagram is qualitative and conceptual, and the placement of the origin is arbitrary. The Kano model diagram shows the effects of varying one attribute while holding all other influences constant. Clearly, the satisfaction curve for a given attribute could change depending on the set point of other attributes. For example, the satisfaction curve for expected performance could increase significantly if the product were at a much lower price point (customers do not expect the same flavor from a $1 cup of coffee as from a $4.50 cup). However, this is still a very useful qualitative model of how changes in one attribute influence satisfaction, and it is a reasonable assumption that satisfaction curves would remain similar for small perturbations about the initial product configuration.

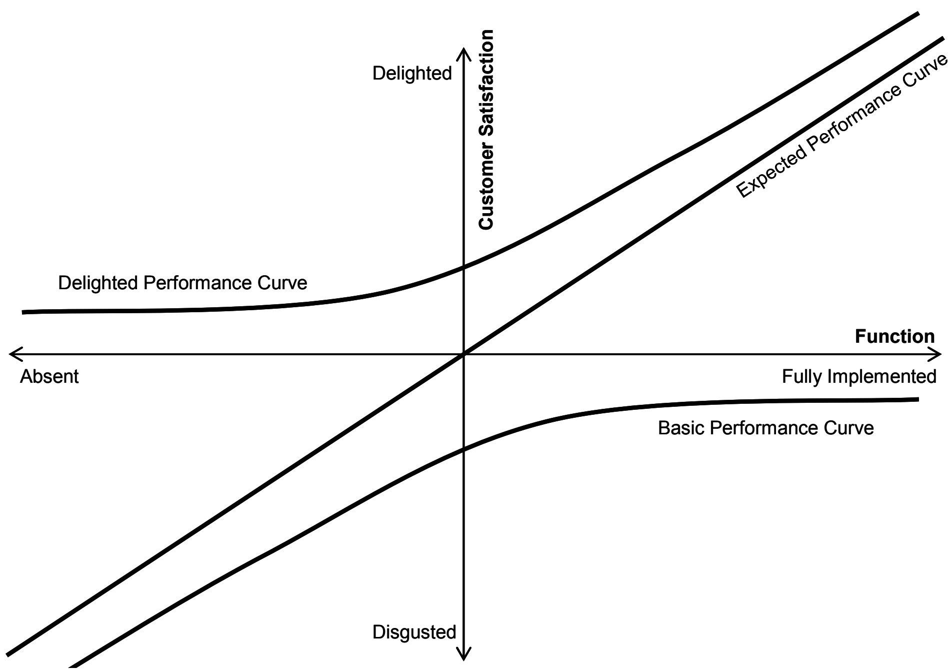


Figure 1.2: Kano Model of Customer Satisfaction (Otto and Wood, 2001).

Figure 1.3 through Figure 1.5 show Kano models modified to include iso-context curves, showing how a change in a single contextual factor influences satisfaction. All other influencing factors such as product attributes and other context factors are held constant. These qualitative curves do not report actual customer perception survey data, but rather illustrate the sensitivity of customer satisfaction to changes in context factors.

Figure 1.3 shows how satisfaction changes with varying levels of lighting brightness depending upon the contextual usage task, a factor of *how* the product is used. The curves are represented as “basic” Kano curves in the sense that customers are not especially impressed that the lighting product is bright enough, but become quickly disgusted if the product does not meet their needs. This threshold of minimum acceptable brightness is different for talking, cooking, and reading tasks. Although the curves indicate that a reading-level of brightness also gives satisfaction for talking, a more detailed representation might show satisfaction dropping off as brightness increases far above the desired level for talking. Other references such as Eggert (2005) illustrate a hill-like satisfaction curve centered around a target value, but for simplicity the illustrations here are limited to traditional Kano curve shapes. Designers developing a product offering for all three of the usage context tasks shown (talking, cooking, and reading) have several options including: targeting only one context task, designing a separate product for each task, or designing one product with adjustable brightness levels suitable for all three tasks.

Figure 1.4 illustrates how satisfaction with product fuel economy depends on fuel cost (a factor of *where,* or the environmental context in which a product is used). The relationship is represented here as linear (or “expected quality”), since any increase in fuel economy is always welcome, provided all other attributes are held constant. The relationships in Figure 1.4 are evident when gasoline prices significantly rise or fall, and the average fuel economy of vehicles purchased varies accordingly.

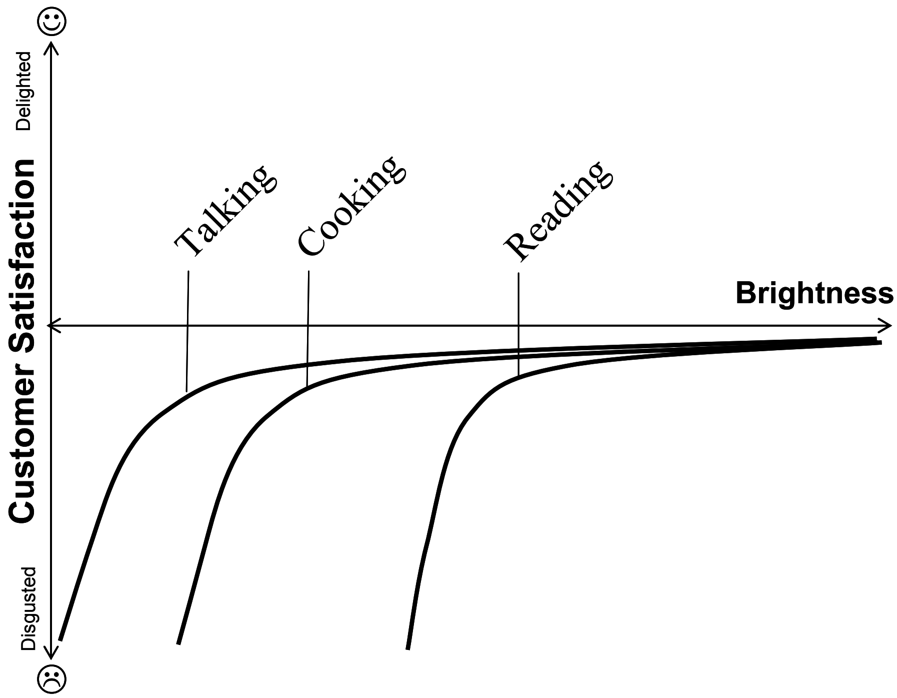


Figure 1.3: Lighting - Satisfaction with Product Brightness Depends on the Task (How).

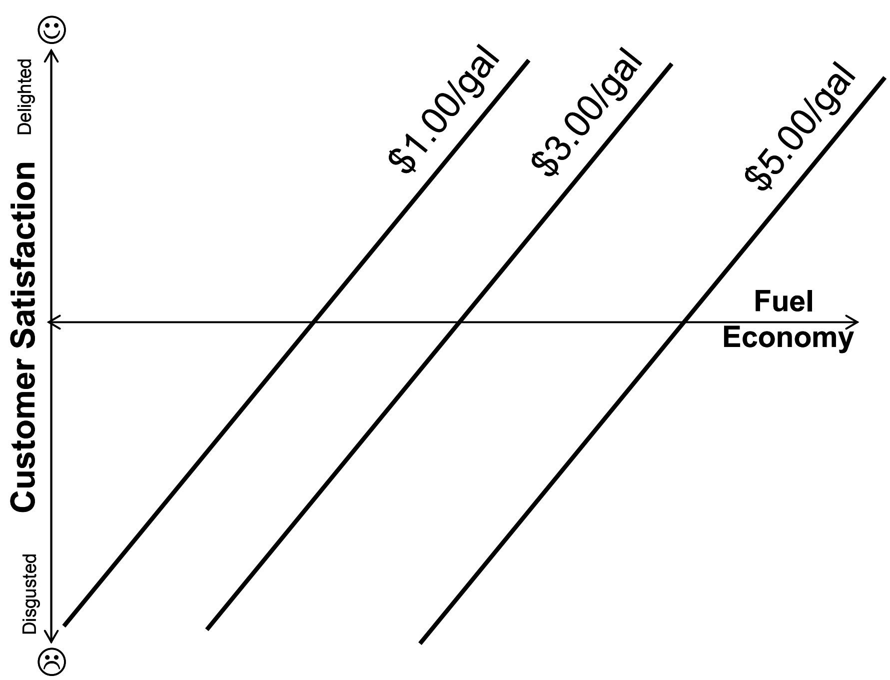


Figure 1.4: Satisfaction With Product Fuel Economy Depends On Fuel Cost (Where).

Figure 1.5 illustrates how satisfaction with product accessibility depends on user abilities, a context factor of *who* is using the product. For the average user, enhanced accessibility may be unexpected and result in a delighted level of satisfaction. On the other hand, since accessibility may be necessary for the user with a disability to use the product at all, the absence of accessibility will result in complete rejection of the product. An example of this is wheelchair accessible ramps supplementing stairways. The smooth ramp may simply add to the convenience and satisfaction of the average user, however for a wheelchair user the stairs represent a barrier that results in complete dissatisfaction. A common sentiment about inclusive or accessible design (sometimes called universal design) is that it can make life easier and better for everyone, not just those with disabilities.

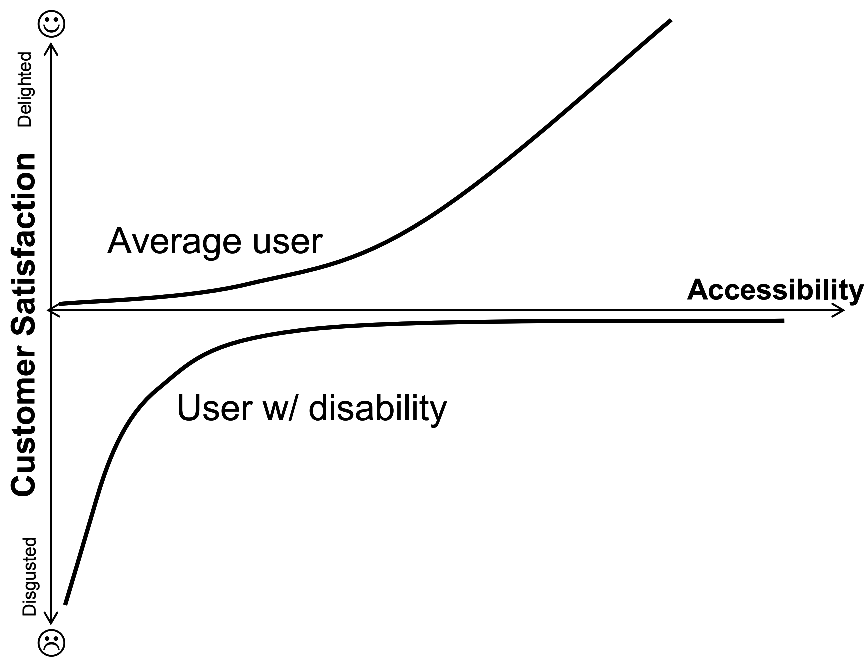


Figure 1.5: Satisfaction With Product Accessibility Depends On User Abilities (Who).

The preceding figures illustrate how customer satisfaction with product attributes depends on contextual factors of how, where, and by whom the product will be used. Figure 1.3 and Figure 1.4 illustrate how satisfaction-attribute curves may *translate* depending on context, and Figure 1.5 shows further how a *transformation* can occur into a different type of curve such as from a "delighted" to a "basic" curve. Since an important goal of product design is achieving a high level of customer satisfaction, it is important to understand the product context as well as how the context will influence customer satisfaction.

1.5 CONTEXT ACCOUNTING IN THE PRODUCT DESIGN PROCESS

The engineering product design processes may be described in three distinct phases as shown in Figure 1.6. Although the actual product design process includes iteration and other complexities, this three-phase description is useful for communicating and thinking about the process. Context is important in all three phases. In the first phase, clarify the design need, context must be discovered and documented. Contextual information is also needed to organize customer needs information, set specifications, and guide the correct identification and application of benchmarking information. In phase two, contextual information guides concept development and selection. In phase three, contextual information plays a final role in embodiment decisions. Current design methodologies prescribe clarification to include customer needs assessment within the "context of use." However, little or no guidance is specifically given to discovering, classifying, documenting, and applying contextual information.

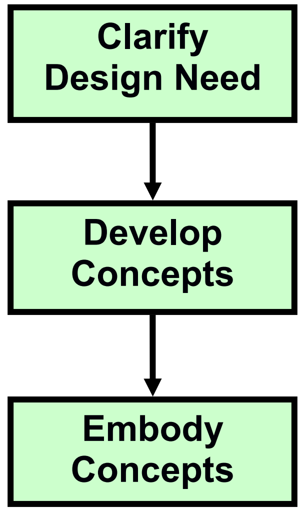


Figure 1.6: A Three-phase Model of Product Design Processes

The lack of guidance in handling contextual information is most problematic in phase one. If contextual information is successfully gathered in phase one, correctly applying it in subsequent phases is at least probable (although specific tools and methodologies could increase the likelihood and effectiveness). The difficulty of gathering contextual information in the first phase is most severe as well as most important for frontier design problems in which context is least understood. For this reason this dissertation focuses on improving context accounting in phase one.

Product design context factors, in addition to primary functional requirements, are fundamental causes which give rise to both customer needs and the resulting product requirements (as illustrated in Figure 1.7). "Primary functional requirements" is used here to refer to the functions a product is designed to achieve independent of the design context. For example, a radio must in some way achieve the functions of receiving and playing a radio frequency, although how these functions are achieved may differ depending on whether the customer context factor of cost expectations is high or low. As the model in Figure 1.7 indicates, the primary function alone is not sufficient to determine the customer needs and product requirements. The function combines with the customer, market, and usage context factors and results in an additional input to needs definition. Additionally, a traditional customer needs list alone is not sufficient to define product requirements, but contextual information is a smaller (dashed line) input into requirements definition. Although in one sense any contextual factor may be recast as a customer need in the form of "Accommodate context," for many contextual factors this is not normal practice.

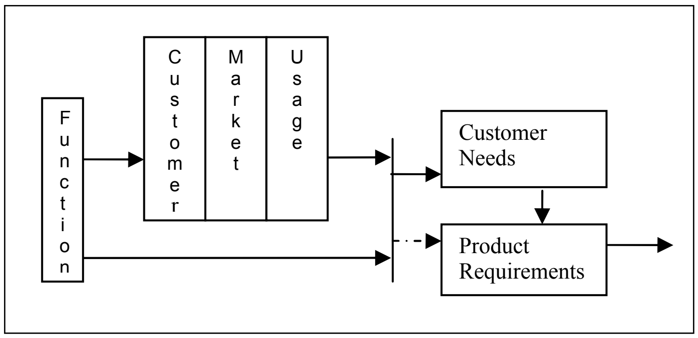


Figure 1.7: Model of Causality for Product Definition Information[10]

1.6 BENEFITS OF UNDERSTANDING DESIGN CONTEXT

Engineers are often called on to design for *frontier design contexts* outside their experience and expertise. This situation occurs by default because engineers are a subset of society; they design products to be used by children, remote villagers, the illiterate, and other groups typically not represented among design engineers. Additionally, the importance multi-national companies place on positioning products in a global marketplace requires design for customers in other countries, cultures, and economies. Although most design engineering is performed in developed countries, 86% of the world lives in a developing country (Mahajan and Banga, 2005). A special case of global design occurs when engineers in affluent societies create life-improving designs for use in high human-need environments, such as the human-powered Freeplay Radio initially targeted at rural African customers. (A case study of the Freeplay Radio design is given by Cagan and Vogel (2002)). Another example is the "robust, fully articulating dental

[10] This model is intended to describe general product performance requirements such as "hours of battery life" for a radio and not specific manufacturing requirements, such as "provide draft angle."

chair and battery-operated hand piece, all in a package you can comfortably carry on your back" developed by the US-based Indigenous People's Technology & Education Center (I-TEC) to enable dental care in remote regions (2005f). One of the top business books of 2004, "*The Fortune at the Bottom of the Pyramid*" makes the case that "the world's poor [are] potential customers …" and that everyone will benefit when recognizing the market potential among the 4 billion people living on less than $2 a day (PPP) (Prahalad, 2004). Numerous opportunities exist for engineering designs to improve the quality of life on a global scale, many of which are in frontier design contexts. In addition to the large international development programs of many wealthy nations, smaller, non-governmental organizations such as Engineers for A Sustainable World (ESW), Engineers without Borders (EWB), and Engineering Ministries International (EMI), are also acting upon such opportunities.

The product definition step is critical for the success of any new product, and particularly problematic for frontier design contexts. An opportunity exists to increase the success of any product design process, particularly when addressing a frontier context, through formalizing methods of discovering, documenting, and addressing the product design context during the design process. Numerous benefits are expected from discovering how context factors influence customer preferences. An improved theoretical understanding of the fundamental contextual causes influencing customer needs and preferences will improve the success of the product definition phase to define products which satisfy and delight customers.

First, an improved understanding of product context will facilitate and organize the needs gathering process. This understanding will improve the quality and quantity of information gathered within resource constraints, and illuminate latent customer needs which might be missed otherwise. Designers will be able to select and interview customers more effectively and better understand and classify the information received in interviews. This improvement is particularly important when interviewees view the product need through lenses of different context scenarios, and thus report different and sometimes conflicting needs. This difference in context scenario viewpoint can easily become muddled or go completely unnoticed if the interviewer is not adequately prepared to appropriately obtain and handle contextual information.

Second, a framework of contextual understanding will improve the task of setting target values by equipping the designer to account for how contextual factors influence customer preferences for product attribute values. Current techniques prescribe capturing the “voice of the customer,” but provide insufficient guidance on how to translate these data into quantifiable numbers. QFD is an excellent technique to *organize and document* this conversion; however, it is left to the designer to translate what the customer means by “light-weight,” for example, into a quantity in kg. Or perhaps even more difficult than quantification is the problem of determining what metrics appropriately measure the fulfillment of needs such as “easy to use” (possibly measured by “number of steps”, and/or “minutes”) or “good beverage taste” (possibly measured by “saturation and bitterness levels”) (Otto and Wood, 2001). The customer may clearly indicate the need for portability, but setting specifications accordingly for mass and volume depends heavily on the means and frequency with which the product will be transported.

Third, a framework of contextual understanding will better equip designers to leverage the known to design for the unknown through an improved understanding of how changes in usage context influence customer preferences. Forming design targets has traditionally relied heavily on benchmarking, but this activity can be difficult or impossible in frontier design contexts in which comparable designs are sparse. With an appropriate contextual understanding, product definition information from an accessible and information-rich environment may be intelligently brought to bear upon a frontier and information-scarce context. A product context framework and the concept of a *functional family* (a group of products which solve the same primary need) will provide the designer with tools to maximize domain cross-over of benchmarking information, intelligently selecting and adapting information from existing products that may exhibit some similarities, but do not occur in the target context. One example is the design of a $100 above-knee prosthetic by a US University for a charity hospital in Kenya[11] (2005h). The challenges of accessing and understanding Kenyan customers were partially

[11] www.letu.edu/legs

addressed through local access to US amputees, and properly translating the knowledge gathered into the Kenyan context.

1.7 PRODUCT DESIGN CONTEXT FRAMEWORK

In response to the need for improved contextual understanding, a *product design context* framework for handling contextual information is presented as a foundation to the following chapters. Product design context refers here to the collection of factors influencing customer attribute preferences. These factors may be divided into three categories defined as follows (Table 1.4): (1) *usage context factors* cover the application and environment in which the product will be used such as task frequency, weather and infrastructure; (2) *customer context factors* include consumer values, practices, and demographics such as wealth and education level; and (3) *market context factors* include aspects of competing products. More details of the context framework are reported in Publications 3 and 5 (Green, et al., 2004a; Green, et al., 2005). Of these three major categories of contextual factors influencing a customer-driven product design process, usage context often receives the least attention from textbook methodologies. Benchmarking (Otto and Wood, 2001) is a well known method to explore the market context, and customer context is partially explored through currently prescribed needs assessment methods. However, even with activity diagram techniques (Otto and Wood, 2001), designers are essentially on their own when it comes to accurately discovering and applying important usage context information.

Table 1.4: Product Design Context Categories

Category	Sub-Category	Sample Context Factors
Usage Context (PUC)	HOW Application Context	• Application task • Usage frequency • Transportation mode • . . .
	WHERE Environment Context	• Infrastructure (e.g. energy supply and cost) • Weather and climate • Maintenance and parts availability • . . .
Customer Context	WHO Customer Context	• Physical Abilities • Skills and education • Cost expectations • . . .
Market Context		• Features of available products • Performance and quality of available products • Cost of available products • . . .

1.7.1 Interpreting the Product Design Context Framework

A helpful perspective from which to understand the context categories in Table 1.4 is to consider the results of changing one category of context while holding the other two categories constant (similar to exploring an equation by allowing one variable to vary while holding all other variables constant). Table 1.5 presents a baseline scenario in which "John" is "cooking rice" in a "domestic kitchen." The three right-most columns present scenarios with a single aspect of context changed from the baseline. In the application column, the application is changed to "cooking oatmeal," but the environment and the customer remain the same as the baseline. In this example, the "type of food cooked" is not an aspect of the environment context or the customer context, but rather an aspect of the application. Although there may be correlations between certain customers and certain food types, these can vary independently (the same food may be cooked in different environments and by different customers, and likewise a differing food may be cooked in the same environment by the same customer). Understanding which of the context categories in Table 1.4 a specific factor belongs in can be difficult since the categories have fuzzy boundaries, but this type of reasoning may be used as an aid.

Table 1.5: Context Category Illustration

Context Category	Baseline	Δ Application	Δ Environ.	Δ Customer
WHO Customer Context	John	John	John	*Susan*
WHAT Application Context	Cook Rice	*Cook Oatmeal*	Cook Rice	Cook Rice
WHERE Environment Context	Domestic Kitchen	Domestic Kitchen	*National Park*	Domestic Kitchen

1.7.2 Product Design Context: Usage Context

Product usage context (PUC) refers here to all factors characterizing the application and environment in which a product is used that may significantly impact customer preferences for product attributes. As shown in Table 1.4, PUC may be thought of as one part of the larger definition of *product design context*, which also accounts for customer context and market context. For the usage context of long-distance backpacking, for example, the remote outdoor environment is an important *usage factor*, which leads customers to choose products with different attributes than they might for a domestic use. Table 1.6 shows examples of differences in usage context which dramatically impact customer expectations of product attributes. Table 1.7 illustrates how usage factors such as storage mode or transportation mode impact customer preferences for attributes such as volume and mass.

Table 1.6: Examples of PUC Differences

Need (Product)	PUC #1	PUC #2	Differences
Cook food (Stove)	Backpacking	Domestic kitchen	Size constraint, Energy supply
Loosen/tighten nuts (Wrench)	Space station	Garage	Durability, Mass constraint
Archive writing (Paper)	Office	Clean room	Allowable particle emissions
Harvest crop (Scythe/Tractor)	Rural village	Commercial farm	Maintenance, Capital intensiveness

Table 1.7: Sample Usage Context Factors and Attribute Preferences Impacted

Usage Factor	Usage Context Scenarios		Affected Attribute Preferences
	Backpacking	Domestic Kitchen	
Storage Mode	backpack	room	volume, mass
Transportation	foot	none	volume, mass
Ventilation	outdoor	limited	gas emission
Energy Supply	user provided	electricity	energy accepted
Usage Duty	light	heavy	operating cost

1.7.3 Product Context Scenarios

A given product may potentially be used in a number of different context *scenarios*. A scenario here refers to a specific set of usage context factor values that form a definable scenario. For example a mobile light might be taken on a backpacking trip or left on a shelf in case of a domestic power outage. These contexts may be decomposed into a set of *context factors* in order to characterize the essence of each scenario and allow for side-by-side comparison. A specific context scenario is defined by setting a value for each of a set of context factors, as shown in Figure 1.8. Because context factors are numerous and are not uniquely defined, considerable judgment is required to identify the most important factors for a particular design need. The following chapters offer guidance and examples for this process.

Need: product to cook food with boiling water.

Context Scenario: Backpacking - *an outdoor adventure in which individuals carry all personal supplies in a backpack for several days or more.*

Characterized by:
1. Significant travel by foot (>1 mile at a time)
2. Outdoors (well ventilated, subject to weather conditions)
3. No electricity (wood is available)
4. Lightly used (infrequent use, trips 3-14 days)
5. Users are skilled and exercise caution

Figure 1.8: Description of a "Backpacking" Context Scenario

As shown in Table 1.8, the "backpacking" context scenario may be decomposed according to the usage factors of: storage mode, transportation, ventilation, weather, energy availability, usage frequency, and usage duty. The values shown are not the only context configuration possible within the general category (particularly with usage frequency and duty), but serve the purpose of defining a clear instance of each context scenario.

Table 1.8: Sample Usage Context Scenario Decompositions

	"Backpacking" Context Scenario	**"Heavy Domestic Use" Context Scenario**
Usage Factors	**Usage Factor Value**	**Usage Factor Value**
Storage Mode	1 = backpack	5 = room
Transportation	1 = foot	3 = none
Ventilation	3 = outdoor	2 = some
Weather	3 = outdoor	1 = indoor
Energy Avail.	1 = no electricity	1 = no electricity
Usage Freq.	1 = infrequent	3 = heavy
Usage Duty	1 = light	3 = heavy

1.8 DISSERTATION ROADMAP: HYPOTHESIS AND RESEARCH OBJECTIVES

The central hypothesis of this dissertation is that *engineers equipped with improved methods and tools for contextual design will show a measurable improvement in contextual understanding of design problems outside their experience and expertise*. The central objective is to developing improved methods to facilitate discovering, documenting, and acting upon contextual information important for successful product design. This objective is divided into several sub-objectives which are the basis for the research contributions. The first objective (addressed in this chapter) is to provide the background information and motivation for the exploration of context in the product design process, along with a foundational framework for classifying contextual information. The second objective is to review the background literature sources pertinent to the research hypothesis and objectives. The third objective is to build upon the classification framework established here with an empirical product study exploring the nature of context scenarios and in what way usage context factors influence customer product preferences. The fourth objective is to apply the results of the first three objectives by developing a contextual needs assessment methodology to assist the designer in discovering and documenting the "what," "where," and "who" factors of the context framework (Table 1.4). Additionally, an advanced component of this methodology is desired to increase the formality and repeatability of grouping context scenarios and factor values. The sixth and final objective is to conduct appropriate case studies providing quantitative and qualitative measures of the usability, usefulness, and designer acceptance of the proposed contextual needs assessment method. In addition, the case studies should result in significant insight for improving the method. Accomplishing these objectives allows evaluation of the research hypothesis validity and whether the contextual needs assessment methodology merits dissemination for widespread use.

The following chapters correspond closely with the research objectives listed. Chapter 1 provides the background information and motivation for the exploration of context in the product design process along with a foundational framework for classifying contextual information. Chapter 2 reviews background literature sources pertinent to this discussion. Chapter 3 presents empirical data showing both the measurable existence and influence of context on customer satisfaction. This sets the stage for the development of new design methods to apply these findings in Chapters 4 and 5. Chapter 6 reports the results of four case studies of the methodology, and Chapter 7 gives final conclusions and future work.

Chapter 2: Prior Work Addressing Context in Product Design

Multiple texts describe formal product design methods (Cagan and Vogel, 2002; Otto and Wood, 2001; Pahl and Beitz, 1996; Ullman, 2002; Ulrich and Eppinger, 2004). These methods collectively recognize the importance of early stage design which may be referred to as the "front-end" of the design process (Cagan and Vogel, 2002), "understanding the opportunity" (Otto and Wood, 2001; Ullman, 2002), "clarification of task" (Pahl and Beitz, 1996), or the "product definition" phase. This beginning phase is characterized by extensive information gathering, and is foundational to creating successful designs. Product definition here refers to the first phase of the design process including elements such as: background research, competitive benchmarking, customer needs gathering and other market research, and formulating product requirements/engineering specifications. The product definition step is critical for the success of any new product, and particularly problematic for frontier design contexts. Chakrabarti, et al. (2004), for example, report results of an empirical protocol study demonstrating that design quality depends significantly upon the quality with which requirements are gathered and applied. Although the study is limited to designer activities within a controlled environment, it gives valuable insight into requirements gathering approaches currently used by experienced designers. The results confirm the importance of requirements formation and application.

Most design methodology texts address the importance of understanding customer needs during the product definition phase. The methodologies discussed in these texts and in the literature, however, provide inadequate guidance on accounting for contextual information. An opportunity exists to increase the success of product design through formalizing methods of discovering, documenting, and acting upon product design context during the design process. The following sections review prior work related to this opportunity.

2.1 References to Context in Product Design Texts

The contemporary texts on design methods reviewed here all address the product definition phase to a greater or lesser extent. Cagan and Vogel (2002) prescribe a number of methods for understanding "the user's needs, wants, and desires" including: new product ethnography, customer scenario development, and lifestyle reference. The authors introduce SET Factors influencing the design of a product: *Social*–culture and social interaction such as common hobbies or lifestyles; *Economic*–the excess income people are comfortable spending; and *Technical*–results of new discoveries. Otto and Wood (2001) discuss gathering customer needs and competitive benchmarking as part of "understanding the problem". They present supporting methods such as: a product mission statement, business case analysis, customer interviews and focus groups, activity diagrams of product usage throughout the lifecycle, and Quality Function Deployment (QFD). Pahl and Beitz (1996) emphasize the importance of "clarifying the task" through a requirements list which itemizes demands and wishes, both qualitative and quantitative. They present lists of questions and suggested categories for the design engineer to reference in order to facilitate defining accurate and complete product requirements. Ullman (2002) organizes his discussion of the product definition phase around the QFD framework. Major steps include: identifying customers, identifying customer requirements through surveys and focus groups, benchmarking competing products, translating qualitative customer requirements into quantitative product requirements, and setting design targets. Ullman discusses the types of customer requirements and presents a checklist to reduce chances of the design engineer overlooking important product requirements. Ulrich and Eppinger (2004) provide a section on customer needs stating that designers should experience a product's "use environment" when studying customer needs.

Pahl and Beitz (1996) (p. 45) divide constraints into *general constraints* (often accounted for implicitly) and *task-specific constraints*. They reference Hubka's (1988) constraint categories: "operational, ergonomic, aesthetic, distribution, delivery, planning, design, production and economic factors." They also present their own categories: safety, ergonomics, production, quality control, assembly, transport, operation, maintenance, recycling, and expenditure. Each constraint category is briefly expanded with a few descriptive words. Of these constraint categories, a few relate to contextual issues: "ergonomics" deals with the context of the human user, "transport" references both inside and outside the factory, "operation" references intended use and handling, and "maintenance" references upkeep. However, all of these categories are aimed at generating product requirements, not at describing or quantifying these aspects of the context. Pahl and Beitz suggest these constraints be translated into product characteristics (stated as requirements) which have implications for function and structure.

Pahl and Beitz (1996) (p. 130) present "clarifying the task" as an activity centered around generation of a requirements list. Seven general question prompts are given (e.g. "What is the problem really about?" and "What properties must [the product] have?") They suggest generating the requirements list based either on an organization by sub-systems or by a checklist of general categories (p.133). Pahl and Beitz note that designers have difficulty generating a first requirements list, but this problem is solved with experience. However, it could be added that a designer repeatedly encountering frontier problems may find each to be like a "first problem," and where experience is lacking there remains a need for additional methodology. Pahl and Beitz cite Franke (1975) as a source of detailed requirements checklists, but instead advocate general lists which are easily memorized, such as the one they present. They note that use of guidelines prevents forgetting important issues, such as low-cost manufacturing. (They further give several criteria for effective requirements checklists: cover a limited field, have longevity, and allow quick mental absorption). Although some of these headings touch on contextual issues, no discussion or examples are given of documenting anything beyond the product requirements discovered. These categories could be usefully extended to become part of a context assessment method as a part of the larger customer needs assessment process.

The checklist Pahl and Beitz give consists of major headings with "example" sub-headings. Of the 17 major headings, approximately 7 could plausibly lead to contextual considerations. These are:

- Geometry: space requirement, connection
- Forces: load (presumably external)
- Safety: operator safety

- Ergonomics: man-machine relationship, lighting (presumably external)
- Transport: clearance, means of transport
- Operation: special uses, destination environment and conditions
- Maintenance: service intervals

Otto and Wood (2001) present several techniques that could potentially shed light on contextual factors relevant to the design need: technical questioning (p. 93), customer needs gathering (p.118), usage activity diagramming (p. 141), black box modeling (p.152, 162), and specification/requirements setting (p. 283). The technical questioning method uses roughly 10 general question prompts, and does not directly address context. The customer needs gathering techniques rely heavily on the presence of an existing product to elicit information from customers, and result in a translated needs list in "the voice of the customer" ready to be translated into quantifiable requirements. (In practice, for original design problems the needs assessment technique is often modified by asking customers to imagine a virtual product to comment on). The customer needs interview procedure suggests recording "typical uses" of the product "to ensure the context of customer statements is understood" and the text emphasizes understanding "the environments in which the product is used." The authors further suggest leaving any "canned questions" to the end of the interview. Generation of activity diagrams involves creating a flow chart of the product usage from purchase through disposal, and explicitly documenting all usage modes the designer can generate. For this reason it has the potential of raising awareness of usage applications and environments which might not otherwise be explicitly thought of; however success of the technique is dependent upon the designer's ability to brainstorm or otherwise independently list all such usage activities.

Black box modeling provides an information-rich documentation of all interactions with the external environment including: energy exchange; material input, output, and interfaces; and information exchange. It therefore has the potential of highlighting contextual interfaces such as contact with external loading, surfaces, "noise" variables, and users. Pahl and Beitz (1996) also advocate the use of a Black Box (p. 149) showing input and output flows.

Otto and Wood (2001) present two complimentary approaches of specification/requirements generation: translating customer need statements through a QFD-type method, and using a checklist of categories. They note that customer needs provide incomplete information for product design, and other criteria (engineering requirements) should be identified that customers may not even perceive. For this reason they include a version of the Franke (1975) categories that is more abridged and specific than the list appearing in Pahl and Beitz. This abridged checklist leaves less room for interpretation, and therefore very little reference to context can be "read into" the categories. An embodiment checklist (p. 547) is also provided for use later in the design process. The embodiment checklist is similar to the earlier requirements checklist with the addition of several questions for each major heading.

Eggert (2005) presents three examples of product-specific question lists to obtain details about original, variant, and selection design problems, respectively. Some of the lists contain questions aimed at uncovering context factors, but they are intended for specific products (in this case a motorcycle, engine, and bearing). Generating a list for different products would rely on the designer's experience base to generate meaningful questions. However, some guidance for this process is offered in the form of a list of headings of common customer and company requirements (p. 51). Each heading is expanded into a several-sentence description. Some of the headings are extremely general, and could possibly elicit contextual information but are not likely to do so. Others which do directly lead to context[12] are:

- Operating environment - temperature, humidity, pressure, contaminants, shock, vibration
- Geometric limitations
- Maintenance

[12] Eggert indicated in a personal communication that inspiration for the "operating environment" checklist items comes largely from his industrial work experience dealing with environmental effects on equipment.

2.2 REFERENCES TO CONTEXT IN DESIGN AND NEEDS ASSESSMENT LITERATURE

2.2.1 Importance of Context

Numerous authors reference the influence of context on product design, and many explicitly express its importance. Empirical studies of the influence of product design context[13] on customer preferences are reported in Publications 3 and 5 (Green, et al., 2004a; Green, et al., 2005). These studies include: exploration of customer needs and attributes of functional product families, customer product choice surveys, and an exploration of how individual factors of a target usage context influence customer preferences for product attributes.

Clarkson, et al. (2004) report a large-scale study of the UK health system to recommend a design approach to improve patient safety. They report that improving patient safety requires an improved understanding of the context of the health care system. "Without a sound understanding – from a design perspective – of the healthcare services as a complex system of interacting organizations, professions, care *environments, procedures and tasks* … there can be no certainty that discrete design solutions will contribute to patient safety" (emphasis added).

Sutinen, et al. (2004) report results of an empirical study of an IT-based requirements management tool. They map the requirements management process, identify tools and information needed by various participants, and recommend a process for introducing new requirements management tools into the product development process. Among other findings they observe that, "the requirements specifications used in the cases studied could have been enriched by adding requirement *context information ... and scenarios* in order to provide a better understanding of why the requirement is stated" (italics added).

Maier and Fadel (2002) discuss the consideration of context in choosing design methods. They suggest that the concept of function is well suited to capture design aspects characterized by input/output relationships, whereas the concept of affordance is well suited to describe the more complex relationships involved when the

[13] Specifically, usage context

interrelationships among the *context of the artifact, designer,* and *user* are taken into account. In other words, the role of contextual information is an important factor in the selection of appropriate design methods.

Norman's classic work (2002) enumerates a myriad of design problems in "everyday things" causing them to be very difficult to use successfully. As part of this discussion, Norman gives significant attention to the interactions among objects and users, and offers design guideline "do's and don'ts." Many of the difficulties in everyday things described by Norman occur from lack of proper accounting for the context of how and where the products will be used, and the context of who (and with what capabilities) will be using them.

2.2.2 Context Related Methodology

Urban and Hauser (1993) provide a detailed discussion of numerous techniques for customer measurement, perceptual mapping, and benefit segmentation. The results of these techniques facilitate identification of a product opportunity, design of a product to fill the opportunity, and product positioning (primarily through marketing and branding) to exploit the opportunity. Although contextual factors are not explicitly dealt with, the effects of context would presumably manifest as differences in customer needs and be identified as separate opportunities through benefit segmentation methods.

Conley (2005) provides a succinct overview of the "relatively new, but proven" field of *contextual research*, an in-context needs gathering procedure bearing similarity to the articulated-use and ethnographic approaches presented in design references such as (Cagan and Vogel, 2002; Otto and Wood, 2001; Ulrich and Eppinger, 2004). Whereas an inflexible customer needs interview might provide information about "what people think," contextual research is targeted at discovering "what people do," which may in reality be quite different. Conley defines context as the "everyday situation of use" that includes the environment, people, goals and processes, and other products. He outlines key aspects of the approach as including: achieving empathy for subjects (customers), achieving rapport with subjects, following the lead of subjects, focusing on what subjects do rather than their opinions, and focusing resources to obtain rich qualitative data from relatively small sample sizes (possibly 10-20 subjects).

In "Understanding Your Users," Courage and Baxter (2005) provide a how-to guide and case studies for "all of the significant" requirements gathering methods relevant to user-centered design (UCD), a discipline for collecting and analyzing user requirements. Although the book is oriented towards the software and web design professions, it is largely applicable to other products. The methods are broadly categorized by chapter into: interviews, surveys, wants and needs analysis, card sort, group task analysis, focus groups, and field studies. The authors also suggest learning about users as a prerequisite to requirements gathering by formulating: (1) user profiles – a compilation of user attributes such as demographics, skills, and education level; (2) personas – personality descriptions illustrative of potential user goals, expectations, skills, and relationships; and (3) scenarios – a "day-in-the-life-of" description from a perona's viewpoint including the setting, actors, and events.

Beyer and Holtzblatt (1998) provide an exposition of "*contextual design*" intended to improve the product development efforts of those in the human-computer interaction field. The book describes how Holtzblatt developed the "Contextual Inquiry field data gathering technique that forms the core of Contextual Design and is now taught and used worldwide." Contextual Design includes the following parts (corresponding to book sections): (1) contextual inquiry – understanding the customer needs, desires, and approach to work; (2) work modeling – concrete representations of customer work patterns; (3) consolidations – aggregation of information from the previous two steps via affinity diagrams of customer needs and consolidated work models; (4) work redesign – a redesign of customer work patterns grounded in the aggregated data, kept abstract to avoid fixation on technical solutions (loosely analogous to functional modeling in physical product design); (5) user environment design – a diagram of the virtual environment the software creates for the user showing the parts of the system and inter-relationships from the user's point of view; and (6) mock-up and customer test – including customer involvement in the design process at multiple points.

The Contextual Inquiry methodology discussed by Beyer and Holtzblatt (1998) involves observing and interviewing the customer while using the product (in this case working with the software), and bears similarity to the articulated-use and ethnographic approaches presented in some design references such as (Cagan and Vogel, 2002; Otto and Wood, 2001; Ulrich and Eppinger, 2004). Contextual inquiry is described as "apprenticeship compressed in time" since the designer plays the role of apprentice to learn from the customer (in the role of craftsman) who teaches by talking while completing their work. The four principles of contextual inquiry include: (1) context – go to the customer's workplace to get the best data, (2) partnership – collaborate with customers in uncovering their work experience, (3) interpretation – "determine what customer words and actions mean together", and (4) focus – guide the customer to relevant topics without taking away their control to express information and importance levels.

Bittner and Spence (2003) provide a how-to handbook on "Use Case Modeling," a technique for representing the behavior of a system. Examples in the book focus on the design of software and software-dominated systems, although broader applications are possible. The method involves identifying and defining *actors* – people or things interacting with the system and *use cases* – things of value the system performs for its actors that are described in detail as stories of actor interactions with the system. A *use-case model* is the set of all actors and use cases describing a system. In addition to the textual descriptions of use-case models, diagrams may also be used to show actor and system interactions for each use case. Use case models provide a context within which requirements may be developed, understood, and correctly applied.

Hull, et al. (2002) provide a how-to book on writing and structuring engineering requirements. Among other things, the methodology presented contains basic elements of: *identifying stakeholders (including actors), identifying use scenarios*, deriving requirements in the problem domain, deriving requirements in the solution domain, and verification and traceability activities. Extensive guidance is given for each of these activities, including common sources and formats for requirements. Hull, et al. also give an overview of a software tool (DOORS) commonly used to enable requirements management.

2.2.3 Cross-Cultural Design

Courage and Baxter (2005) include a case study by Ann (2003), "Cultural Differences Affecting User Research Methods in China" citing numerous cultural differences posing challenges to market research. Differences mentioned include: differing cultural concepts can cause difficulty in translating language without loss of actual concepts; a greater focus on relationships requires more attention to building trust and respecting privacy of the home than in western countries, and the intuitive/subjective mentality vs. the scientific/rational focus of the West can reduce effectiveness of objective and direct interview approaches. The discussion of these differences shows both the challenge and importance of understanding the cultural context.

Crawley et al. (2001) present the "Design, Development and Marketing of Solar Lanterns" for the rural poor of African countries. They specifically address Kenya, which has a large population without hope of access to electricity in the near future; more than 90% of households use kerosene lighting, and 70% also use scarce cash supplies to buy batteries. Crawley et al. employ focus groups and general discussions to gather information about what customers want in a solar lantern. They note the importance of: (1) picking groups not dominated by a few dominant members, (2) holding surveys during the day for travel safety of participants, and (3) focusing on individuals with incomes similar to the target customers, who often had significantly different spending patterns than wealthier individuals. The authors note that product development is in general expensive and high-risk for companies in developing countries, and for the new products they design conventional customer needs gathering techniques are often incomplete and inaccurate in accounting for lifestyles and cultures.

Chen et al. (2003) advise that when tapping global markets, multinational companies must be wary of segmentation errors on two extremes: attempting to standardize the product for significantly different markets, or excessive customization for essentially similar markets. A balance must be struck which properly accommodates real and important differences, without unnecessarily undercutting economies of scale through standardization. Examples of major differences faced when political and/or cultural boundaries are crossed include: language, ethnic, religious, social structure, tradition, literacy, income patterns, geography and climate, infrastructure, product distribution, advertising, and legal climate.

Chen et al. (2003) predict that "... multicultural factors are the most difficult issues for organizations to address … [and will be a] future direction in NPD [(New Product Development)]." They address the need for research in this area, commenting "… there are few successful or effective techniques available for the evaluation of multicultural factors in customer requirements." Chen et al. propose one system employing a laddering technique and radial basis function (RBF) neural network to help overcome multicultural barriers to customer needs gathering. A mobile phone design case study is included. The cultural factors addressed primarily deal with the customer context.

Other design researchers also explicitly address the consideration of "culture" in the design process. Culture may be defined as the customary beliefs, values, social forms, and material traits of a group of people that are learned from preceding generations (author's adaptation from (Merriam-Webster, 2002)). Ellsworth et al. (2002) report on the "effects of culture on refrigerator design." This paper does not define culture, but references the "needs and values" of customers which differ from place to place. The authors build a case for improved cultural understanding among design engineers, stating that products will be more successful worldwide as design engineers account for cultural needs. The authors propose the development of a Design for Culture (DfX) methodology, citing a lack of attention to the subject evidenced by a dearth of literature and suggesting that cultural considerations must include not only marketing but also design. They suggest studying the use of similar products across different cultures to begin development of such a method. Refrigerators were chosen for this study because they are in widespread use globally and the designs have stabilized with distinct differences in various countries. The paper itemizes a number of macro physical differences (such as volume, energy efficiency, and construction) in refrigerators used in the US, Europe, Japan, and Brazil, and comments on the apparent cultural reasons for these differences. The authors conclude by suggesting the following categories of cultural aspects to account for: aesthetic appeal, cultural habits (e.g. tendency to snack), traditions, available resources, and the physical environment.

Donaldson (Donaldson, 2002; Donaldson and Sheppard, 2001) proposes various items to improve product design for developing countries, and comments extensively on the particular barriers and problems associated with designing for this context. Some of Donaldson's findings may be generalize-able to other frontier design environments.

Donaldson, et al. (2004) describe Customer Value Chain Analysis (CVCA) as a tool to improve identification of needs and requirements in the product definition phase. One of the case studies is a micro-irrigation pump successfully designed and marketed in Kenya, implicitly illustrating the applicability of the CVCA tool to the complexities of projects in this economy and culture.

Donaldson and Sheppard (2004) provide detailed observation and analysis of product design practice in Kenya, an example of a "less industrialized economy." They analyze design practice in the informal sector, the formal sector, and by donor-funded groups. They identify four types of product design: (1) imitated design, (2) imported design, (3) basic original design and (4) specialty design. Donaldson and Sheppard note that virtually all Kenyan products are designed outside the country or are imitations of imports. The local language has no complete equivalent for the verb "to design" and designers and producers typically view "design, sketching, pondering and brainstorming" as an extravagance. No formal design processes such as those defined in design literature were observed in the formal or informal sectors, and NGOs followed semi-formal processes. Economic and political instability along with business monopolies are possible contributors to the lack of attention to customer needs and the associated product definition steps. These findings suggest the continued importance of donor-funded design until the local sectors begin designing products in response to customer needs, and likewise the need for design methodologies applicable in frontier design environments.

2.2.4 Classifying Problem Definition Information

Young (2004) provides a handbook on requirements acquisition, analysis, and management written from the point-of-view of software and hardware design. After introductory chapters on the importance of requirements and the needed roles and skills of the requirements analyst, one chapter is dedicated to classifying the types of requirements. Another chapter covers requirements gathering approaches, including a checklist of potential sources of requirements. A list of commercially available requirements tools is also given (p. 87).

Van Der Vegte, et al. (2004) report the extension of function-behavior representation language (FBRL) for modeling other-than-intended product usage. This extension involves accounting for the user and the environment in the product-use context. Van Der Vegte, et al. provide an "ontological scheme" to model the *product, user, environment, and related use processes*.

LaFleur (1992) proposes a general framework for describing engineering design problems in terms of fundamental variables. Included in these variables are "environmental constraints" and "environmental conditions." The engineering environment is divided into four categories, including the "Application Environment (APP)" described as the "actual situation the device will encounter; real conditions and constraints, actual tasks to perform and real behavior." The Application Environment is described as a large source of public domain information, which is "fuzzy due to real complexities." Additionally, this work mentions the role of experience in the design process, noting that this experience "can be tracked and represented as information," thus making an experienced designer's knowledge accessible to others.

Galvao and Sato (2004) provide a framework to isolate information from the context-of-use defined by users. The paper defines three knowledge sets: structure-functional, procedural and contextual. "Structure and function" pertain to the product's behavior and attributes, "procedures" refers to the tasks users engage in during product interaction, and "context-of-use" refers to the wide range of influences by which product performance can potentially be affected.

Kurakawa (2004) proposes an information model to support a scenario-driven design process, and reports significant improvements result (Kurakawa and Tanaka, 2004). In a scenario-driven design process, solutions to achieve product function are developed in parallel with solutions to accommodate aspects of product scenarios. In this case "scenario" refers to design information relating to: actors, actions, and situations, which often map to: user interactions, product uses/applications, and environmental conditions. This structure closely parallels the "How, Where, Who" (application, environment, customer) structure proposed in Chapter 1. Kurakawa notes that although scenarios receive relatively little attention in the product design literature, defining product scenarios is critical to determining product requirements and functions and in practice design scenarios are often used in design meetings. He cites Bødker's (2000) observation that the use of scenarios facilitates presenting multiple solutions in context as well as identifying potential problems. He also notes that the IDEO design firm recommends using scenarios in design.

Kurakawa cites the landmark development of the Sony Walkman in 1979 as a product innovation made possible through the use of scenarios. By thinking on the scenario level, the designers were able to define a product usage scenario that included "anytime and anywhere," and design accordingly. Although this may have been possible without the explicit use of scenarios, based on Kano's research findings[14] it is plausible that customers would have been unlikely to articulate this type of portability as a customer need for their hi-fidelity sound systems at home.

Kurakawa suggests that scenarios be formed as "designers try to imagine a situation … in which the product will function … [and] interactions of the product with other objects [including people]." Design success also requires synthesizing multiple scenarios. The methodology proposed in this dissertation suggests incorporating scenario-building into the needs assessment process, using information directly from customers to the extent possible.

[14] I.e. that new product innovations require going beyond what customers express verbally, since customer statements usually lead to only minor improvements in existing products.

Rounds and Cooper (2002) report three taxonomic approaches to incorporating environmental requirements in the design process. The three approaches classify product attributes, environmental concerns, and environmental management actions, respectively. Rounds and Cooper report that classification of environmental concerns and management actions improves the "comprehensiveness, objectivity, [and] validity … [of] the resulting design requirements …" They further report that such classification is resource intensive and calls for archival to facilitate re-use.

Hauge and Stauffer (1993) propose a taxonomy-based customer requirements elicitation system to improve breadth and depth over other methods. They point out that although QFD provides structure for the conversion of customer requirements into design requirements, it is not helpful for eliciting the voice of the customer. Current methods are marketing research techniques such as focus groups, customer surveys, interpreting warranty data, and interpreting sales data. They note that some companies rely on engineers' interaction with and "innate sense" of the customer. Hauge and Stauffer note that although this customer interaction is useful, engineers are not trained for this and may glean very limited data. Controlled experiments show that ELK dramatically increases the quality and amount of customer requirements elicited in a focus group session. Rather than guessing what is important to research in a market study, the taxonomy provides a basis for developing the questions which must be answered. Hauge and Stauffer's work has a direct parallel with this dissertation. Just as they demonstrated that engineers much more effectively gather important requirements when equipped with a taxonomy of key issues, so this work demonstrated that designers much more effectively gather contextual information when equipped with a categorization of contextual issues. This work also includes generalized elicitation questions to improve context gathering, as well as techniques for identifying new contextual factors not in the context questions template provided.

Gershenson and Stauffer (1999) divide requirements into four types based on their source: end-user, corporate, technical and regulatory. They describer end-user requirements as expectations about the product's capabilities, aesthetics, and usability.

"User context" is described as characterizing the end-user of the product, and thus is distinct from all other types of requirements but plays an important role in applying them.

Gershenson and Stauffer (Gershenson, 1995; Gershenson and Stauffer, 1999) build on ELK by proposing a taxonomy for design requirements (in this case limited to corporate customers) for use with the Methodology of Organizing Specifications in Engineering (MOOSE). They note that the taxonomy improves eliciting, storing, and retrieving requirements; and serves as a template for the creation of new taxonomies. They discuss the qualities of completeness, perceptual orthogonality, and parallel structure. The taxonomy entries have a data structure of a top function level, followed by multiple task levels, and part attributes as the lowest levels. A single sample entry is shown in Table 2.1 with part attributes of geometry, features, tolerances, material, surface, and facilities. These attributes also appear on many other entries; however their occurrence under the specified task levels guides the designer as to what information is expected. Although the lower levels are termed part attributes, one exception is "facilities" which prompts the user to consider available manufacturing facilities and "the environment that the facilities create for the process."

Table 2.1: Sample Taxonomy Entry From (Gershenson and Stauffer, 1999)

1. Manufacturing
1.1. Part production
1.1.1. Casting/molding
1.1.1.1. Venting
1.1.1.1.1. Geometry
1.1.1.1.2. Surface Conditions
1.1.1.1.3. Facilities

Hauge (1993) presents a taxonomy for requirements gathering which includes the "context identification" categories of user, task, and environment. Table 2.2 shows this part of the taxonomy.

Table 2.2: “Context Identification” Taxonomy From (1993)[15]

1. **User Identification**
   - 1.1. Age
   - 1.2. Gender
   - 1.3. Race
   - 1.4. Socioeconomic Status
   - 1.5. Clothing
   - 1.6. Disabilities
   - 1.7. Level of Expertise
   - 1.8. Special Populations (military, body builders)

2. **Task Description (for each task)**
   - 2.1. Number of Users (required to complete the task)
   - 2.2. Importance (of the task)
   - 2.3. Difficulty
   - 2.4. Time Constraints
   - 2.5. Intended Rate of Output
   - 2.6. Time Spent at Each Task
   - 2.7. Methods of Completing Each Task
   - 2.8. Automation Involved
   - 2.9. Product Handling/Portability
   - 2.10. Type of Work (precision, light, heavy)
   - 2.11. Workload Effects (of the product on the user performance)

3. **Environment**
   - 3.1. Climate
   - 3.2. Illuminance/Lighting
   - 3.3. Noise
   - 3.4. Special Concerns (micro gravity, acceleration, radiation)
   - 3.5. Toxins
   - 3.6. Vibration

2.3 REVIEW OF CUSTOMER NEEDS LITERATURE

Bayus (2006) provides an extensive review of the marketing, engineering, and industrial design literature related to the theory and practice of customer needs assessment. He maintains that in spite of great challenges, understanding customer needs is possible and critical to the success of the product development process. For example, even customers themselves often have difficulty knowing, or at least articulating, what they need and want. However customers base purchasing decisions on how well they believe a product will fulfill their needs.

Bayus (2006) reviews three levels of abstraction of customer needs, using a digital camera to illustrate: (1) *features* are concrete, such as “autoflash” and “scene

[15] Updated version obtained through personal communication.

modes"; (2) *consequences* include "easy to use" or "gives confidence"; and (3) *desired end-states* are the underlying purposes such as "to re-live fond memories." Needs are more difficult to assess as the abstraction level increases, but abstract needs are also more likely to lead to product innovation.

Bayus reports three categories of needs assessment identified by Squires and Byrne (2002) as: (1) discovery research for original design, including customer culture (2) definition research, which seeks to develop a pre-existing concept, and (3) evaluation research, which is based on a working prototype. This three-pronged classification illustrates how "discovery" of customer culture is fundamental to the development of new and original products. "[T]he engineering and marketing … literatures typically deal with product characteristics and attributes rather than a broader set of customer needs … [thus] the relatively large number of failures reported in the press should not be that surprising."

Bayus (2006) relates Kano's discovery that new product innovations require going beyond what customers express verbally, since customer statements usually lead to only minor improvements in existing products. Bayus distinguishes between articulated needs and unarticulated needs, or those which customers can not readily verbalize. Needs may be unarticulated for a variety of reasons including unawareness, reluctance, or inability to explain. Articulated needs may be gathered through what customers "say," whereas unarticulated needs must come from observing what customers "do" or even "make."

Approaches to gathering articulate-able needs (and maximizing the number articulated) include (from industrial design literature): empathetic design, user-centered design, contextual inquiry, ethnography, non-traditional market research, and Kansei engineering. Other need gathering methods include: focus groups, personal depth interviews, surveys, email questionnaires, and product clinics. Market research methods include: conjoint analysis, perceptual mapping, segmentation, preference modeling, simulated test markets, category problem analysis, repertory grids, echo procedures, verbal protocols, laddering and means-ends analysis, personality profiling, customer-sketch of the "ideal product", and archetype analysis. Emerging methods take similar principles to the next level by exploiting the Internet's massive connectivity and information sharing capabilities.

Gathering unarticulated needs involves learning what customers "do": participant observation, applied (rapid) ethnography, and contextual inquiry; all taking place in the actual context of use. The development team can also "be the customer", and perform human factors and ergonomics research.

Unarticulated needs may also be investigated through what customers "make" through: lead user analysis, customer toolkits, metaphor elicitation, serious play (e.g. with LEGOs), collages, cognitive image mapping, and Velcro modeling.

The costs of gathering customer needs are very high, but the costs of failure are higher, thus driving the continual demand for improved needs assessment methods. Bayus (2006) cites Urban and Hauser's (2004) statistics on typical costs of need assessment studies such as a study with 100,000 mailed surveys and another with 300 personal interviews covering 40-50 features, each $500,000.

Bayus (2006) cites a key finding from Bettman et al.'s (1998) review of the literature on consumer choice that, "preferences are highly context dependent." The further implication that *the information articulated by customers is also context dependent* may explain the success of certain methods which attempt to account for context during needs assessment.

Bayus (2006) suggests a key future research direction will include development of a hierarchy of universal need dimensions that may be used as a framework for defining needs in a specific instance of a context and customer.

2.4 References to Context in Marketing literature[16]

A chapter on international market research (1986) notes that unfamiliarity with a foreign country is a hazard faced by market researchers which can cause ambiguity and false conclusions. Common blunders originate from unstated assumptions which may differ from one country and culture to another. Some types of market research in certain countries is not feasible. "… particularly in developing countries – it is virtually

[16] This section was prepared in collaboration with Junjay Tan.

impossible to design an adequate quota sample …" due to lack of social structure definition, or lack of knowledge. Interviews do not work in some settings; for example, "Question-and-answer interaction with a stranger can sometimes seem strange, even uncomfortable or threatening." Therefore there is "no substitute for close familiarity with the local culture." Even in some developing countries the cost of market research has risen to nearly European levels, which increases the importance of economical solutions to overcome the listed problems.

The effect of usage context on product design and consumer preference is mentioned in marketing and consumer research literature. Belk, for example, suggests that consumer research needs to explicitly account for situational variables and context (Belk, 1975), while Park states that consumer research often incorrectly assumes consumer consumption to be "independent of usage situations" (Park, 1993).

Belk defines a usage situation as "all those factors particular to a time and place of observation that do not follow from a knowledge of personal (intra-individual) and stimulus (choice alternative) attributes and which have a demonstrable and systematic effect on current behavior." He groups situational characteristics into five groups, shown in Figure 2.1, two of which are of primary interest to engineering design: physical surroundings and task definition. Belk's definition of a usage context is similar to ours in that it incorporates application (task) and environmental characteristics. The remaining three elements represent possible sources of variation which were not controlled in the empirical study, and likewise are difficult or impossible to accommodate during a product design process.

Belk points out that the main problem in accounting for usage context is the lack of a comprehensive taxonomy of "situational characteristics" and combinations of these characteristics.

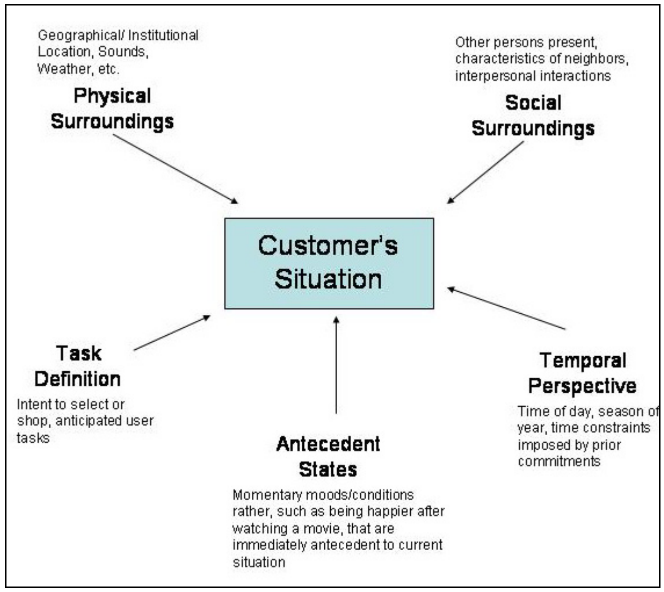


Figure 2.1: Situational Variables Affecting Customer Choice (Belk, 1975)

In research concerning market segmentation, Dickson claims that besides the popular use during the 1970s of person-based characteristics to segment markets, markets can also be segmented by usage situation, since demand often results from person-environment interaction (Dickson, 1982). He presents a general framework for person-situation analysis and says it is probably most useful for product development, among other activities.

Warlop and Ratneshwar, based on studies of consumer choice for desserts and candies, speculate that usage context may remind customers of "known solutions" when they choose between products and may impose constraints on possible product choices (Warlop and Ratneshwar, 1993). They state that their research (ca. 1993) is part of an emerging stream of research studying the role of context and goals in consumers' learning and decision making. Similarly, accounting for usage context might remind designers of "known solutions" and allow them to better select successful concepts for unfamiliar environments.

The Substitution in Use (SIU) Approach developed by Stefflre involves having customers generate a set of usage contexts and list substitute products they would use in those contexts (Stefflre, 1971). The underlying idea behind SIU is that "usage contexts act as environmental constraints that help define consumers' ends or goals, and thus limit the nature of the means (products) that can achieve those goals." (Ratneshwar and Shocker, 1991). In engineering design, usage context also creates constraints that limit engineering means to achieve certain functional goals.

2.5 Conclusions

The literature reviewed here reveals a significant opportunity for the development of tools and methods bringing contextual information to bear on the product design process. For the purposes of engineering product design, none of the methods were found to give adequate attention to exploring the fundamental contextual factors leading to customer needs and product requirements, or an adequate framework for discovering, documenting, and correctly applying this information to a variety of design problems.

The marketing literature review shows that the influence of usage context on customer choice and preferences has received some attention in the past. There is a need for improving the formal application of contextual information in the design of engineered products. Specifically, the development of methods and tools to discover, document, and apply contextual information in the product design process hold great potential to improve the satisfaction of customer needs.

Chapter 3: Empirical Study of the Influence of Usage Context on Product Choice

This chapter builds upon the classification framework established in Chapter 1, and reports an empirical product study showing how usage context factors influence customer product attribute preferences. In addition to demonstrating that context plays an important role in product attribute preferences, the study also explores the nature and extent of such relationships. Thus this empirical study is a necessary step towards achieving the central objective of this dissertation (to develop the foundational understanding, methods, and tools to equip engineers in discovering, documenting, and acting upon contextual information) and testing the central hypothesis that such methods will be effective.

The empirical study begins with customer interviews using sets of “mobile lighting” and “food boiling” products to enable identification and characterization of product usage scenarios for each family. Interactive surveys measuring customer product choice support the hypothesis that customer product preferences differ for each usage context identified. Further analysis shows that attributes of these chosen products are related to factors of the usage context (e.g. the mass attribute of preferred products is related to transportation mode of the context scenario). These results demonstrate that valuable insight for product design is available through an understanding of usage context. This affirms the importance of developing methods to discover, document, and apply contextual information in the design process, particularly for use in poorly understood “frontier” contexts for which needs assessment has traditionally been difficult.

3.1 Key Definitions

Table 3.1 and Table 3.2 present key definitions for the discussion which follows. These definitions are divided into two groups: definitions relating to products and to the customer.

Table 3.1: Key Definitions: Product

• *Functional family* – a group of substitutable products performing the same primary function, such as "cook food by boiling" or "broadcast light with mobility." • *Product attribute(s)* – important product characteristics such as volume, mass, operating cost, and convenience (characteristics often included in product specifications or a customer requirements list). • *Product [attribute] metric* – a quantifiable measure of a product attribute, such as mass in kg or safety on a 1-5 scale (subjective). • [Product] usage context (PUC) – the application and environment in which a product will be used that may significantly influence customer attribute preferences.

Table 3.2: Key Definitions: Customer (User)

• *Customer* – generally includes the product chooser, buyer, and user (often one person fulfills all three roles). • *Customer [product attribute] preferences* – The customer's preferences for product attribute values; e.g. a strong preference for mass ≤ 1kg. • *Customer product preferences* – the aggregation of customer attribute preferences as manifested in product choice. • *Customer product choice* – the product(s) a customer selects from a given choice set for use in a specific context. • *Customer perceptions* – customer evaluation of how well a product satisfies individual customer needs, often ranging from "very unsatisfactory" to "very satisfactory."

3.2 Research Approach

This chapter presents an empirical investigation the influence of usage context upon customer product attribute preferences, measured by the products customers choose from a product set. The results give insight into questions such as, "How does the way a product will be stored (the storage usage factor) affect customer choice from a set of products of various volumes and masses?" And, "Is this effect on customer choice similar from one functional family of products to another?" The belief that customer product preferences are strongly influenced by factors of the intended usage context leads to the hypothesis that:

> (a) Customers will prefer different products for different usage context scenarios, and (b) Products preferred for a specific usage context scenario will exhibit attributes related to that context.

The hypothesis suggests, for example, that for usage contexts such as "power outage" and "heavy domestic use" which have a usage context factor of "storage=cabinet," customers will prefer products with similar "volume" attributes. It is expected that attributes will show correlations with driving usage factors, whereas attributes driven by customer factors (such as disposable income) will vary independently of usage factors since the customer factors also vary independently of usage factors.

The hypothesis is tested with the methodology shown in Figure 3.1, adapting several elements from reverse engineering methodologies (Otto and Wood, 1998). First, two functional families of successful, market-mature products are selected to allow cross-functional comparisons: eleven products that broadcast light with portability, and ten products that cook food through boiling. Second, customer interviews yield customer needs lists and usage contexts. Third, the products are measured across key attributes determined from the customer needs list. Fourth, interactive surveys show which products customers prefer for each usage context identified. Finally, the data are analyzed to investigate the relationship between product attributes and factors of the contexts for which they are preferred. The following sections expand upon each step.

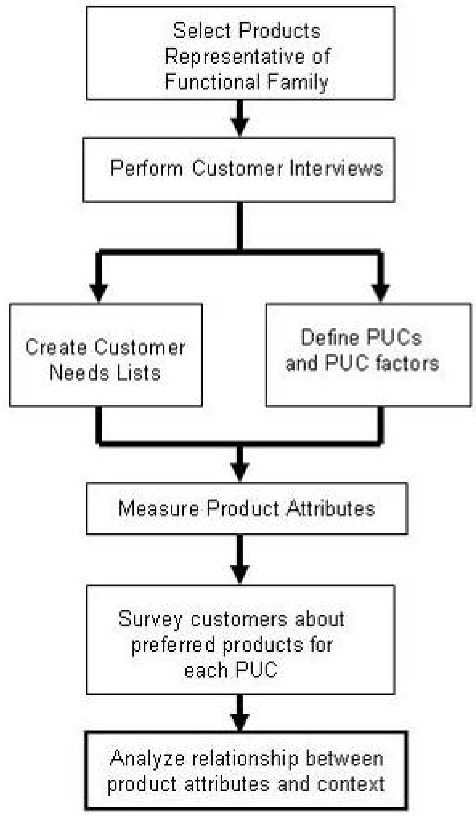


Figure 3.1: Usage Context Exploration Methodology

3.2.1 Selecting Products for the Empirical Study

To determine correlations between usage context factors and product attributes, two functional families of products are partially reverse engineered. Functional families are defined here to consist of products addressing the same primary functional need.

Product families chosen for the study must fulfill several criteria: (1) address a need that most consumers are familiar with; (2) be technologically mature and stable (high on the S-curve) so that customer desires for product features are relatively stable; (3) contain products addressing a ubiquitous need spanning multiple usage contexts so that differences can be compared; and (4) contain products of reasonable size, availability, and cost for an empirical study.

The most obvious products fulfilling these criteria are those addressing basic needs. The two domains of lighting and cooking are selected because each encompasses a variety of products satisfying the above criteria.

The domain of lighting is broad because human need for lighting spans many applications and environments. Since thousands of distinct products fulfill this need, for this study, it is narrowed to the need for *"mobile lighting that allows broad visibility of other objects."* The term *mobile lighting products* is used hereafter to refer to products fulfilling this need. Mobile lighting products exclude permanently installed lighting products, self illumination and signaling products, and flashlights (which focus light rather than broadcast light broadly within a space). This definition leaves a manageable domain of lantern-type products for the study.

The cooking domain is also broad, as cooking encompasses many different cooking styles (Bittman, 1998; McGee, 1997). Boiling is chosen as the required cooking style for several reasons. First, boiling cooks food evenly, which removes the need to account for this hard-to-measure metric. Second, products used for boiling food are varied, ranging from large kitchen cooktops to portable camping stoves. Boiling products are therefore a good representation of all cooking products. Lastly, boiling is a ubiquitous cooking method used throughout the world. This study is limited to products which "*cook food through boiling*." The term *food boiling products* is used hereafter to refer to products meeting this need.

Products are found by researching local and online retailers[17]. Because these functional families include hundreds of similar products, groupings are devised for each functional family and representatives from each grouping are selected for testing. A sample size of eleven mobile lighting products and ten food boiling products are selected after extensive research and deliberation in order to represent the domain as thoroughly as possible without subjecting interview participants to an unreasonable interview burden and set consideration size.

Mobile lighting products may be grouped effectively by energy domains, and boiling products by industry categorization. Each chosen product fulfills the intended primary need and is representative of its group, but lacks unnecessary frills and features that might be considered luxuries (e.g., reputable but not professional-chef branded cooktops). This choice allows comparison of product costs based on function and basic features rather than on brand names and luxury features.

The eleven mobile lighting products and ten food boiling products selected are shown in Figure 3.2 and Figure 3.3, respectively. Product descriptions and further details are reported in Publications 3 and 5 (Green, et al., 2004a; Green, et al., 2005).

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[17] Including: amazon.com, epinions.com, Oshman's, Wal-Mart, Academy, and REI

			
1: Butane Gas	**2: Propane Gas**	**3: Liquid Fuel Pump**	**4: Kerosene**
Cost: $35 Fuel: $4.50 for 3 hrs	Cost: $23 Fuel: $1.50 for 8 hrs	Cost: $38 Fuel: $0.35 for 8 hrs	Cost: $5 Fuel: $0.25 for 10 hrs

			
5: Candle Stick	**6: Candle Lantern**	**7: Paraffin Bottle**	**8: Light Stick (Grn)**
Cost: $1 for 3 hrs	Cost: $18 Fuel: $1 for 9 hrs	Cost: $2 for 19 hrs	Cost: $2 for 12 hrs

			
9: Krypton (4D Batt.)	**10: Fluorescent (6D)**	**11: LED (4D Batt.)**	
Cost: $11 Fuel: $5 for 14 hrs	Cost: $18 Fuel: $8 for 10 hrs	Cost: $40 Fuel: $5 for 40 hrs	

Figure 3.2: Mobile Lighting Products Selected for Empirical Study[18]

[18] Pictures from: www.coleman.com, www.outinstyle.com, www.rei.com, www.jd-therapy.co.uk, www.candleshop.com, www.ortec-products.de

Figure 3.3: Food Boiling Products Selected for Empirical Study[19]

3.2.2 Gathering Customer Needs

Gathering and understanding customer needs is achieved through three means: researchers experience the products through setup and usage, researchers interview potential customers one-on-one after letting them set up and use the products, and researchers review customer comments from online retailers.

In a one-on-one interview, each potential customer is asked to examine, set up, and use each product, and then comment on prompts including, "What do you like?", "What do you dislike?", and "In what situations could you envision yourself using this product?" Because of time and budget limitations, interviewed customers include both experienced and inexperienced users of each product, rather than solely experienced

[19] Pictures from: hem.passagen.se/rfrgu/campfire.jpg, www.amazon.com, www.sears.com

users. This choice increases dependence upon experienced users to articulate needs unfamiliar to other users, and in the researchers' opinion this dependence did not significantly degrade the aggregate needs list. Interviews are recorded in the "voice of the customer."

Customer comments from online sites such as amazon.com and epinions.com are also reviewed. These comments, along with the interview comments, are then translated into weighted needs. Needs are inferred and weighted based on a combination of how frequently a need is mentioned, how forcefully it is articulated, and the researchers' assessment of a product and its intended usage based on accumulated customer comments. Table 3.3 shows the customer needs list for boiling products. Customer needs for mobile lighting products are reported in Publication 3 (Green, et al., 2004a).

Usage contexts are inferred from interviews based on questions to each customer explicitly addressing usage context. Each customer is asked to describe the environments and situations in which they would use each product. Contexts are also inferred from online customer reviews, as reviewers often explicitly mention situations where the reviewed product could be used. General usage context scenarios are identified and defined from these data by the researchers.

The customer needs list for food boiling products is shown in Table 3.3 along with the five primary product usage context scenarios identified. Customer needs are rated on a scale of 1 to 5, with 5 indicating very high importance. Certain basic needs, such as boiling quickly and low product cost, are equally important across all context scenarios. Many other needs, however, vary considerably in importance across context scenarios. For example, customers wanting a food boiling product to use while backpacking mentioned compactness as very important, while customers wanting a food boiling product to use in the home kitchen show little concern for compactness.

Assigning meaningful weightings to customer needs across differing contexts is complicated by the fact that *customer perceptions* of a given product are sensitive to context factors. What constitutes a "compact" product differs according to context factors such as how it will be transported, if at all. This difficulty further supports the need to properly identify relevant usage contexts before and during customer needs gathering. The weightings in Table 3.3 are assigned based on judgment of the collected data in order to illustrate the variation of the needs across contexts. The significance of customer preference differences across contexts is shown in more depth in results Sections 3.3.1 and 3.3.2 through an exploration of the relationship of product attributes with associated context factors.

Table 3.3: Customer Needs for Boiling Products

		Usage Contexts					
		1:Backpacking	**2: Camping Near Car**	**3: Picnic/Tailgate**	**4: Average Home**	**5: Tiny Kitchen**	
Cooks well	Boils quickly	**5**	**5**	**5**	**5**	**5**	s (±30)
	Maintains simmer	**4**	**4**	**4**	**4**	**4**	[Y/N]
Portable	*Compact*	5	4	3	2	5	m^3
	Lightweight	5	4	3	1	3	kg
Low cost	Low product cost	**4**	**4**	**4**	**4**	**4**	$
	Low fuel op. cost	3	3	3	5	5	$/L-water
Easy to use	Easy to start	**4**	**4**	**4**	**4**	**4**	[1-5]
	Easy to clean	**3**	**3**	**3**	**3**	**3**	[1-5]
	Large capacity	2	3	4	4	3	L
	Intuitive Controls	**5**	**5**	**5**	**5**	**5**	[1-5]
Safe	*Low fire hazard*	3	3	4	5	5	[1-5]
	Low burn hazard	**4**	**4**	**4**	**4**	**4**	[1-5]
	Stable to cook on	**5**	**5**	**5**	**5**	**5**	[Y/N]
Reliable	*Tolerates weather*	5	5	2	1	1	[1-3]
	Durable	**5**	**5**	**5**	**5**	**5**	

3.2.3 Measuring Product Attributes

To study the impact of usage context factors on customer preferences for product attributes, key attributes of each product are measured. *Product attribute metrics* (shown in Table 3.3) are defined based on the compiled customer needs lists using a house of quality style approach. Measurements for both mobile lighting and food boiling products are obtained from a combination of manufacturer data, direct measurements, and third-party reviews. Equipment and fuel costs are taken as the average retail price from five or more retail sources.

The ranges of scales selected to quantify product attributes are chosen to approximate the resolution believed to exist in *customer perceptions*. For example, customers would be unlikely to sort products into more than three distinct groups when categorizing them by perceived burn hazard. Here we use primarily physical quantities to differentiate products; however, measuring customer perceptions in future work will add a more meaningful way to distinguish products.

3.2.4 Identifying Usage Context Factors and Scenarios

During customer interviews, customers are asked the open-ended question, "In what situations would you consider using this product?" For the mobile lighting products, customer responses to this question may be grouped into the general usage context scenarios of: backpacking, camping near a car, intermittent electrical outage, heavy domestic use (no electricity), and domestic mood lighting. For the food boiling products, customer responses may be grouped into the usage context scenarios of: backpacking, camping near a car, picnic, average home, and small housing. These contexts are decomposed into individual *context factors* in order to characterize the essence of each scenario and allow for side-by-side comparison.

As shown in Table 3.4, the usage factors used to characterize the context scenarios include: storage mode, transportation, ventilation, weather, energy availability, usage frequency, and usage duty. (Identification of these factors flowed from customer statements; however, considerable judgment was involved and future development of a common factors list will considerably reduce the likelihood of overlooking a significant factor). A specific example of each general usage context scenario is defined for both the lighting and boiling product families, as shown in Table 3.4 and coded according to the accompanying usage factor value key. The values shown are not the only context configuration possible within the general category (particularly with usage frequency and duty), but serve the purposes of this study by giving customers a clear instance of each context scenario.

Table 3.4: Usage Context Scenario Factor Values Used for Survey

Usage Factors	Lighting Contexts						Boiling Contexts						Usage Factor Value Key
	1:Backpacking	2: Camping Near Car	3: Occasional Elec. Outage	4: Heavy Domestic Use	5: Dom. Décor. & Mood		1:Backpacking	2: Camping Near Car	3: Picnic/Tailgate	4: Average Home	5: Tiny Kitchen (RV/Apt./Dorm)		
Storage Mode	1	2	3	5	5		1	2	3	5	4		1=backpack, 2=car, 3=cabinet, 4=small space, 5=room
Transportation	1	2	3	3	3		1	2	2	3	3		1=foot, 2=car, 3=none
Ventilation	3	3	1	2	1		3	3	3	2	2		1=none, 2=some, 3=outdoor
Weather	3	3	1	1	1		3	3	2	1	1		1=indoor, 2=calm, 3=outdoor
Energy Avail.	1	1	1	1	2		1	1	1	2	2		1=no electricity, 2=electricity
Usage Freq.	1	1	1	3	2		1	1	1	3	3		1=infrequent, 2=moderate, 3=heavy
Usage Duty	1	1	1	3	2		1	1	2	3	2		1=light, 2=medium, 3=heavy

3.2.5 Surveying Customer Product Preferences

After identifying usage contexts based on customer comments and establishing a specific instance of each (Table 3.4), interactive surveys are used to determine which products customers prefer for each usage context scenario. The interview begins with the customer using each product in one family (either lighting or boiling) and receiving data an experienced user would know about the product. For mobile lighting products, this information includes: product cost, fuel type, run time, and cost per fueling (similar to what is shown in Figure 3.2). For food boiling products, interviewees are provided with: product cost, weight, volume, fuel type, and burn time. The goal of having the customer experience the products and review the provided data is to educate them to a “quasi-user” level of product familiarity because so few people have adequate experience with every product in the family. Operating cost is not given directly in terms such as $/L-boiled since this information is not available to customers, but rather it is often available in terms of the cost of a purchase unit of fuel and total burn time. In order to facilitate survey logistics, customers are shown videos of full product usage from set-up through boiling for the gas cooktop and other cumbersome products.

After the interviewee becomes familiar with each product, they complete a survey indicating which products they prefer for use in each PUC. A specific context scenario is defined by giving a value for each context factor (Table 3.5). As shown in Table 3.6, customers then rank the strength of their preference (usage likelihood) for each product on a scale of 1-5, and then rank all products in the family in order of preference from 1-10 (with ties allowed). This process is repeated for each context.

Table 3.5: Survey Excerpt for "Backpacking" Context

Imagine that you need to bring water to a boil to cook food, and you are contemplating purchasing one of the products shown previously in the grid of products. Please carefully read the usage context described in the box below, and then on the rest of the page tell us how suitable you think each product is for <u>this</u> usage context:
Backpacking - *an outdoor adventure in which individuals carry all personal supplies in a backpack for several days or more.* <u>Characterized by:</u> 1. Significant travel by foot (>1 mile at a time) 2. Outdoors (well ventilated, subject to weather conditions) 3. No electricity (wood is available) 4. Lightly used (infrequent use, trips 3-14 days) 5. Users are skilled and exercise caution

Table 3.6: Customer Product Preference Survey

Circle a number beside each product below: *For the situation described above, I would:* (1) Definitely not consider using this product (2) Probably not consider use this product (3) (Undecided) (4) Probably consider using this product (5) Definitely consider using product			Usage Likelihood (1-5)	Ranking (1-10)
1) Firewood	1 2 3 4 5			
2) Charcoal	1 2 3 4 5			
3) Butane Piezo-ignition	1 2 3 4 5			
4) “White Gas” Liquid	1 2 3 4 5			
5) Two-burner Propane	1 2 3 4 5			
6) Electric multi-cooker	1 2 3 4 5			
7) Microwave	1 2 3 4 5			
8) Electric Coil Cooktop	1 2 3 4 5			
9) Electric Smoothtop	1 2 3 4 5			
10) Gas Cooktop	1 2 3 4 5			

3.3 RESULTS

3.3.1 Results: Customer Product Preferences

The survey data support part (a) of the hypothesis[20] (Section 3.2), indicating different product preferences exist for different usage contexts as shown in Table 3.7 and Table 3.8. The data include eleven surveys for the food boiling products, and fifteen for the mobile lighting products. The strength of each preference reported here is an aggregate measure of the average usage likelihood score (1-5) and the number of interviewees ranking the product in their top two choices for the usage context of interest.

Thresholds are selected to distinguish products favored by most respondents from those favored by only a few. For the usage likelihood data, an average score of 4.0 or greater is classified as a strong preference, and a score from 3.0-3.99 is classified as a weak preference. For the ranking data, products ranked first or second by 6 or more interviewees (more than 50%) are classified as a strong preference, and 3-5 top two

[20] “Customers will prefer different products for different usage context scenarios …”

rankings is interpreted as weakly preferred. This analysis gives similar results for usage likelihood and ranking data, indicating internal consistency and supporting survey validity.

In certain cases the usage likelihood and ranking data give slightly differing results for preference strength. In these cases tie-breaking is performed to decide the final results shown here. Tie-breaking influences the rating of "strong preference" for only one boiling product, but for eight lighting products. This result is plausibly due to the fact that the lighting functional family is more tightly defined than the boiling family, and thus exhibits less variation in product attributes. It also appears from the data that most of the lighting products are well matched to multiple context scenarios. Both of these reasons make it more difficult to distinguish preferences for the lantern products under study. However, larger distinctions are still evident; in every case observed if either data set (usage likelihood or ranking) indicates a strong preference for one product the other data set indicates at least a weak preference for the same product.

Table 3.7: Customer Boiling Product Preferences

Products	1: Backpacking	2: Camping Near Car	3: Picnic/Tailgate	4: Average Home	5: Tiny Kitchen
	Context Scenarios				
Firewood (1)	•	•	•		
Charcoal (2)		■	■		
Butane (3)	■	•			
White gas (4)	■	■			
Propane (5)		■	■		
Multi-cooker (6)				•	■
Microwave (7)				■	■
Electric coil (8)				■	■
Elect. Smoothtop (9)				■	•
Gas cooktop (10)				■	•
■ = strong preference; • = weak preference					

Table 3.8: Customer Lighting Product Preferences

	Context Scenarios				
Products	**1: Backpacking**	**2: Camping Near Car**	**3: Occ. Elect. Outage**	**4: Heavy Domestic**	**5: Mood**
Butane/Prop.(1)	•	•			
Propane (2)		■		■	
Liquid Fuel (3)		•		■	
Kerosene (4)					
Candle Stick (5)			•		■
Candle Lantern (6)	■		■	•	•
Paraffin Bottle (7)			■		■
Light Stick (8)					
Krypton Batt.(9)	•	■	■	•	
Fluorescent Batt.(10)		■	■	•	
LED (11)	•	■	■	■	
■ = strong preference; • = weak preference					

The preference survey results in Table 3.7 and Table 3.8 show that the customers surveyed have distinct product preferences for each usage context. For each context there is not unanimous agreement on one or two products, but rather a range of products is preferred. Additionally, most products show suitability for more than one context.

Some products are not strongly preferred for any context, as is seen in the boiling product family with firewood (1), and in the lighting family with: butane/propane (1), kerosene (4), and the light stick (8). This lack of a strong preference for these products suggests that although these products do "broadcast light with portability," they may not be perceived by customers as viable solutions to fill this need. For example, firewood may be purchased in this country for the function of heating or aesthetics, and not cooking food by boiling. Similarly, the basic kerosene lantern used here may be preferred for nostalgia and the light stick for recreation or signaling rather than the function of "mobile lighting for visibility of other objects."

The lack of strong preference for the butane/propane piezo-ignition is more difficult to explain, since it currently exists on the market as a mobile lighting product. This result suggests that either the population surveyed does not statistically represent all customers, or that even though the average preference is weak, there are enough customers who prefer the lantern to create a profitable market segment. These above occurrences are exceptions in the data, however, and the overall results are both internally and logically consistent.

3.3.2 Results: Product Attributes vs. Context Factors

The results of the empirical study partially support part (b) of the hypothesis, showing that in certain cases product attributes are related to usage context factor values. Figure 3.4 shows product volume plotted against the dominant transportation mode of the usage contexts. (Note that if a product is strongly preferred for multiple contexts with differing transportation mode factor values, the product appears on the graph more than once). The graph does not show a pattern of clustering attributes, as might be expected, but rather a pattern of increasing maxima. The largest boiling product chosen for contexts with foot transportation has less than 10% of the volume of the largest product approved for transportation by car, and less than 1% of the volume of the largest product approved for contexts that do not require transportation. A similar pattern is seen for lighting products; however no difference is observed between the maxima for car transportation and "no transportation." This result is not surprising since the mobile lighting functional family is defined to include only portable products. In contrast, the food boiling functional family includes both portable and non-portable products, which naturally encompass a broader range of mass and volume. The same insights derived from Figure 3.4 also apply to Figure 3.5, product mass plotted against transportation mode.

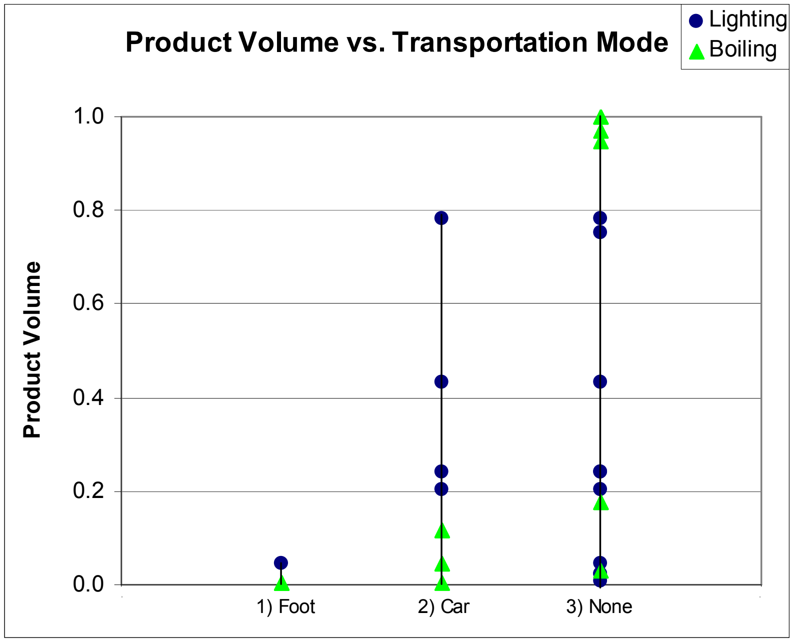


Figure 3.4: Product Volume vs. Transportation Mode

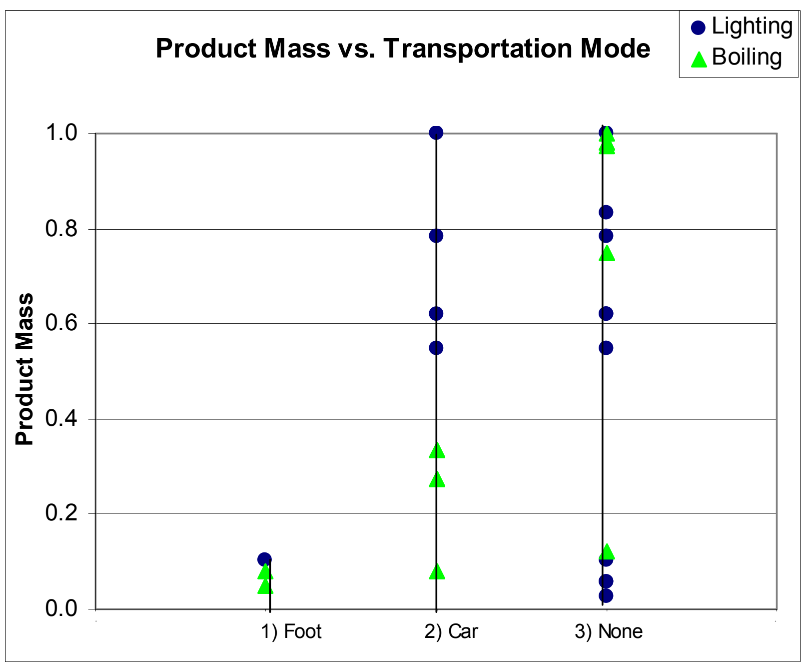


Figure 3.5: Product Mass vs. Transportation Mode

In contrast to the above graphs, for mobile lighting products Figure 3.6 does not show a clear relationship between product volume and storage mode. Boiling products are distinct between room storage (4 & 5) and smaller storage modes represented as 1-3. Figure 3.7 shows maximum operating cost decreasing as usage duty increases for both lighting and boiling products. This result is consistent with intuition that as usage context involves greater usage amounts, customers have a stronger preference for lower operating costs.

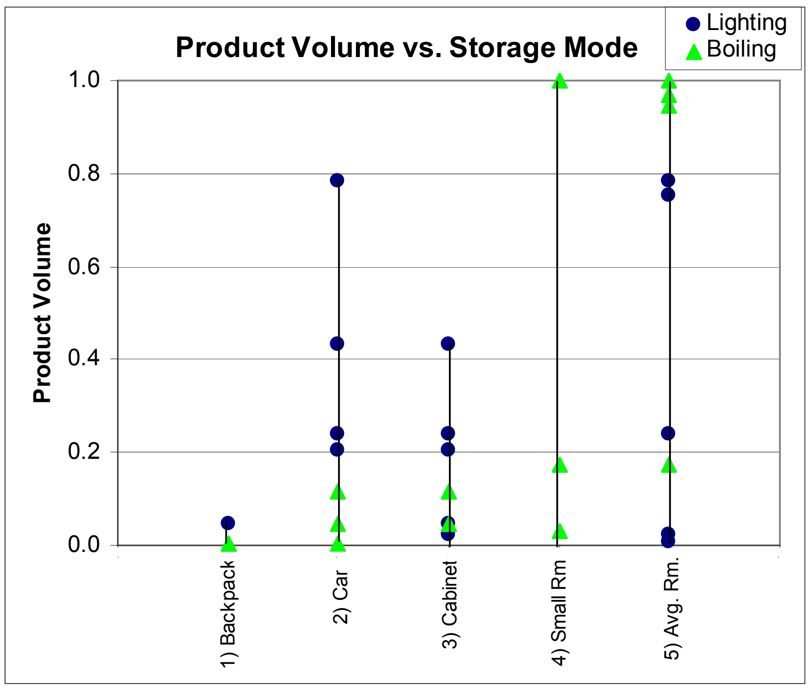


Figure 3.6: Product Volume vs. Storage Mode

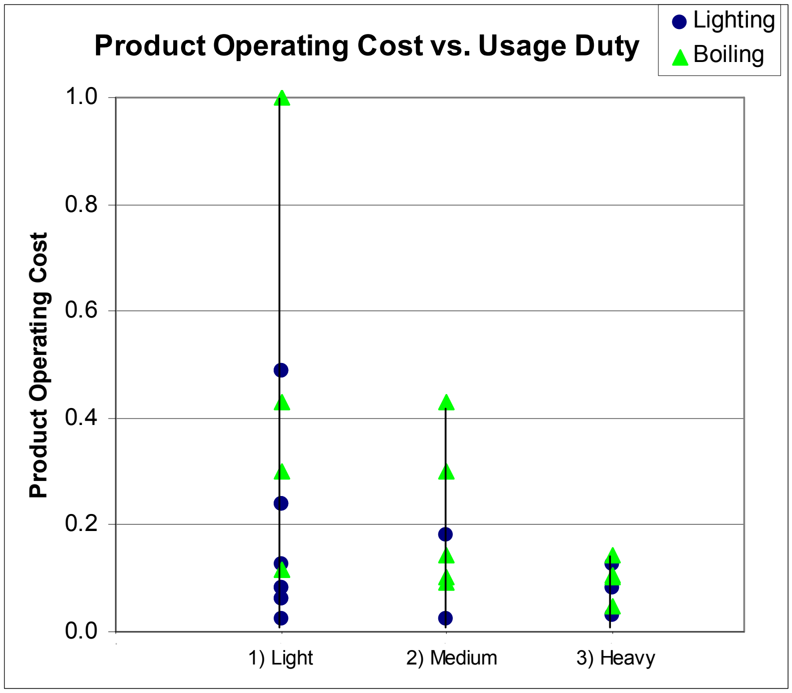


Figure 3.7: Product Operating Cost vs. Usage Duty

Figure 3.8 plots the ventilation required by products on the vertical axis against the ventilation available in various contexts. The X and Y scales are defined with a one-to-one correspondence, such that a product requiring a ventilation level of “2” is only safe in a context with an available ventilation rating of 2 or higher. Therefore, the lower right half of the graph is the “feasible space” in which available ventilation meets or exceeds product requirements. The graph shows that, for the scale intervals defined, the feasible space is fully populated. This result provides as a check, since customer preference survey data does not violate the feasible space. It also shows that products do not necessarily exploit all available ventilation, as may be seen with a battery lantern (requiring no ventilation) preferred for camping near a car. Similar graphs may be shown for energy availability and weather conditions.

In all of the data showing patterns, preferred products exhibited a range of attributes for each context factor value, up to a maximum value.

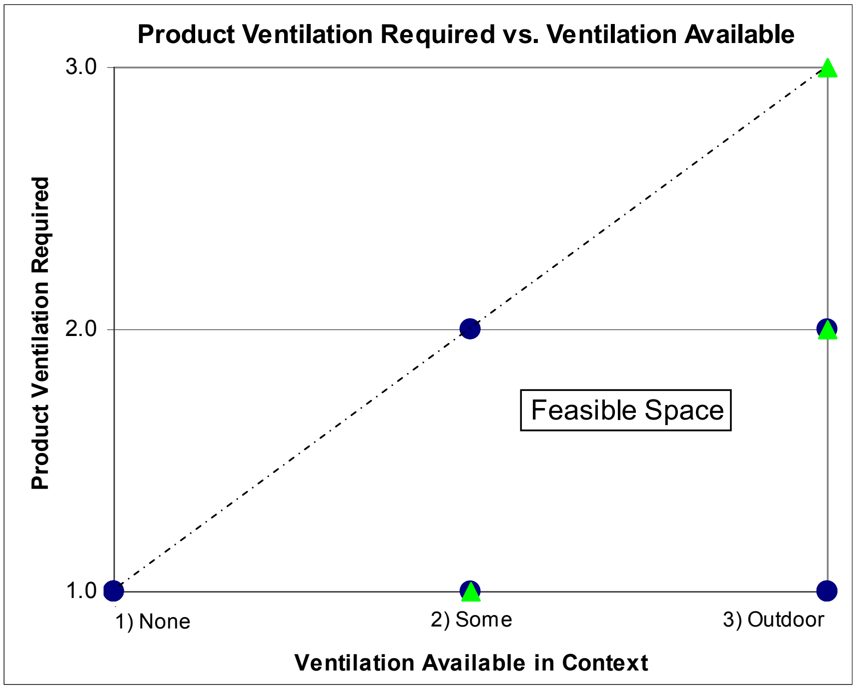


Figure 3.8: Product Ventilation Need vs. Available

Table 3.9 presents predictions of context factors driving customer preference for product attributes. Highlighted factors are those shown in this study to have strong relationships with maximum attribute values. (Note that storage is crossed in the table to signify that Figure 3.6 does not show a clear influence of storage mode upon product volume). The remaining product attributes are thought to be at least partially driven by customer factors, which are beyond the scope of this study. For example, "user time required" is likely correlated to convenience expectations, and "acceptable hazard" is likely correlated to safety expectations. All customers wish to minimize these "costs" of inconvenience and hazard, but the amount of other attributes they are willing to trade for them varies from person to person. Note that market factors are expected to have some influence on preferences for all product attributes, in the sense that customers desire Pareto optimality[21] in their product choice. The influence of market factors is controlled

[21] In a Pareto optimal product every attribute is the best that can be achieved in the available set without compromising another attribute (including cost).

in this study by limiting customer choice to the set of products presented. Testing the hypotheses contained in Table 3.9 is a topic for future work.

Table 3.9: Context Factors Hypothesized to Drive Customer Attribute Preferences

Lighting Metrics	Usage Context factors	Customer factors
Mass w/ fuel (g)	*transportation*	
Volume (cm^3)	*transportation*, ~~storage~~	
Fuel Op. Cost ($/hr)	*usage duty*	disposable income
Weather resistance	*location - outdoor/indoor*	
Ventilation required	*ventilation available*	
Brightness (fc)	application - lighting task	functional expectations
Run Time (hr)	application	convenience expectation
Equip. Cost ($)		disposable income
User Time (s/hr)		convenience expectation
Hazard [1-5]		skill, safety expectation

Boiling Metrics	Usage Context factors	Customer factors
Mass (Kg)	*transportation*	
Volume (L)	*transportation*, ~~storage~~	
Fuel Op. Cost ($/L)	*usage duty*	disposable income
Weather resistance	*location - outdoor/indoor*	
Ventilation required	*ventilation available*	
Boil Time $\pm$ 30 (s)		convenience expectation
Product Cost ($)		disposable income
Time to Start (s)		convenience expectation
Maintains Simmer		convenience expectation
Cooking Capacity	application - meal size	convenience expectation
Fire Safety	surrounding flammability	skill & caution
Burn Safety to User		skill, safety expectation
Stable	surface available	skill, safety expectation

3.4 Conclusions and Implications for Product Design

This empirical study of two product families shows that: (1) different context scenarios exist within the same functional family and even the same products, (2) the customers surveyed prefer different products for different context scenarios, and (3) clear relationships exist between context factors and attributes of the preferred products. These findings give strong evidence that product attribute preferences depend, in part, upon factors of the intended usage context scenario. This result affirms the importance of accounting for contextual factors in product design processes intended to realize products delivering customer satisfaction. Further, these findings establish a foundation for incorporating contextual information into the design process through data on context factors and scenarios for the products studied.

Chapter 4: Contextual Needs Assessment Methodology

This chapter presents a design method for contextual needs assessment. The method is modeled after traditional customer needs methodologies, and contains placeholders into which a variety of existing needs gathering and need aggregation techniques may be inserted. However, it extends beyond what any of these other methods offer. This method facilitates and directs the process of discovering, documenting, and applying contextual information throughout the design process. Table 3.1 presents key definitions for the chapter.

Table 4.1: Key Definitions

- *Product attribute(s)* – important product characteristics such as volume, mass, operating cost, and convenience (characteristics often included in product specifications or a customer requirements list).
- *Product [design] context* – the collection of factors influencing customer attribute preferences including: product usage context, customer context, and market context.
- *Context factor* – a single characteristic of a product's context. For example, "usage frequency" or "product surroundings."
- *[Context] factor value* – a single characteristic of a product's usage context.
  Example (quantitative): usage frequency = 3-5 times/day.
  Example (qualitative): product surroundings = rural village, or urban slum.
- *Context scenario* – a set of specific values for a set of context factors.

4.1 Types of Design Needs and Contextual Needs Assessment

Successful design requires an adequate understanding of the design need context, and attaining this adequate understanding is much more difficult for some design needs than others. Table 4.2 itemizes three indicators to consider when assessing the difficulty of needs assessment. Low values of any of these indicators (e.g. unfamiliarity, inaccessibility, and non-uniformity of the context) warn of a more difficult needs assessment task. This difficulty increases the importance of the methodology in this chapter and the advantages it offers.

The first indicator is the existing *familiarity* of the design team with the design context. This is the indicator referenced by the term "frontier design context" which defines a frontier context as one unfamiliar (outside of the experience and expertise) of the design team. For example, a design team is likely to be much more familiar with sharpening a pencil as compared to eating in zero gravity or using a surgical tool. A higher level of previous familiarity with the application, environment, and customer context leaves less work to be done to complete adequate contextual needs assessment. The second indicator, accessibility, is a measure of how feasible it is to increase familiarity with the design context through observation, experience, and communication. More difficulty in this area will decrease the amount of information that may be obtained within fixed resources. Although the term "frontier design context" explicitly refers only to a low level of familiarity, it is often coupled with a low level of accessibility. This limitation exists because the design team is less likely to be familiar with contexts that are not accessible to them. The third indicator, uniformity, is a measure of how much variation may be expected in the design need contexts. A low level of uniformity makes informal context accounting much more difficult, and calls for formally exploring and documenting this variability with the contextual needs assessment methods presented here. Table 4.2 presents questions to guide evaluation of each indicator of difficulty for contextual needs assessment.

Table 4.2: Assessing the Difficulty of Adequate Contextual Needs Assessment

	Familiarity	**Accessibility**	**Uniformity**
Application (What)	How familiar is the design team with the task to be performed?	How easily can the design team observe the task being performed?	How uniform are the tasks across customers?
Environment (Where)	How familiar is the design team with the usage environment?	How easily can the design team observe or experience the actual usage environment?	How uniform are the environments the product will be used in?
Customers (Who)	How familiar is the design team with customer characteristics and expectations?	How easily can the design team directly communicate with the customers?	How uniform are customer characteristics and expectations?

One additional indicator[22] of needs assessment difficulty which is not directly referenced above is the accessibility of existing products that already address a need and context similar to the design need and context. Analogous products are useful props for identifying customers, gathering needs, and gathering context. Significant departures from existing products may result in a customer base and usage contexts that are difficult to discover or predict.

The accessibility of design contexts may be mapped into a space with the dimensions of environment accessibility and customer accessibility, as shown in Table 4.3. Environment accessibility (horizontal) is a measure of how feasibly the design team may experience the environment in which the product will be used. Customer accessibility (vertical) is a measure of how feasibly the design team may interact in an unencumbered[23] way with the customers who will use the product. The map shows four quadrants, along with the position of the four case studies presented in Chapter 6. The PersonaWarmth design example is a personal warming device for university students in China. Although interviews were conducted with students who have expertise in this environment, access to the actual target customers and environment are both extremely limited, and so the design need falls in the upper-left quadrant. Shown in the upper-right quadrant, the UT assistive technology case study is a graduate course involving the

[22] Other difficulty factors are possible as well, such as design need complexity and variability with time.
[23] Examples of barriers include geography, language/cultural differences, and communication disability.

design of enabling devices for high school students with physical and mental disabilities. Although the design teams were able to experience the usage environment and interview experts (teachers), communication with the students who would use the devices was often extremely limited due to their impaired communication abilities. The controlled interview study, in which participants interview an experimenter posing as a villager in need of an improved cooking system, is placed in the lower-left quadrant since data was accessible solely through an interview with the simulated customer. Study participants had little or no experience with the environmental context. The UT Reverse Engineering example in the lower-right involves the reverse engineering of everyday products used in the U.S. The design teams were generally able to interview actual users of the products in the intended context. The case studies reported in the next chapter support the value of the contextual needs assessment method in all four quadrants, as well as indicating that the method is increasingly critical for the leftmost and upper-left quadrants.

Table 4.3: Frontier Contexts 2D Map with Case Study Examples Positioned

		Environment Accessibility	
		Low	**High**
Customer Accessibility	**Low**	PersonaWarmth Design	UT Assistive Technology
	High	Controlled Interviews	UT Reverse Engineering

Many design projects fall in the left or upper-left quadrants of Table 4.3. Table 4.4 itemizes a number of example design projects drawn in part from Publications 1, 2, and 4 (Green, et al., 2000; Green, et al., 2002; Green, et al., 2004b) and (2005b; 2005h). The problem of contextual needs assessment in the left quadrants is a challenge faced by organizations such as Engineers for a Sustainable World, Engineers without Borders, Engineering Ministries International, and other NGOs designing high human-impact solutions in frontier contexts.

Table 4.4: Examples of Frontier Design Projects

School and Course	Project Example	Type	"Who" Context	What & Where	Needs Assessment Used
UT Reverse Engr. (Undergraduate)	Portable pencil sharpener	Re-design	Familiar Accessible	Familiar Accessible	Interview end users in use environment
UT Assistive Tech. (Graduate)	Switch-activated ball thrower	Original design	Unfamiliar Accessible	Unfamiliar Accessible	Interview teachers (experts)
UT Capstone	Basic Utility Vehicle (2005b) sub-system	Re-design	Unfamiliar Access difficult	Unfamiliar Access difficult	Obtain guidelines and specs from staff (expert)
Calvin Capstone	Charity hospital in Nigeria	Site planning (A&E)	Unfamiliar Access difficult	Unfamiliar Access difficult	Team site visit; discuss w/ hospital planners (experts)
Dordt Capstone	Crop irrigation system for Honduras mountain community	Civil works design	Unfamiliar Access difficult	Unfamiliar Access difficult	Team site visit; discuss w/ NGO staff (experts)
Grove City Capstone	Modular, scalable solar power system for remote areas (Uganda)	Original design	Unfamiliar Access difficult	Unfamiliar Access difficult	Instructor site visit; discuss w/ NGO staff (expert)
Messiah Capstone	Water purification system for Guatemalan school	Original design	Unfamiliar Access difficult	Unfamiliar Access difficult	Team site visit; discuss w/ end users
LeTourneau Capstone	$100 above-knee prosthetic for rural Kenya (2005h)	Original design	Unfamiliar Access difficult	Unfamiliar Access difficult	Team leader site visit; discuss w/ staff (experts); interview & observe end users

4.2 CONTEXTUAL NEEDS ASSESSMENT

The generalized procedure for contextual needs assessment is shown in Figure 4.1. The method accommodates traditional customer needs methodologies, but extends significantly beyond these by formally incorporating contextual information. Although some iteration is important to the method, it remains a predominately sequential process.

1. Identify relevant contextual factors
2. Generate list of contextual questions to be answered
3. Gather customer needs and factor values
   - 3.1. Gather customer needs
   - 3.2. Gather factor values
4. Aggregate customer needs into weighted list
5. Aggregate factor values into context scenario(s)

Figure 4.1: Contextual Needs Assessment Methodology

Step (1) calls for identification of as many of the relevant contextual factors as possible. This is no small task, so multiple supporting techniques are provided for this step. Step (2) is more straightforward to accomplish, and involved translating each factor identified in step one into the form of one or more questions. For example, the factor of "energy supply" becomes "What energy sources are available for use?" and "What are the costs of available energy sources?" Step (3.1) refers to any of the established needs elicitation techniques such as interviews, focus groups, or in some cases questionnaires (Otto and Wood, 2001; Urban and Hauser, 1993). Although this is considerably complicated in cases with no accessibility to a comparable physical product and/or a customer, these techniques may be modified to interview customers with their imagined products, or to seek secondary sources of customer information. Step (3.2) involves answering the questions generated in Step 2 through customer interviews (ideally, appended to the end of each customer needs interview) or research. It is possible that the factor values gathered in Step 3.2 may lead to identification of additional customer needs. Step (4) refers to standard needs aggregation techniques such as affinity analysis. Step (5) involves identifying the different factor values to be addressed by one or more products, and is in essence a market segmentation decision based on context. The following sections detail each of these five steps, and Appendix A contains supporting templates.

4.2.1 Identify Relevant Contextual Factors

As discussed in previous chapters, understanding and accounting for design context factors is critical to effectively satisfying a design need. It is useful to begin contextual needs assessment by forming a list of the context factors likely to be relevant to satisfying the design need. The list should include factors covering the application, environment, and customer contexts. However, it is neither desirable nor feasible to explicitly account for all contextual information related to a product's design. The body of contextual information is large, and not all contextual information is of high relevance. Therefore, judgment is required to identify *relevant* contextual factors. The key is to identify factors that have a *probable importance to satisfying the design need*.

With a lantern design, for example, the fact that the ground is red rather than brown does not meet this criterion. On the other hand, the fact that it rains once a day, rather than once a year, may be relevant, and the fact that batteries are not readily available is clearly relevant. As another example, for a mobile pencil sharpener the usage altitude does not meet the criteria of probable importance, the safety expectations of the user may, and the type and characteristics of pencils used are clearly important. Secondly, contextual factors should be listed with an *appropriate level of detail*. The fact that pencils to be sharpened are a combination of graphite and wood is of probable importance to sharpener design, but these and other characteristics might be captured more generally, for example, by the fact that #2 pencils will be sharpened.

Table 4.5 itemizes techniques for identification of contextual factors which may be relevant to a product design need. The techniques are roughly ordered from the least to most resource intensive. The last technique in particular can be very resource intensive if carried out to the extent detailed in Chapter 4. The following sections discuss each technique in more detail.

Table 4.5: Context Factor Identification Techniques

• Use context factor checklists, such as the template provided (App. A)
• Translate customer needs and product reviews into factors
• Translate black box model into factors
• Translate activity diagram into factors
• Translate available data (e.g. physical characteristics) and experiences
• Identify functional family members, noting attribute distinctions

Use context factor checklists, such as the template provided (App. A).

As discussed in Chapter 2, various authors have proposed the use of checklists and taxonomies to improve the effectiveness of requirements gathering and application. Although these lists are aimed at requirements identification, items which touch on contextual issues may also prompt identification of contextual factors for the purpose of contextual needs assessment. Table 4.5 shows a partial checklist (the full version is in Appendix A) for the purpose of identifying contextual factors common to consumer products. The checklist includes generalized elicitation questions designed for use in step 2 of the contextual needs assessment methodology (Figure 4.1). This contextual checklist is drawn from multiple sources: results of an empirical product study (Chapter 4), design literature references to contextual factors (many indirect), a small set of customer interviews conducted to elicit contextual factors, and results from application of the checklist in graduate and undergraduate classes (Green, et al., 2006).

Table 4.6: Partial Context Factor Checklist

#	Context Factor	Question Prompts v2.0
HOW: Usage Application		
a0	task (application, function)	What specific purpose will product be used for? How will the product be used?
a1	task frequency	How often will product be used?
a2	task duration	How long will product be used each time?
	. . .	
WHERE: Usage Environment		
e0	surroundings	Where and in what type of surroundings will product be used? What characteristics of the surroundings affect what the product must be like?
e1	weather/ climate	What weather/climate will product be exposed to?
e2	environment ruggedness	Will product be exposed to any unusual substances or conditions?
	. . .	
WHO: Customer Characteristics		
c0	user	Who will use the product? What user characteristics affect what the product must be like?
c1	user skills & education	How skilled/experienced is the user with this task? What is the user's education level?
c2	physical ability	Does the user have any physical conditions that may cause difficulty performing the task? (strength, control, range-of-motion, vision).
c3	user tolerance for complexity	What is the most complex product the user is comfortable using? Must this product be less complex? How long is user willing to spend learning the product?
	. . .	

Translate customer needs and product reviews into factors

Product reviews and consumer advisory information can be used to identify customer needs, which in turn may be used to identify relevant contextual factors. For example, the need for a product to be "portable" may lead to identification of the usage context factor of "transportation mode," because how the product is transported will have a significant effect on what product attributes will result in customer perceptions that the product is satisfactorily portable. This is even more effective after customer needs interviews have been conducted and a more thorough and accurate needs list is available. This requires executing the procedure in Figure 4.1 as an iterative process in which each interview potentially leads to identification of additional contextual factors, which are in turn used as prompts in the next interview. An example of translating customer needs into context factors is given in Table 4.7. The need of "compact," for example, indicates the factors of "storage volume available" and "transportation mode" should be determined, since these shed light on what product attributes (what volume and mass, for example) will satisfy the need of compactness.

Table 4.7: Translation of Customer Needs into Context Factors

Customer Needs		**Possible Context Factors**
Cooks well		
Boils quickly		Elevation, Ambient temperature
Maintains simmer		Operating time expectations
Portable		
Compact		Storage volume available, Transportation mode
Lightweight		Transportation mode, User strength
Low cost		
Low product cost		User purchase cost expectations
Low fuel op. cost		User operating cost expectations
Reliable		
Tolerates weather		Weather conditions, Durability expectations
Durable		Usage roughness
Easy to use		
Easy to start		User complexity expectations
Easy to clean		Maintenance time expectations
Large capacity		Application task
Intuitive Controls		User complexity tolerance
Safe		
Low fire hazard		Flammability of surroundings
Low burn hazard		User skill, User safety expectations
Stable to cook on		Available surfaces

Translate black box model into factors

A black box model graphically represents the energy, material, and information (signal) flows entering and exiting a product. Because these flows signify interaction with surroundings, they may cue the identification of important contextual factors, particularly the environment (where) and human interface (who) aspects of the context. The success of this approach relies upon the ability of the designer to translate flows into contextual factors. As future work, a classification may be developed of contextual factors commonly associated with various types of flows in order to facilitate rapid and thorough completion of this technique. An example is shown in Figure 4.2, Table 4.8, Table 4.9, and Table 4.10.

Figure 4.2: Battery Pencil Sharpener[24]

Table 4.8: Battery Pencil Sharpener Black Box

Flow Type	Input Flows		Output Flows
Energy	• Electricity • Human energy • Gravity		• Energy loss • Noise • Material deformation
Material	• Pencil • Battery • Hand &/or surface	**Sharpen Pencils** **-or-** **Separate Material**	• Pencil • Battery • Hand &/or surface • Shavings
Information	• On/off		• Done or on/off • Full • Sharpening in progress

[24] http://www.bostitch.com/default.asp?type=category&category=bos_pencil_sharpener

Table 4.9: Translation of Black Box Flows into Context Factors – Input Flows

	Input Flows	Possible Context Factors
Energy	• EE • Human energy • Gravity	• Cost and availability of energy sources • User physical abilities, Pencil type/strength • Possible high or low g environments?
Material	• Pencil • Batteries • Hand &/or surface	• Pencil: size, hardness, coatings • Battery: cost, availability, size & mass • User physical abilities, User skill, Surfaces
Information	• On/off	• User expectation of complexity & ease-of-use

Table 4.10: Translation of Black Box Flows into Context Factors - Output Flows

	Output Flows	Possible Context Factors
Energy	• Energy loss • Noise • Material deformation	• Cost of energy sources, Ambient temperature • Acceptable noise • Pencil material characteristics
Material	• Pencil • Battery • Hand &/or surface • Shavings	• Pencil: size, hardness, coatings • Battery: cost, availability, size & mass • User physical abilities, User skill, Surfaces • Disposal receptacles available
Information	• Done or on/off • Full • Sharpening in progress	• User expectation of complexity & ease-of-use • User visual ability • User visual and hearing ability

Translate activity diagram into factors

An activity (or process) diagram graphically represents the sequence of steps in the product life cycle from purchase through retirement. Because a well developed activity diagram itemizes each type of usage a product may experience, it can be used to cue identification of context factors of the usage application. Additionally, reference to the diagram can prevent overlooking non-obvious steps when generating a list of environmental and customer context factors. An example is shown below in Figure 4.3 and Table 4.11. For example, the table lists item 1b (flow chain #1, second activity box) "Hold Pencil (sharpen)" along with possible context factors related to the sharpening activity. Holding the pencil depends upon the users gross and fine motor control as well as how difficult the pencil is to grip, thus indicating the designer may need to know the context factors of "user grip & strength" as well as the "pencil slickness."

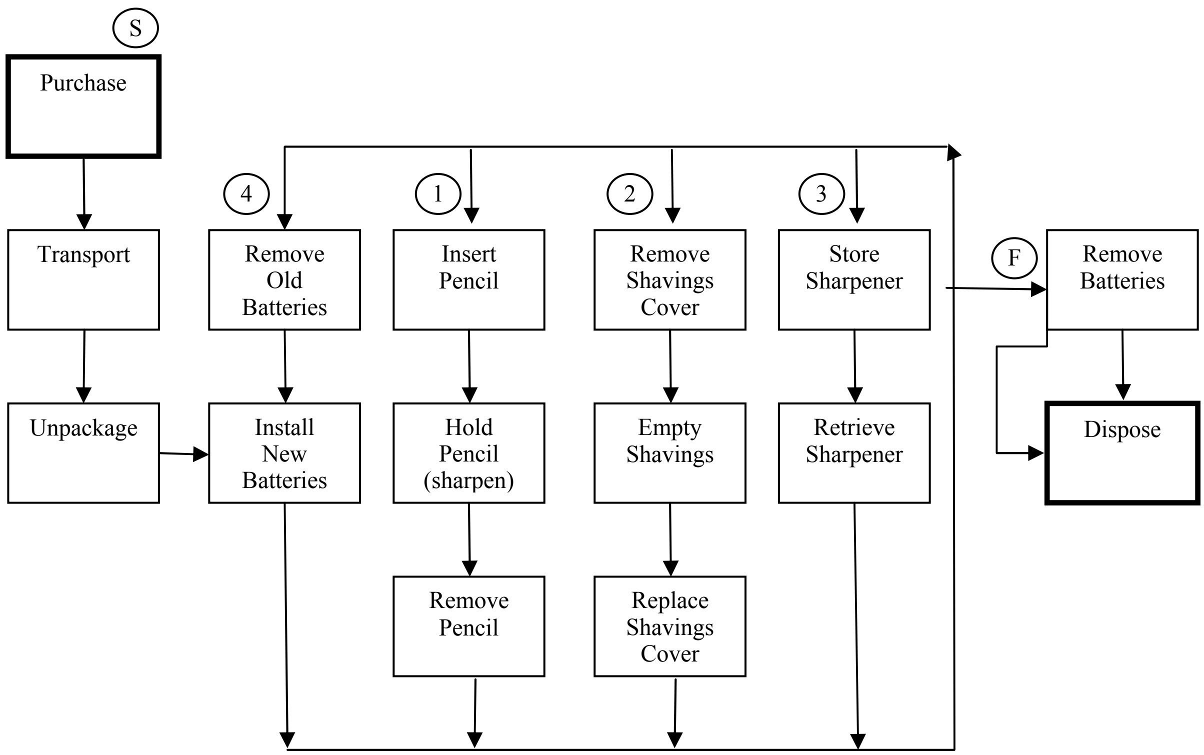


Figure 4.3: Battery Pencil Sharpener Activity Diagram[25]

[25] S = starting flow chain, F = finishing flow chain, 1 = flow chain #1, 2 = flow chain #2, etc.

Table 4.11: Translation of Activity Diagram into Context Factors

Item	Item Description	Possible Context Factors
1a	Insert Pencil	Pencil size, hardness, coatings; User abilities; User simultaneous tasks (free hands?)
1b	Hold Pencil (sharpen)	User grip & strength, Pencil slickness
1c	Remove Pencil	
2a	Remove Shavings Cover	User abilities, Clean-ness of surfaces
2b	Empty Shavings	User abilities, Proximity of disposal receptacle, Clean-ness of surfaces
2c	Replace Shavings Cover	User abilities
3a	Store Sharpener	Storage mode, Storage space available, Humidity, Extraneous substances
3b	Retrieve Sharpener	Surrounding aesthetics (easy to find?)
4a	Remove Old Batteries	User fine motor coordination, User tolerance for complexity, Proximity of disposal receptacle
4b	Install New Batteries	User fine motor coordination, User tolerance for complexity, Cost and availability of energy supply, User operation cost expectations
Sa	Purchase	User first cost expectations, surrounding aesthetics
Sb	Transport	Transportation mode, Transportation frequency
Sc	Unpackage	
Fa	[same as 4a]	
Fb	Dispose	Disposal/recycling facilities.

Translate available data (e.g. physical characteristics) and experiences into factors

One type of data which may be translated into factors is human characteristics data. For example, the Cambridge inclusive design website[26] (2005g) provides data on percentages of the population with varying levels of physical and cognitive abilities. Lists such as these can serve to prompt different contextual factors to consider. The Cambridge list includes: Locomotion, Reach & Stretch, Dexterity, Vision, Hearing, Communication, and Intellectual Functioning. In this instance the data also provides a useful rating scale for each factor, providing ready-made context factor values. For example the vision scale includes values of: “not applicable,” “can’t recognize a friend nearby,” “can’t recognize a friend across the room,” “full vision capability,” and additional points in-between. This is an example of using a semantic scale to elicit the context factor of user visual ability. The use of a semantic scale is also discussed by Otto and Wood (2001) in Chapter 4, p. 129 for the elicitation of customer expectations of product "feel."

Causes of past product failures is another valuable type of data to aid in identifying relevant contextual factors. Table 1.3 shows historical reasons for the failure of improved village cooking systems in the left column, adapted from Barnes et al. (2002). Each cause of failure is accompanied in the right column by a context elicitation question which is likely to avert repeating the failure if it is adequately answered and accounted for in the future design of village cooking systems. A variety of data sources including the experiences of team members and experts may be translated into relevant contextual factors in a similar way as the two examples given in this section.

Table 4.12: Historical Reasons for Failure of Improved Village Cooking Systems

Causes of Failure	**Contextual Information Required for Success**
The new cooking system does not:	
… account for actual conditions of use and is therefore uneconomical and inconvenient.	What are actual conditions of use?
… resemble the traditional cooking system.	What is the traditional cooking system?
… accommodate large pieces of wood.	What size and types of fuel are available?
… improve a fuel supply problem.	What size and types of fuel are available?
… improve a smoke problem due to low-ventilation.	What is location and ventilation available?
… accommodate design for manufacture needs of local artisans.	What are local manufacturing practices?
… use locally available materials (increases cost).	What are locally available materials?
… utilize mass-production of critical components.	What local mass-production or import capabilities are available?

[26] http://www.eng.cam.ac.uk/inclusivedesign/index.php?section=data&page=exclusion_calc

Identify functional family members, noting attribute distinctions

Contextual factors may be identified by finding products which fall in the same functional family as the design need, but exhibit different attributes in part due to different contextual factors. The attribute differences observed across products may then be investigated to determine potential contextual factors causing the differences. This approach is extremely effective, but equally resource intensive. A detailed explanation and example of this technique is given in Chapter 4, and summarized in Figure 4.1. Depending on the uncertainty of the design context and available resources, this factor identification technique can easily be scaled up or down by varying the number of products and the number of interviews.

4.2.2 Generate List of Contextual Questions to Be Answered

This step involves converting each context factor identified in step one into the form of one or more questions. The generalized context questions template provided in Appendix A lists context factors along with generalized context questions as a starting point. The purpose of these elicitation questions is to guide the design team in discovering the contextual information needed for the design process. Usually these questions will be asked directly in multiple interviews with customers or experts; however, some or all of the questions may best be answered by the team through research. Regardless of how the information is gathered, the questions serve to direct the gathering process and indicate when the needed information has been found. Table 4.13 shows an example of converting context factors into elicitation questions for use in an interview (based on the template in Appendix A and sampled in Table 4.6).

Table 4.13: Conversion of Context Factors into Elicitation Questions

Context Factor	Elicitation Questions (Customized from Template)
HOW: Usage Application	
Task (application, function)	How will sharpener be used? What will the sharpened pencils be used for?
Task frequency	How often will sharpener be used?
Task duration	How long will sharpener be used each time?
. . .	
WHERE: Usage Environment	
Surroundings	What type of surroundings will sharpener be used in?
Weather / climate	What weather/climate will sharpener be exposed to?
Energy cost and availability	What is the cost and availability of various batteries? [Note: ask customer perceptions, but research as well.]
. . .	
WHO: Customer Characteristics	
User	Who will use the sharpener?
User skills and education	How familiar is the user with sharpening pencils? What is the user's education level or age?
Physical: strength, control, range-of-motion	Does the user have any physical conditions that may interfere with sharpening?
. . .	

4.2.3 Gather Customer Needs and Factor Values

Gather Customer Needs

Well established customer needs gathering techniques such as those discussed in Chapter 2 and available in many needs gathering references (Bayus, 2006) will work well for this step within the contextual needs assessment method. One of the most effective techniques for rapidly gathering customer information for a vague product design need is to conduct one-on-one customer interviews (Otto and Wood, 2001). If possible, these interviews should include actively observing the customer using a similar product in the actual design context. When this is not possible, adaptations may be made such as verbally asking the customer how the design need is currently satisfied, and what is liked and disliked about the current solution. The “voice of the customer” should be recorded throughout the interview, and translated into positively phrased, form-independent customer need statements.

Gather Factor Values

Gathering context factor values (often qualitative) is simply a matter of obtaining answers to the context elicitation questions generated in step 2. The possible ways to gather answers to the factor questions closely mirror customer needs gathering techniques. For most contextual questions the most effective technique is to perform multiple one-on-one interviews as described in the previous paragraph, and conclude the needs interview by running through the questions list and obtaining answers in the "voice of the customer" to any questions that remain unanswered. The questions do not necessarily need to be asked if the answers have already become obvious during the needs interview. It is important to complete the freeform interview first before asking the questions in the list, in order to avoid biasing the customer in such a way that needs are not accurately elicited. The template in Appendix A provides a format for recording this information from multiple interviews. Note that due to the iterative nature of needs assessment, the growing list of customer needs may be used to generate additional context factors as the process progresses. Table 4.14 presents an example of recording context factor values (shown in the four rightmost columns) for the battery pencil sharpener example. For example, the values determined for the second context factor of "task frequency" are "once every few weeks" and "5-10 time/day" for interviews #1 and #2 respectively.

Table 4.14: Gathering Factor Values (Pencil Sharpener Example)

Context Factor	**Elicitation Questions (Customized)**	**Interview #1 - Notes**	**Interview #2 - Notes**	**. . .**	**#n**
HOW: Usage Application					
Task (application, function)	How will sharpener be used? What will the sharpened pencils be used for?	Sharpen pencils at home	Sharpen pencils while teaching at school		
Task frequency	How often will sharpener be used?	Home (once every few weeks)	5-10 times a day		
Task duration	How long will sharpener be used each time?	Get it sharp (a few seconds)	Get it sharp (a few seconds)		
. . .					
WHERE: Usage Environment					
Surroundings	What type of surroundings will sharpener be used in?	Desk in bedroom	Elementary teacher's desk Note: only one brick wall.		
Weather / climate	What weather/climate will sharpener be exposed to?	Indoor, climate controlled	Indoor, climate controlled no ac in summer		
Energy cost and availability	What is the cost and availability of various batteries? [Note: ask, but research too.]	Easy (HEB); reasonable cost	Easy (HEB); reasonable cost		
. . .					
WHO: Customer Characteristics					
User	Who will use the sharpener?	Me - 20 year old female UT student	Teacher + a variety of elementary kids		
User skills and education	How familiar is the user with sharpening pencils? What is the user's education level or age?	Very familiar w/ electric sharpeners; college education	Some familiar, some not; elementary education		
Physical: strength, control, range-of-motion	Does the user have any physical conditions that may interfere with sharpening?	No	No		
. . .					

4.2.4 Aggregate Customer Needs into Weighted List

The same traditional customer needs aggregation techniques discussed in many references will work well within this contextual needs assessment method. See for example Urban and Hauser (1993). Otto and Wood (2001) propose either the use of an affinity diagram by the design team, or a customer-sort method which results in a co-occurrence matrix allowing hierarchical clustering of needs. Importance weightings should be assigned to each need. Two techniques for deriving these weightings are from interview data or a follow-up questionnaire asking customers to rate need importance (Otto and Wood, 2001).

4.2.5 Aggregate Factor Values into Context Scenario(s)

Aggregating context factor values (often qualitative) into a single scenario involves summarizing the range of responses across multiple interviews for a given factor. The summary values of each factor can be expressed as a single value (fuel supply = \$1/L), a range (fuel supply = \$1-2/L), a list (rural = \$1/L, city = \$2/L), or an inequality (fuel supply ≥ \$1/L). Each of these record types may also be qualitative (e.g. surroundings = bedroom, surroundings = small to medium bedrooms, surroundings = bedroom, classroom. A scenario is composed of a list of summary values for all factors. The design team may choose to place most or all of the range of values found into a single scenario to be addressed by one product. On the other hand, in many cases it is useful to identify distinct scenarios (as illustrated in Chapter 3) and address only a limited number of the scenarios with a single product. This decision is a part of market segmentation based on contextual information. Table 4.15 shows an example of forming a single scenario from the interview data. For example, the second context factor of task frequency received responses that ranged from light to heavy usage duty. This is captured in the boxed column as “from 2/mo to 200/mo.” Such a large range may indicate a multi-product offering is more appropriate if achieving the higher usage frequency is found to significantly compromise the cost or other product attributes.

Table 4.15: Combining Factor Values into Context Scenario (Pencil Sharpener Example)

Context Factor	Elicitation Questions	Combined Context Scenario	Interview #1 - Notes	Interview #2 - Notes
HOW: Usage Application				
Task (application, function)	How will sharpener be used? What will sharpened pencils be used for?	Sharpen pencils at home and at school	Sharpen pencils at home	Sharpen pencils while teaching at school
Task frequency	How often will sharpener be used?	From 2/mo to 200/mo	Home (once every few weeks)	5-10 times a day
Task duration	How long will sharpener be used each time?	Get it sharp (a few seconds)	Get it sharp (a few seconds)	Get it sharp (a few seconds)
. . .				
WHERE: Usage Environment				
Surroundings	What type of surroundings will sharpener be used in?	Desk in bedroom; elementary teacher's desk (lack of mounting walls)	Desk in bedroom	Elementary teacher's desk Note: only one brick wall.
Weather / climate	What weather/climate will sharpener be exposed to?	Indoor, climate controlled, but possibly no AC in summer	Indoor, climate controlled	Indoor, climate controlled no AC in summer
Energy cost and availability	What is the cost and availability of various batteries? [Note: ask, but research too.]	Easy (HEB); reasonable cost	Easy (HEB); reasonable cost	Easy (HEB); reasonable cost
. . .				
WHO: Customer Characteristics				
User	Who will use the sharpener?	College students, elementary teachers, elementary students	Me - 20 year old female UT student	Teacher + a variety of elementary kids
User skills and education	How familiar is the user with sharpening pencils? What is the user's education level or age?	Mixed familiarity; range from 2nd grade to college+	Very familiar w/ electric sharpeners; college education	Some familiar, some not; elementary education
Physical: strength, control, range-of-motion	Does the user have any physical conditions that may interfere with sharpening?	No, not normally. Some students might, but teacher can assist them.	No	No – not usually.

4.3 CONCLUSIONS

The methodology detailed above and explored through case studies in the Chapter 6 facilitates and directs the process of discovering, documenting, and applying contextual information. The method is easily adaptable to a variety of design needs, as discussed in the first section. The straightforward methodology provides valuable structure and insight for organizing and driving the assessment process, and the templates in Appendix A place the power of contextual assessment in the hands of even novice engineers who find themselves designing outside of their experience and expertise.

An advanced technique based on hierarchical clustering is presented in the following chapter that provides additional guidance in grouping context factors, context factor value scales, and context scenarios. Although this advanced technique is not necessary to achieve significant results with the methodology, it increases the formality and repeatability of these groupings.

Chapter 5: Refining Context Assessment with Hierarchical Clustering

This chapter presents an advanced extension to the contextual needs assessment methodology presented in Chapter 4. This extended methodology, *context scenario hierarchical clustering*, provides additional guidance in forming context scenarios from interview data and identifying meaningful levels of distinction among context factor values. The methodology increases the formality and repeatability of scenario formation through the application of a context factor similarity measure. This guides the designer in grouping an appropriate breadth of context variation into a scenario suitable to address with a single product, or multiple scenarios corresponding to a multiple product offering. Although the direct result is a scenario grouping, an even more valuable outcome of this chapter may be the increased insight into the nature of how context influences design. Table 5.1 presents several key definitions for the chapter.

Table 5.1: Key Definitions

- *Product attribute(s)* – important product characteristics such as volume, mass, operating cost, and convenience (characteristics often included in product specifications or a customer requirements list).
- *Context factor* – a single characteristic of a product's context. For example, "usage frequency" or "product surroundings."
- *[Context] factor value* – the value of a single characteristic of a product's context.
  Example (quantitative): usage frequency = 3-5 times/day.
  Example (qualitative): product surroundings = rural village, or urban slum.
- *Context scenario* – a set of specific values for a set of context factors.
- *Hierarchical clustering* – forming hierarchical groupings such that objects within a group have greater average similarity to each other than to objects outside the group.
- *Dendrogram* – a branching tree-like diagram illustrating hierarchical relationships among a set of objects; e.g. a binary tree displaying hierarchical clustering results.

Figure 5.1 outlines the methodology for context scenario hierarchical clustering. Step 1 is to form a needs-attributes relationship matrix (or table) similar to that used in a House of Quality. Step 2 is to form a factors-needs relationship matrix analogous to Step one, but instead showing the relationship of context factors to customer needs. Step 3 is to translate the matrices from the first two steps into a table format and add the factor values from the contextual interview data (obtained through the methodology of Chapter 4). Step 4 is to establish the similarities among all factor values on a scale of 0% to 100%. Step 5 is to calculate the similarity among complete scenarios with a weighted sum of individual factor similarities. Step 6 is to assess the results through hierarchical clustering, often visualized as a dendrogram. The following six sections present each of the six steps in the method.

1. Form Needs-Attributes Relationship "Matrix"
2. Form Factors-Needs Relationship Matrix
3. Form Factors-Needs-Attributes Table with Factor Values
4. Define and Rate Similarities Among Factor Values
5. Calculate Weighted Similarity Among Scenarios
6. Cluster Scenarios by Similarity

Figure 5.1: Methodology for Context Scenario Hierarchical Clustering

5.2 FORM NEEDS-ATTRIBUTES RELATIONSHIP "MATRIX"

5.2.1 Form Weighted Customer Needs List

Completing the first step of the clustering methodology requires a weighted customer needs list. The methodology in Chapter 4 includes formation of such a list using any of the approaches outlined in the mainstream design texts. Although the customer needs methods from these texts are similar to each other, a precise definition of the meaning of customer need weighting is important for accurate implementation of the methodology in this chapter, so more detail is given here on the meaning of customer need weighting. Both quantitative and qualitative customer need weighting rubrics are given in Table 5.2. The *customer need weight* is defined here as the degree of importance of achieving a minimum threshold of customer satisfaction for the need. Note that this definition is based on satisfaction levels rather than attribute levels. This is a subtle but important distinction, because the relationship of satisfaction to attribute levels often changes with changing context factor values. Therefore, an increased need weight does not mean that satisfying the need requires different product attributes than if the same need were weighted less heavily. An increased weight is used here to indicate an increased importance of achieving satisfaction, not increased performance (Table 5.2.)

Table 5.2: Customer Need Weighting Rubric

Quantitative Weight	**Qualitative Weight**	**Weighting Interpretation**
9	Must	Achieve need satisfaction … for feasibility (non-negotiable)
3	Should	Achieve need satisfaction … as far as possible
1	Nice	Achieve need satisfaction … if "cost" is low

Since the definition of customer need weights depends upon a satisfaction level threshold, it is important to quantify satisfaction levels. Two possible rubrics for quantifying satisfaction levels are shown in Table 5.3. These rubrics may be used to rate the level of customer satisfaction resulting from how well a product attribute fulfills a customer need. Figure 5.2 shows Kano satisfaction curves illustrating several different types of relationships that may exist between attribute levels (horizontal axis) and satisfaction levels (vertical axis). These attribute-satisfaction relationships are illustrated and discussed in more detail in Section 1.4 of Chapter 1.

Table 5.3: Two Customer Satisfaction Rubrics

Coding	**Satisfaction Scale #1**	**Satisfaction Scale #2**
5	Very satisfied (delighted)	Greatly above expectations
4	More than satisfied	Above expectations
3	Satisfied	Meets expectations
2	Less than satisfied	Below expectations
1	Very dissatisfied (disgusted)	Greatly below expectations

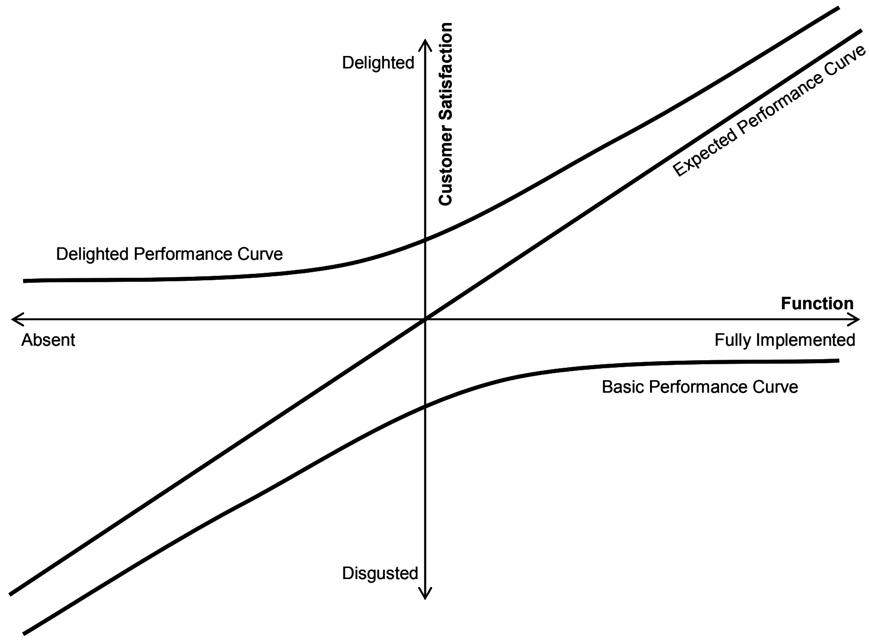


Figure 5.2: Kano Satisfaction Curves

Table 5.4 summarizes the suggested satisfaction level thresholds for various satisfaction curve types. For customer needs characterized by "delighted" satisfaction curves, the need weighting refers to the importance of achieving a level of "more than satisfied (4)." For customer needs characterized by "linear (expected)" and "basic" satisfaction curves, the weighting refers to the importance of achieving a satisfaction level of "satisfied (3)." Other need types not following one of the traditional Kano curves (a hill-shaped satisfaction curve, for example) also follow this second interpretation. In some cases the need weighting is also an indicator of the value of increasing need fulfillment beyond the threshold levels given here, but this is not always accurate (as can be seen with the "basic" Kano curve type, for example, which never exceeds the threshold).

Table 5.4: Satisfaction Level Thresholds Defined for Various Satisfaction Curves

Need Satisfaction Curve Type	**Meaning of Need "Satisfaction"**
Kano – delighted	(4) more than satisfied
Kano – linear (expected)	(3) satisfied
Kano – basic	(3) satisfied
Other curves	(3) satisfied

The preceding definitions allow the precise interpretation of the sample customer needs list given in Table 5.5, derived from interview data for a personal hand warming device. The first row indicates that the design team *should achieve as far as possible* (Table 5.2) product attributes that satisfy the customer need for an "un-encumbered grip" to a level of "(3) satisfied" (Table 5.4). The second row indicates the design team *must achieve for feasibility* product attributes that satisfy the customer need for "heat long-lasting" to a level of "(3) satisfied." Clearly, how "long lasting" the product's heat must be in order to achieve satisfaction will depend on contextual factors such as for what duration the product will be used.

Table 5.5: Sample Weighted Customer Needs (Hand Warmer)

Weight	**Customer Need**
3	Un-encumbered grip
9	Heat long-lasting
3	Heat controllable
9	Heat hand adequately
3	Durable
9	Portable
9	Safe - low risk
	. . .

5.2.2 Identify Attributes for the Relationship "Matrix"

Completing the first step of the clustering methodology (forming the needs-attributes relationship "matrix") requires identifying the product attributes which capture the level of fulfillment of each customer need, as illustrated in Table 5.6 for a personal hand warming device. This step is similar to the well-known relationship matrix in the House of Quality created as part of Quality Function Deployment. (A tabular format is used below rather than the more traditional matrix, since few attributes are re-used for multiple needs and equal relationship weighting is assumed). The mainstream design texts prescribe very similar approaches, and the approach here is most similar to the guidelines of Ulrich and Eppinger (2004).

Attribute metrics are chosen by asking the question, "What measurable quantity directly explains the fulfillment (satisfaction level) of the customer need in question?" For example, the second need of "heat long-lasting" is measurable by "heat duration" in hours. If the hours of "heat duration" are greater then need fulfillment is higher, and conversely if "heat duration" is lower then need fulfillment is lower. Customer satisfaction with the "heat long lasting" need being fulfilled is a function of the "heat duration" attribute. Measuring the fulfillment of some needs may require more than one metric; for example perceptions of how "portable" a product is are closely related to both "mass" and "volume." When no physical metric is suitable, a subjective (yet quantitative) rating scale may be the most suitable, such as rating "styling" on a scale of 1-3 or 1-5, depending on how many points are meaningfully distinguishable.

Table 5.6: Sample Customer Needs and Attribute Metrics (Hand Warmer)

Need Weight	**Customer Need**	**Attribute Metrics**	
3	Un-encumbered grip	Encumberment (%)	
9	Heat long-lasting	Heat duration (hr)	
3	Heat controllable	On/Off [Y/N]	
9	Heat hand adequately	Net hand heat loss reduction (W)	
3	Durable	Allowable drop height (m)	MTBF (hr)
9	Portable	Mass (kg)	Volume (L)
9	Safe - low risk	Fire safety [1-3]	Spill safety [1-3]

5.3 Form Factors-Needs Relationship Matrix

The second step of the clustering methodology is to form the factors-needs relationship matrix, analogous to the matrix from Step one. Table 5.7 shows a sample portion of the context questions template with interview data[27] for a personal hand warmer product for faculty and students at Chinese universities. Table 5.8 shows a factors-needs relationship matrix portion showing the relationships among the customer needs from Table 5.6 and the factors in Table 5.7. Context factors are associated with each customer need by answering the question, "What context factors significantly influence customer satisfaction with the attributes measuring the customer need in question?" Context factors directly influencing the attribute satisfaction relationship are indicated with a "1."

For example, a "1" marks the intersection of the need for "heat long lasting" (measured in hours of heating) with the context factor of "task duration" ("How long will warmer be used each time?") This indicates that task duration significantly influences customer expectations of the hours of heating attribute (customers will want heating to last the duration of the task.) A second need shown in Table 5.8 is the need to have an "Un-encumbered grip" (measured as "encumberment %" where 100% is normal hand function and 0% is complete loss of hand usefulness). This need is shown associated with the context factor of the task the user will be performing ("What will the person be doing with their hands?") Whether the answer to this question is "walking to class" or "writing" will make a large difference in what "encumberment %" level the customer considers satisfactory. If the product is used only while walking to class very little hand function is needed and a hand encumberment as high as 50-90% may be acceptable; however, if the product is used while writing then an encumberment level near 20% or less may be required.

[27] Modified from actual interview data to enhance example clarity.

Table 5.7: Sample Context Factors and Interview Data (Hand Warmer "How" Factors)

	Context Factor	Elicitation Questions	Scenario #1	Scenario #2	Scenario #3
a0	**Task (application)**	What will the person be doing with their hands?	Walk to class	Walk to class	Write on chalkboard
a1	**Task frequency**	How often will warmer be used? (/day? /wk?)	3/day; 15/wk	6/day; 30/wk	10/wk
a2	**Task duration**	How long will warmer be used each time?	10min	10min	1.5hr
a2a	**Task duration**	What months will warmer be in use?	5mo	5mo	3mo
a3	**Task quantity (W)**	[By Research] What is T_{avg} & V_w (wind speed)?	-30F; U=6m/s	-30F; U=6m/s	+30F; U=0m/s
a3b	**Task quantity**	[By Calculation] What is the usage duty (hr/yr)?	50hr/yr	100hr/yr	180hr/yr
a4	**Task ruggedness**	How roughly will warmer be handled/treated?	Gently	Moderate	Gently
a5	**Transportation type**	How will warmer be transported & how much?	Worn/held	Worn/held Backpack	Worn/held

Table 5.8: Factors-Needs Relationship Matrix Portion (Hand Warmer)

Context Factors	Task (application)	Task duration (per use)	Task quantity (heat)	Task quantity (time)	Task ruggedness	Transportation type		
	a0	a2	a3	a3b	a4	a5	**Customer Needs**	**Wt.**
	1						Un-encumbered grip	3
		1					Heat long-lasting	9
		1					Heat on/off controllable	3
			1				Heat hand adequately	9
				1	1		Durable	3
						1	Portable	9
						1	Safe - low risk	9

Another type of factor-need relationship not shown in Table 5.8 is that of factors which influence how a need is physically embodied. For example, the "cost and availability of energy" influences how "heat hand adequately" is fulfilled, but does not change the level of heating (the attribute) the customer finds satisfactory. When a context factor influences how an attribute level is achieved by the product (but not the satisfaction relationship) this relationship may be indicated with a distinct number or symbol such as a "*." Context factors marked with a "*" will be important considerations in the embodiment design stage rather than in specification setting. The scenario clustering demonstrated in this Chapter is based on the similarity of product attributes that measure customer need fulfillment (such as those in Table 5.6); formally accounting for the indirect influence of context factors on embodiment decisions is a topic for future work. However, context factors such as "cost and availability of energy" may be accounted for within the current scope by including in the analysis the associated (often latent) needs such as "use available energy supplies" which have attribute metrics of "energy types accepted."

5.4 FORM FACTORS-NEEDS-ATTRIBUTES (FNA) TABLE WITH FACTOR VALUES

The *factors-needs-attributes (FNA)* table (Table 5.9) is assembled from: the weighted customer needs list (Table 5.5), the need-attribute relationship table (Table 5.6), the context factors list with interview data (Table 5.7), and the factor-needs relationship matrix (Table 5.8). Table 5.9 is only a combination of the information in these previous steps; no additional information has been added yet. Each context factor may have zero, one, or more than one customer needs associated with it. Each customer need will have one or more attribute metrics associated with it. The second row of the table shows the first context factor, "a0: Task (application)" along with the interview elicitation question (included for clarification) and customer data from four interviews. The next (third) row of the table shows the customer need associated with this context factor, the need weight, and the associated attribute metric. More than one need and attribute metric may be included in additional rows beneath any given context factor. The elicitation question for context factor a3 includes "[By research]" indicated the data is determined through research rather than customer interview responses. The elicitation question for context factor a3b includes "[By calculation]" indicating the data is determined through a calculation, in this case based upon the interview responses to other elicitation questions.

Table 5.9: Factors-Needs-Attribute (FNA) Items with Factor Values (Hand Warmer)

	Context Factor Customer Need	**W**	**Interview Elicitation Question** Attribute Metric	**Scenario #1**	**Scenario #2**	**Scenario #3**	**Scenario #4**
a0	**Task (application)**		**What will the person be doing with their hands?**	Walk to class	Walk to class	Write on chalkboard	Take notes, walk to class
	Un-encumbered grip	3	Encumberment (%)				
a1	**Task frequency**		**How often will warmer be used? (/day? /wk?)**	3/day; 15/wk	6/day; 30/wk	10/wk	20/wk
a2	**Task duration**		**How long will warmer be used each time?**	10min	10min	1.5hr	1.5hr
	Heat long-lasting	9	Heat duration (hr)				
	Heat controllable	3	On/Off [Y/N =1/2]				
a2a	**Task duration**		**What months will warmer be in use?**	5mo	5mo	3mo	3mo
a3	**Task quantity (W)**		**[By research] What is T_{avg} & V_w (wind speed)?**	T=-30F; V=6m/s	T=-30F; V=6m/s	T=+30F; V=0m/s	T=+30F; V=0m/s
	Heat hand adequately	9	Net hand heat loss reduction needed (W)				
a3b	**Task quantity (hr/yr)**		**[By calculation] What is the usage duty (hr/yr)?**	50hr/yr	100hr/yr	180hr/yr	360hr/yr
	Durable	3	MTBF (hr)				
a4	**Task ruggedness**		**How roughly will warmer be handled/treated?**	Gently	Moderate	Gently	Moderate
	Durable	3	Allowable drop height (m)				
a5	**Transportation type**		**How will warmer be transported & how much?**	Worn/held	Worn/held Backpack	Worn/held	Worn/held Backpack
	Portable	9	Mass (kg)				
	Portable	9	Volume (L)				
	Safe - low risk	9	Fire safety [1-3]				
	Safe - low risk	9	Spill safety [1-3]				

5.5 Define and Rate Similarities Among Factor Values

5.5.1 Define a Similarity Measure for Context Factor Values

A clear definition of context factor value similarity is needed in order to evaluate how changes in factor values may influence the product attributes required. The similarity among context factor values may be defined in a variety of ways. The major purpose of design is to achieve high customer satisfaction levels, and these satisfaction levels result from how the actual product attributes compare to customer attribute expectations (preferences). Therefore, from the standpoint of achieving customer satisfaction, it is most useful here to define similarity in terms of attribute preferences.

Therefore c*ontext factor value similarity* is defined here as how closely the attribute preferences resulting from each context factor value resemble each other. By this definition, two context factor values are "similar" if they result in similar attribute preferences, and dissimilar if they result in dissimilar attribute preferences. For example, "keep customer dry" is a customer need for a light jacket garment. Two different context scenarios in which the weather context factor value is "heavy rain every day" for one, compared to "heavy rain *every other* day" for the other, will both require product attributes of "waterproof." Thus, these context factor values of "heavy rain every day" compared to "heavy rain *every other* day" are very similar. However, a factor value of "light rain once a month" is quite different since it is likely to result in satisfaction with an attribute of "water resistant" rather than "waterproof." Note that by this definition the similarity of context factors is heavily dependent on the particular product of interest and the associated customer needs.

Based upon this similarity definition, the similarities among context factor values obtained in interview data may be subjectively rated from 0% to 100% similar. This allows full expression of designer judgment, analogous to the Pugh chart method for concept selection. However, when a more formal approach to assigning these ratings is desired, the following optional numerical procedure is suggested.

5.5.2 Quantify Attribute Satisfaction Relationships for FNA Table Items (Optional)

The similarity of two factor values may be quantified as the percentage overlap of the *satisfactory attribute spans* of the two customer satisfaction curves which result from the two context factor values being compared. Figure 5.3 illustrates a satisfactory attribute span, shown in this case as the attribute levels causing a satisfaction level ranging[28] from 2 to 3. For example, for a portable light source being transported long distances by foot, an attribute metric measuring portability is mass in kg (decreasing mass is to the right in Figure 5.3). A mass attribute of 1.0 kg may result in a satisfaction level of "2 = Less than satisfied" (Table 5.3) and a mass attribute of 0.5 kg may result in a satisfaction level of "3 = satisfied." Therefore the *satisfactory attribute span* for this example is from 1.0 to 0.5 kg.

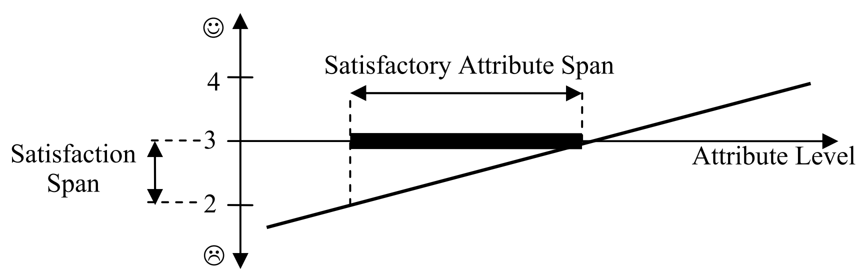


Figure 5.3: Identifying a Satisfactory Attribute Span from a Satisfaction Curve

Figure 5.4 illustrates an equation (Eq. 5.1) for the similarity between two satisfactory attribute spans. Extending the previous example, consider the customer satisfaction curves for the customer need of "lightweight" for two values of the context factor "transportation mode": "1 = foot," and "2 = car." For transportation by foot, the customer may be satisfied with the product's "lightweight-ness" if the mass attribute ranges from 0.5 to 1.0kg, as discussed earlier. However if the transportation mode changes the attribute-satisfaction curve may also change. For transportation by car, for

[28] Rather than [2,3], the satisfaction span may also usefully be defined from (2,4), i.e. as the satisfaction level range from just above "less than satisfied" up to just below "more than satisfied."

example, the customer may be satisfied if the mass ranges from 0.75 to 5.0kg. The overlapping distance is from 0.5 to 1.0kg, and the overlapping distance divided by the larger span distance is (1.0 – 0.5) / (5.0 – 0.75) = 12%. Defining satisfactory attribute spans for all factor values listed (for each factor-need-attribute item) allows the calculation of the similarities among all factor values.

Eq. 5.1: %Similarity = Overlap / Largest_Span

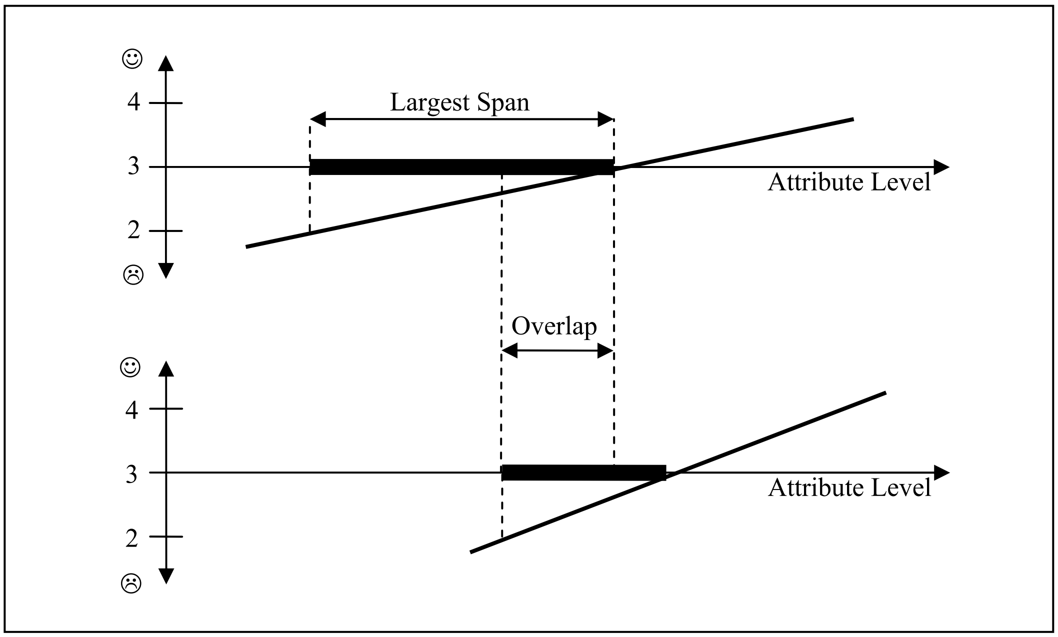


Figure 5.4: Calculating the Similarity of Two Attribute-Satisfaction Curves

Table 5.10 shows the Factors-Needs-Attributes table with satisfactory attribute spans listed for the factor values for each scenario. For example, for the FNA item "a3b: task quantity (usage duty), need=Durable (3), attribute=MTBF (hr)" the factor value of 50hr/yr is assigned a satisfactory attribute range of 70-100hr/yr, indicating customers expect the device to last through the cold season. Likewise, the scenario context factor value of 100hr/yr is assigned a satisfactory attribute range of 120-200hr/yr.

As a second example, for the FNA item "a0: Task (application), need=Un-encumbered grip (3), attribute=Encumberment (%)" the factor values of scenarios #1 and #2 are both "walk to class." These are assigned satisfactory attribute spans of 90-50%, indicating the customer is at the upper edge of satisfaction (just below “more than satisfied”) with a hand encumberment of 50%, and on the brink of becoming “less than satisfied” if encumberment exceeds 90%. The factor values of “writing on chalkboard” and “take notes,” however, require much less encumberment to achieve satisfaction and are therefore assigned spans of 20-10%. This data is extremely resource intensive to measure from customers, but may be estimated for the purposes here. The sensitivity of results to the uncertainty in estimation assumptions may be tested by making small adjustments in the satisfactory attribute span data and observing how the results change.

Table 5.10: Factors-Needs-Attributes Table Items with Satisfactory Attribute Span Data

	Context Factor Customer Need	W	**Interview Elicitation Question** Attribute Metric	**Scenario #1**		**Scenario #2**		**Scenario #3**		**Scenario #4**	
a0	**Task (application)**		**What will the person be doing with their hands?**	Walk to class		Walk to class		Write on chalkboard		Take notes, walk to class	
	Un-encumbered grip	3	Encumberment (%)	90	50	90	50	20	10	20	10
a1	**Task frequency**		**How often will warmer be used? (/day? /wk?)**	3/day; 15/wk		6/day; 30/wk		10/wk		20/wk	
a2	**Task duration**		**How long will warmer be used each time?**	10min		10min		1.5hr		1.5hr	
	Heat long-lasting	9	Heat duration (hr)	0.5	0.6	1	1.1	1	1.5	1	1.5
	Heat controllable	3	On/Off [Y/N =1/2]	1.5	2.5	1.5	2.5	0.5	2.5	0.5	2.5
a2a	**Task duration**		**What months will warmer be in use?**	5mo		5mo		3mo		3mo	
a3	**Task quantity (W)**		**[By research] What is T_{avg} & V_w (wind speed)?**	T= -30F; V=6m/s		T= -30F; V=6m/s		T=+30F; V=0m/s		T=+30F; V=0m/s	
	Heat hand adequately	9	Net hand heat loss reduction needed (W)	8	10	8	10	0.5	1.5	0.5	1.5
a3b	**Task quantity (hr/yr)**		**[By calculation] What is the usage duty (hr/yr)?**	50hr/yr		100hr/yr		180hr/yr		360hr/yr	
	Durable	3	MTBF (hr)	70	100	120	200	200	400	300	600
a4	**Task ruggedness**		**How roughly will warmer be handled/treated?**	Gently		Moderate		Gently		Moderate	
	Durable	3	Allowable drop height (m)	0	0	0	0.5	0	0	0.25	0.5
a5	**Transportation type**		**How will warmer be transported & how much?**	Worn/held		Worn/held Backpack		Worn/held		Worn/held Backpack	
	Portable	9	Mass (kg)	0.5	0.2	0.5	0.2	0.2	0.1	0.2	0.1
	Portable	9	Volume (L)	0.4	0.2	0.4	0.2	0.4	0.2	0.4	0.2
	Safe - low risk	9	Fire safety [1-3]	1	2	1	2	2.5	3.5	3	3
	Safe - low risk	9	Spill safety [1-3]	2	3	2	3	3	3	3	3

5.5.3 Rate Factor Value Similarities

The quantitative similarity definition described (Eq. 5.1) may be used to calculate similarity tables such as those shown in Table 5.11 through Table 5.14. These similarity tables will serve as the basis for grouping similar scenarios and factor values with hierarchical clustering. Table 5.11 shows that for the factors-needs-attributes (FNA) table item "a0: task (application), need=Un-encumbered grip (3), attribute=Encumberment (%)" scenario #1 and #2 factor values have 100% similarity, and so do scenarios #3 and #4. However, there is no similarity for any other comparison such as scenario #1 to #3, or #2 to #3. Table 5.13 on the other hand, shows that for this FNA item all scenario factor values share at least 50% similarity, with some 100% similar. These similarity tables are calculated from the satisfactory attribute spans in Table 5.10 using Eq. 5.1. Alternatively, the similarity tables may be filled in based directly on the designer's judgment. If attribute spans are not assigned, the similarity values must be determined by some other means such as designer judgment.

Table 5.11: Similarity Table for Factors-Needs-Attribute Table Item
[a0: task (application), Un-encumbered grip (3), Encumberment (%)]

	1	2	3	4
1	100%	100%	0%	0%
2		100%	0%	0%
3			100%	100%
4				100%

Table 5.12: Similarity Table for Factors-Needs-Attribute Table Item
[a2: task duration, Heat long-lasting (9), Heat duration (hr)]

	1	2	3	4
1	100%	0%	0%	0%
2		100%	20%	20%
3			100%	100%
4				100%

Table 5.13: Similarity Table for Factors-Needs-Attribute Table Item
[a2: task duration, Heat long-lasting (9), Heat controllable On/Off (Y/N)]

	1	2	3	4
1	100%	100%	50%	50%
2		100%	50%	50%
3			100%	100%
4				100%

Table 5.14: Similarity Table for Factors-Needs-Attribute Table Item
[a3: task quantity, Heat hand adequately (9), Net hand heat loss reduction (W)]

	1	2	3	4
1	100%	100%	0%	0%
2		100%	0%	0%
3			100%	100%
4				100%

5.6 Calculate Weighted Similarity Among Scenarios

The similarity of two scenarios may be defined as the weighted average of the factor value similarities between the two scenarios. The customer need weightings can be used to weight the similarity scores. Table 5.15 places the data from the previous similarity tables in a line-item format to the right of the associated attributes. The column headings indicate the scenarios compared, for example the column labeled “#1-#2” contains similarity scores comparing factor values from scenario 1 to scenario 2. The bottom row shows the weighted average of similarity scores (e.g. scenario #1 is rated as 77% similar to scenario #2). The aggregate scenario similarity table resulting from this calculation is shown in Table 5.16.

Table 5.15: Factor Value Similarity Scores with Weighted Scenario Averages

				Scenario Factor Value Similarity Scores					
	Context Factor Customer Need	**W**	**Interview Elicitation Question** Attribute Metric	#1-#2	#1-#3	#1-#4	#2-#3	#2-#4	#3-#4
a0	**Task (app., function)**		**What will the person be doing with their hands?**						
	Un-encumbered grip	3	Encumberment (%)	100%	0%	0%	0%	0%	100%
a1	**Task frequency**		**How often will warmer be used? (/day? /wk?)**						
a2	**Task duration**		**How long will warmer be used each time?**						
	Heat long-lasting	9	Heat duration (hr)	0%	0%	0%	20%	20%	100%
	Heat controllable	3	On/Off [Y/N =1/2]	100%	50%	50%	50%	50%	100%
a2a	**Task duration**		**What months will warmer be in use?**						
a3	**Task quantity (W)**		**[By research] What is T_{avg} & V_w (wind speed)?**						
	Heat hand adequately	9	Net hand heat loss reduction needed (W)	100%	0%	0%	0%	0%	100%
a3b	**Task quantity (hr/yr)**		**[By calculation] What is the usage duty (hr/yr)?**						
	Durable	3	MTBF (hr)	0%	0%	0%	0%	0%	33%
a4	**Task ruggedness**		**How roughly will warmer be handled/treated?**						
	Durable	3	Allowable drop height (m)	0%	100%	0%	0%	50%	0%
a5	**Transportation type**		**How will warmer be transported & how much?**						
	Portable	9	Mass (kg)	100%	0%	0%	0%	0%	100%
	Portable	9	Volume (L)	100%	100%	100%	100%	100%	100%
	Safe - low risk	9	Fire safety [1-3]	100%	0%	0%	0%	0%	0%
	Safe - low risk	9	Spill safety [1-3]	100%	0%	0%	0%	0%	100%
		66		**77%**	**20%**	**16%**	**19%**	**21%**	**79%**

Table 5.16: Similarity Table for Four Scenarios
(Weighted Average of All FNA Items)

	1	2	3	4
1	100%	77%	20%	16%
2		100%	19%	21%
3			100%	100%
4				100%

5.7 CLUSTER SCENARIOS BY SIMILARITY

The sixth and final step of the clustering methodology is to group the context scenarios by similarity through *hierarchical clustering* – a technique of forming hierarchical groupings such that objects within a group have greater average similarity to each other than to objects outside the group. Hierarchical clustering has been applied to various problems in engineering design. For example, Hölttä-Otto (2005) applies hierarchical clustering to identify modules and identify candidates for product platform modules. Dai and Scott (2004) apply hierarchical clustering visualized with dendrograms as the basis of identifying commonalities for product platforming. Takai and Ishii (2004) propose the use of a "subjective clustering" technique to avoid the potential bias of affinity analysis for clustering customer needs. Their technique averages the perceived similarity among all needs reported by each participant in a co-occurrence matrix. The averaged similarity is then displayed as a dendrogram generated using a hierarchical clustering algorithm. This approach to grouping customer needs through hierarchical clustering bears some similarity to the need to group context scenarios.

The results of hierarchical clustering may be displayed as a *dendrogram*[29] – a branching tree-like diagram (in this case binary) illustrating hierarchical relationships among a set of objects. Many common statistical software programs contain hierarchical clustering algorithms that will generate a dendrogram from a similarity table. (These programs will also calculate a similarity table from multivariate data using various similarity criteria such as the Euclidian distance; however, the definition of similarity used here requires a custom algorithm to derive the similarity table.) The hierarchical clustering algorithm begins by searching the similarity table for the two objects (in this case the two scenarios) with the greatest similarity, and defining them as a cluster. This cluster then becomes a new object in the similarity table, and the distances between the new cluster and every other object in the table are re-calculated as the average of the distances of the objects within the cluster to all other objects. This is known as the *unweighted pair-group average linkage* criterion for clustering. Other common clustering criteria such as "nearest neighbor" and "farthest neighbor" are less appropriate for this application.

The hierarchical clustering process is illustrated step-by-step in Table 5.17 through Table 5.19 and the resulting dendrogram in Figure 5.5. In Table 5.17 objects 1 and 2 have the greatest similarity of 80% (shown as 0.80 on the vertical dendrogram bar joining them) and are therefore clustered. The new similarity between object 1-2 and object 3, for example, is 20% averaged with 10%, the previous similarities of object 3 with objects 1 and 2 respectively. In the second step (Table 5.18) objects 3 and 4 are clustered. In the third and final step (Table 5.19) the two remaining objects, cluster 1-2 and cluster 3-4, are combined at 20% similarity. This last cluster is represented in Figure 5.5 as the right-most bar labeled positioned at "0.80" along the horizontal "difference" axis.

Table 5.17: Sample Similarity Table

	1	2	3	4
1	100%	**80%**	20%	40%
2		100%	10%	10%
3			100%	60%
4				100%

[29] Analyzing similarity with hierarchical clustering and dendrograms was inspired by research applying this approach for product architecture and modularity decisions (Hölttä-Otto, 2005).

Table 5.18: Sample Similarity Table
(Objects 1 and 2 Combined)

	1-2	3	4
1-2	100%	15%	25%
3		100%	**60%**
4			100%

Table 5.19: Sample Similarity Table
(Objects 3 and 4 Combined)

	1-2	3-4
1-2	100%	**20%**
3-4		100%

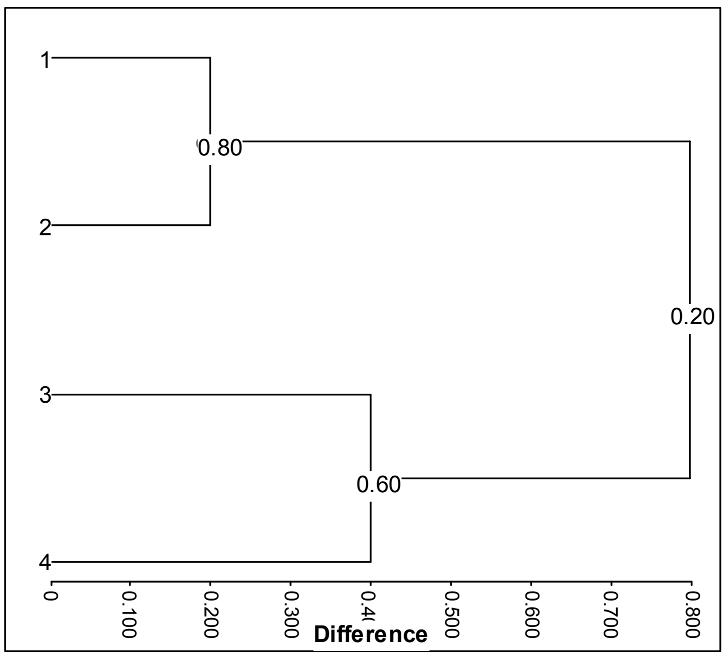


Figure 5.5: Sample Dendrogram

To illustrate the power of grouping scenarios through hierarchical clustering, the personal hand warmer example used previously is expanded to include eight scenarios derived from contextual interview data. Plausible attribute preference ranges are defined based on the scenario descriptions defined in Table 5.21.

Table 5.20. Half of the scenarios are defined to represent two teachers and two students in the northern region of China (e.g. Beijing) where January temperatures average -30F and classrooms are heated, so hand warmers are needed while walking to and from class. The other half of the scenarios are defined to represent two teachers and two students in the southern region of China (e.g. Shanghai) where January temperatures average 30F and classrooms are not heated, so hand warmers are needed both while walking and during class time. The resulting similarity table (calculated according to Section 5.5) is shown as Table 5.21.

Table 5.20: Eight Context Scenarios

Region	**Occupation**	**#**	**Coding**
North	Teacher	1	1: N-Teach_a
		2	2: N-Teach_b
	Student	3	3: N-Stu_a
		4	4: N-Stu_b
South	Teacher	5	5: S-Teach_a
		6	6: S-Teach_b
	Student	7	7: S-Stu_a
		8	8: S-Stu_b

Table 5.21: Similarity Table for Eight Scenarios

	North				**South**			
	Teacher		**Student**		**Teacher**		**Student**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	100%	98%	69%	67%	19%	19%	13%	13%
2		100%	67%	69%	19%	19%	13%	13%
3			100%	98%	16%	16%	19%	19%
4				100%	16%	16%	19%	19%
5					100%	94%	80%	74%
6						100%	74%	80%
7							100%	94%
8								100%

Note that the number of similarity comparisons (the number of unique scenario pairs) contained in a similarity table is equal to a sum indexed from one through one less than the number of scenarios compared (Eq. 5.2). Thus, comparing eight scenarios involves 28 individual similarity comparisons (Table 5.21), compared to four scenarios resulting in 6 comparisons (Table 5.16).

Eq. 5.2: $$Num\_Comparisons = C_2^{ns} = \frac{ns!}{2(ns-2)!} = \frac{ns \cdot (ns-1)}{2} = \sum_{i=1}^{ns-1} i$$

where ns ≡ number of scenarios

As the number of scenarios increases, the number of scenario comparisons quickly becomes difficult to interpret from a table. Hierarchical clustering is used to convert the similarity table into the scenario groupings shown as a dendrogram in Figure 5.6. The dendrogram shows the most similar scenarios grouped closest together (with the vertical joining bar farthest to the left), and the most dissimilar scenarios farthest apart (with the vertical joining bar farthest to the right). For example, scenarios #1 and #2 are displayed as having a similarity of "0.98" (dissimilarity of 0.02), and the cluster containing 1 and 2 is shown as "0.68" (68%) similar to the cluster containing 3 and 4.

The dendrogram successfully highlights the structure which was embedded in the scenarios to illustrate the methodology. This approach has the potential to reveal important structure in actual interview data that could otherwise be missed. The largest clusters (divided geographically) are strong candidates for consideration of a separate product offering. If additional market segmentation is desired, the next lower levels indicated are the context differences between students and teachers in the south.

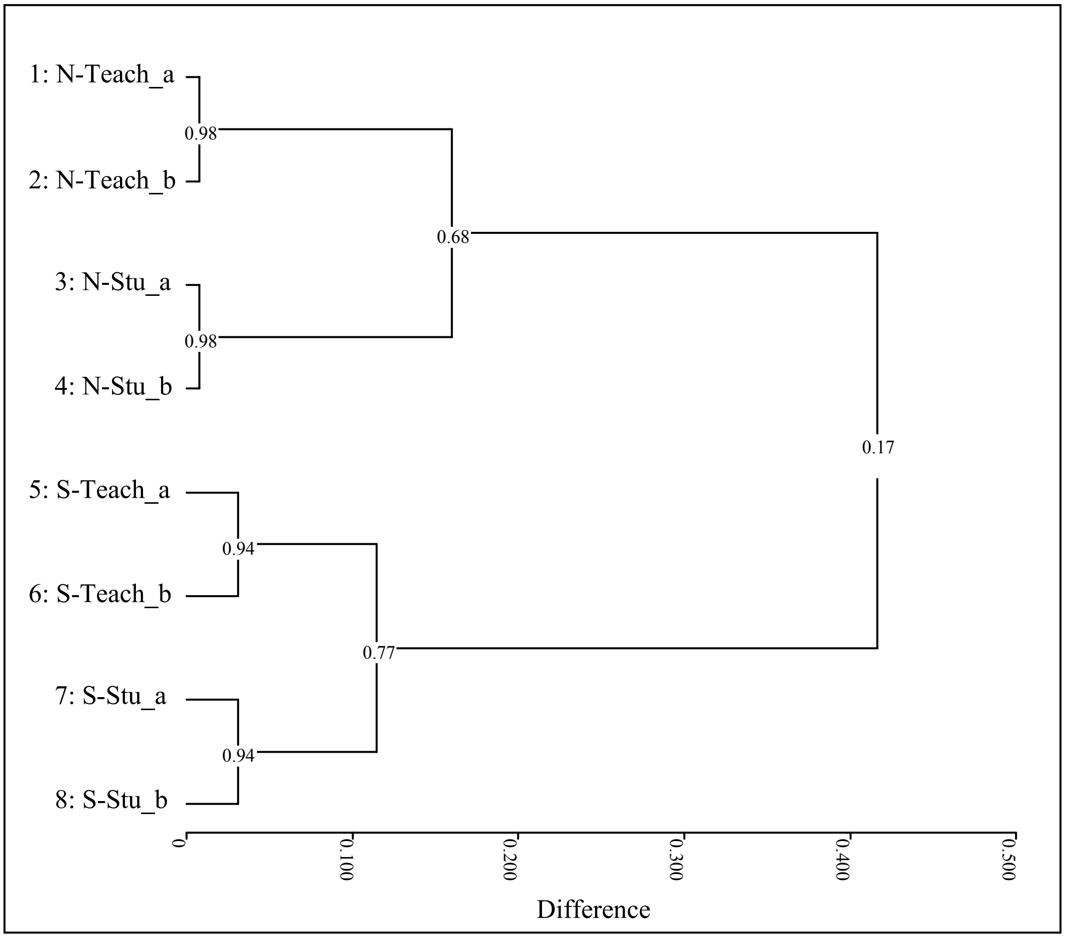


Figure 5.6: Hierarchical Clustering of Eight Scenarios

5.8 Notes On Exploring A Context Space With n-Factor Dimensions

5.8.1 Coding Factor Values (and Factor Value Clusters)

A unique coding may be developed for the possible values of a given context factor. One approach is to assign a different code to every unique interview response given. However, it may be advantageous to group identical or nearly-identical responses together. (Note that raw interview data has significant "noise" in it, and the interview data was significantly "filtered" to form clear scenarios for the examples in this chapter. For example, in some cases a single customer discusses multiple factor values and these have been divided into separate scenarios.) Grouping nearly-identical factor values together is facilitated by the similarity tables shown previously. The similarity table (Table 5.11) for the interview data in Table 5.22 shows that from an attribute preference standpoint the responses for scenarios #3 and #4 are identical, even though the responses are in different words and include different activities. The reason for this result is that the writing activity places a limit on the acceptable hand encumberment, and thus "writing notes + walking" receives the same satisfactory attribute span as "writing on chalkboard." Using this information, the interview responses may be coded as shown in Table 5.23. Basing coding on a similarity table can help insure that factor values identified show an appropriate level of distinction from one another. This type of coding is needed in order to exhaustively explore a context space with n-factor dimensions.

Table 5.22: Interview Factor Values (Before Coding Values)

Context Factor Customer Need	Attribute Metric	**Interview #1**		**Interview #2**		**Interview #3**		**Interview #4**	
a0: Task (application)		Walk to class		Walk to class		Write on chalkboard		Take notes, walk to class	
Un-encumbered grip	Encumberment (%)	90	50	90	50	20	10	20	10

Table 5.23: Interview Factor Values (After Coding Values)

Context Factor Customer Need	Attribute Metric	**Interview #1**		**Interview #2**		**Interview #3**		**Interview #4**	
a0: Task (application)		1 = walking		1 = walking		2 = writing		2 = writing	
Un-encumbered grip	Encumberment (%)	90	50	90	50	20	10	20	10

5.8.2 Number of Scenarios and Similarity Comparisons Required

To exhaustively explore a context space, context scenarios may be created representing every possible combination of the factor values coded in the previous section. The scenarios may be thought of as vectors in a space with one dimension for each factor, and the magnitude in each dimension representing the coded value for the corresponding factor. This approach produces a quantity of scenarios roughly equal to the average number of coded factor values (per factor), raised to the power of the number of Function-Need-Attribute items (Eq. 5.3). The number of coded factor values may not be equal across factors, but can be approximated as such for rapid estimation.

A large number of calculations would be required to explore a contextual space with n-factor dimensions. Although the examples in this chapter are limited to 10 Function-Need-Attribute items for succinctness, 30 items is a more realistic number for a thorough context comparison. Additionally, most factors will have three or more coded factor values. As shown in Table 5.24, this requires building $\approx 3^{30} = 2.1 \cdot 10^{14}$ scenarios to explore every possible combination in the context space.

Eq. 5.3: $$Num\_Scenarios = \prod_{i=1}^{Num\_FNA\_items} Num\_factor\_values_i \approx Avg\_num\_values^{Num\_FNA\_items}.$$

Table 5.24: Number of Scenarios Required to Exhaustively Explore a Context Space

# of FNA Items	Average # of Factor Values		
	2	**3**	**4**
10	1.0E+03	5.9E+04	1.0E+06
20	1.0E+06	3.5E+09	1.1E+12
30	1.1E+09	2.1E+14	1.2E+18
40	1.1E+12	1.2E+19	1.2E+24

The total number of similarity comparisons required to explore a context space may be calculated by combining the approximation for the required number of scenarios (Eq. 5.3) with the equation for the number of similarity comparisons per scenario (Eq. 5.2, p.113). This calculation yields Table 5.25 and Figure 5.7. As shown in the table and figure, exploring a contextual space of 30 FNA items with three factor values for each factor requires $6.4 \cdot 10^{29}$ total similarity comparisons. Note that through the use of factor value coding, actual similarity *calculations* may be limited to a few hundred and the large number of similarity *comparisons* can consist of retrieving values from a similarity look-up table. Although this reduces the computational task of scenario similarity comparison to keeping running averages of values retrieved from a look-up table, it is still currently unrealistic for large numbers of FNA items.

Table 5.25: Total Similarity Comparisons to Explore a Context Space

		Average # of Factor Values		
		2	**3**	**4**
# of FNA Items	**10**	5.2E+06	1.7E+10	5.5E+12
	20	1.1E+13	1.2E+20	1.2E+25
	30	1.7E+19	6.4E+29	2.0E+37
	40	2.4E+25	3.0E+39	2.9E+49

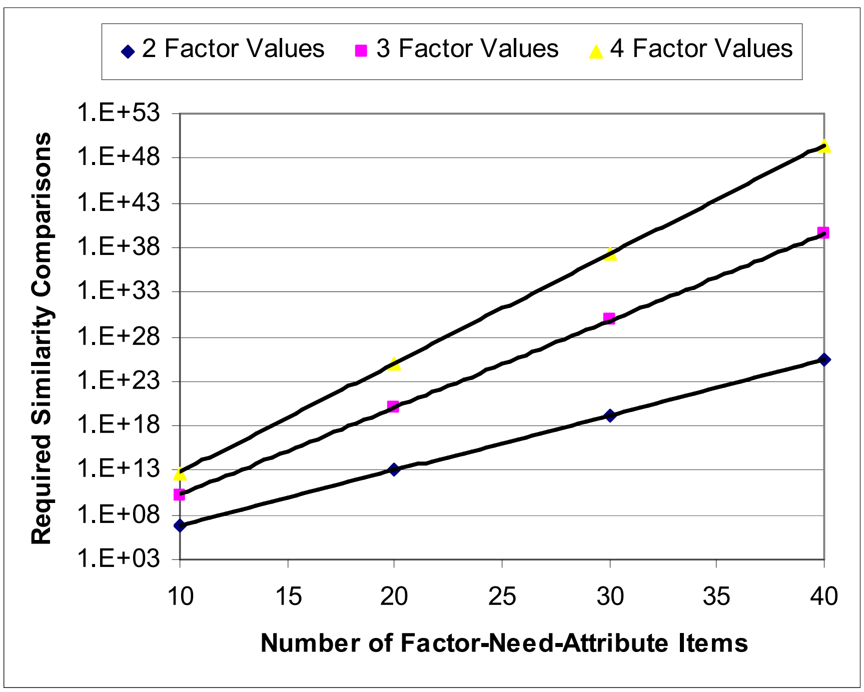


Figure 5.7: Total Similarity Comparisons Required to Explore a Context Space

5.8.3 Alternatives to Exhaustive Computational Exploration of a Context Space

Even if the computational time were invested to exhaustively explore a context space, it is unclear how meaningful a dendrogram of trillions of scenarios would be. Since an exhaustive contextual space would be very sparsely populated with real scenarios, a different type of analysis of the interview data may yield greater insight for the resources invested. Multiple Correspondence Analysis (MCA) may be used to identify patterns within the interview data showing relationships between factors. In the example used here, MCA would show that one group of interviews (northern) typically have temperatures of -30F, use the device only while walking, and have a low usage duty. MCA would further show the other group of interviews (southern) typically have temperatures of +30F, use the device while walking and writing, and have a high usage duty. Identification of such relationships greatly reduces the number of scenario combinations to explore by eliminating many scenario combinations not necessarily representative of reality.

5.9 CONCLUSIONS

The contextual needs assessment methodology facilitates and directs the process of discovering, documenting, and applying contextual information. The basic methodology presented in Chapter 4 may be extended through the *context scenario hierarchical clustering* method which provides additional guidance in forming context scenarios from interview data and identifying meaningful levels of distinction among context factor values. This guides the designer in grouping an appropriate breadth of context variation into a scenario suitable to address with a single product, or multiple scenarios corresponding to a multiple product offering.

Development of the advanced methodology in this chapter revealed multiple insights which may be applied to the basic methodology as well. When context comparisons are being made, it is important to have a clear definition of customer needs weightings grounded in satisfaction, not attribute levels (because satisfaction-attribute relationships are context-dependent). Some context factors directly influence the need satisfaction-attribute relationship, whereas others influence only the design embodiment needed to achieve the attributes, but not the satisfaction relationships themselves. The definition of similarity offered here shows that, for the purposes of customer-driven product development, the similarity of context factors is heavily dependent on the product and customer needs of interest. The answer to the question of "how similar are these two context factor values?" hinges on how similar the attribute-satisfaction relationships are for each context.

As the number of context scenarios analyzed increases, the number of required similarity comparisons grows rapidly and quickly becomes difficult to assess in the form of a similarity matrix. Hierarchical clustering is a valuable tool in analyzing the similarity relationships among a large set of context scenarios. Exhaustive exploration of a context space is computationally intense for the number of context factors and factor values discussed here, suggesting that analysis of actual interview data may be the most fruitful application of the methodology. However, future work includes the development of a technique to rapidly predict the largest groupings expected based on need weights and similarity score data, without performing an exhaustive search. Future work also includes accounting for the difference between context factors which influence attribute preferences and those which influence the fulfillment of those attributes by the product.

Chapter 6: Case Studies of Contextual Needs Assessment

This chapter presents four case studies of the contextual needs assessment methodology, shown in Table 6.1. The case studies are spatially positioned in the table according to the dimensions of environment accessibility and customer accessibility. The PersonaWarmth design example, Case 4, is a personal warming device for university students in China. Although interviews were conducted with students who have expertise in this environment, access to the actual target customers and environment are both extremely limited, and so the design need falls in the upper-left quadrant. Shown in the upper-right quadrant, the UT assistive technology Case 2 takes place in a graduate course involving the design of enabling devices for high school students with physical and mental disabilities. Although the design teams were able to experience the usage environment and interview experts (teachers), communication with the students who would use the devices was often extremely limited due to their impaired communication abilities. Case 3, the controlled interview study, is placed in the lower-left quadrant since data was accessible solely through an interview with a simulated customer. Study participants had little or no experience with the environmental context, but face-to-face and same-language access to the customer. The UT Reverse Engineering Case 1 in the lower-right involves the reverse engineering of everyday products used in the U.S. The design teams were able to interview actual users of the products in the intended context. The discussion of these case studies in the following sections supports the value of the contextual needs assessment method in all four quadrants, as well as indicating that the method is increasingly critical for the leftmost and upper-left quadrants.

Table 6.1: Frontier Contexts 2D Map with Case Study Examples Positioned

		Environment Accessibility	
		Low	**High**
Customer Accessibility	**Low**	Case 4: PersonaWarmth Design	Case 2: UT Assistive Technology
	High	Case 3: Controlled Interviews	Case 1: UT Reverse Engineering

As noted in the previous chapter, many real design projects fall in the left or upper-left quadrants of Table 6.1. The problem of contextual needs assessment in the left quadrants is a challenge faced by organizations such as Engineers for a Sustainable World (2005d), Engineers without Borders (2005e), Engineering Ministries International (2005c), and other NGOs designing high human-impact solutions in frontier contexts[30].

6.1 Case 1: Reverse Engineering - Consumer Products

6.1.1 Design Team Background

The UT Austin Department of Mechanical Engineering undergraduate curriculum includes a senior design methods course followed by a semester of capstone design. Students in the design methods course apply design methodologies in a semester-long project involving the reverse engineering and re-design of a consumer product. The text used for the course (Otto and Wood, 2001) conceptually presents the design process in three phases: (1) task clarification (understanding the re-design need), (2) concept generation, and (3) concept implementation (detailed design and prototyping). In the first phase students use a number of tools to understand the re-design need such as: a mission statement, a checklist of technical questions, and articulated-use or like/dislike customer needs interviews (Otto and Wood, 2001; Urban and Hauser, 1993). Additionally, students perform a number of reverse-engineering steps such as prediction, product

[30] Engineers for a Sustainable World, http://www.esustainableworld.org/; Engineers without Borders http://www.ewb-usa.org/; Engineering Ministries International http://www.emiusa.org/;

teardown, and functional modeling to identify re-design avenues. The students choose one or two high-priority, re-design avenues based on the understanding gained of the re-design need. The accuracy and completeness of customer needs understanding directly influences the correct selection and implementation of a re-design avenue that will maximize value added to the customer. This design methods course was chosen as a case study in part because students are already learning design methods and are therefore open to learning and implementing a newly developed method. Additionally, since the students are near the end of their undergraduate degree they are a good representation of the intended users of the proposed methodology.

6.1.2 Classroom Delivery of the Methodology

For this study the task clarification lectures given in past semesters are augmented with some additional steps intended to enhance understanding of the re-design need context. Students are provided the five-step method shown in Figure 6.1 and a supporting tool in the form of an MS-Excel template (Figure 6.2) in which each Excel worksheet tab corresponds to one step of the method. The method would ideally be presented step-by-step in an interactive lecture format in which each step is illustrated "live." After each step is partially demonstrated, a complete version would be reviewed in a prepared example using the template (Appendix A) and distributed via a courseware website. However, classroom realities limited the time available, so in this case the methodology was reviewed in a single lecture with an emphasis on conceptual understanding of the methodology and detailed exploration left for homework. (Although the study results are very positive, there is also evidence of the need for increased teaching time to improve understanding of the method).

Procedure for Gathering Customer Needs & Product Context

1. Brainstorm interview questions: "What do we need to know about Where, How, and Who?"
2. Customize context questions template: add, delete, and modify questions as needed.
3. Interview customers using product in a realistic context:
   3.1. Actively question customer during product use, recording "voice of the customer"
   3.2. Ask any remaining* questions in the customized context questions template
4. Form customer needs list: Translate voice of customer; combine & prioritize needs
5. Form context scenario by combining context answers to each question

[Advanced: Identify distinct context scenarios to address with a multi-product offering]

* Note: some questions may already have been answered, or may be better answered through research.

Figure 6.1: Contextual Needs Assessment Methodology

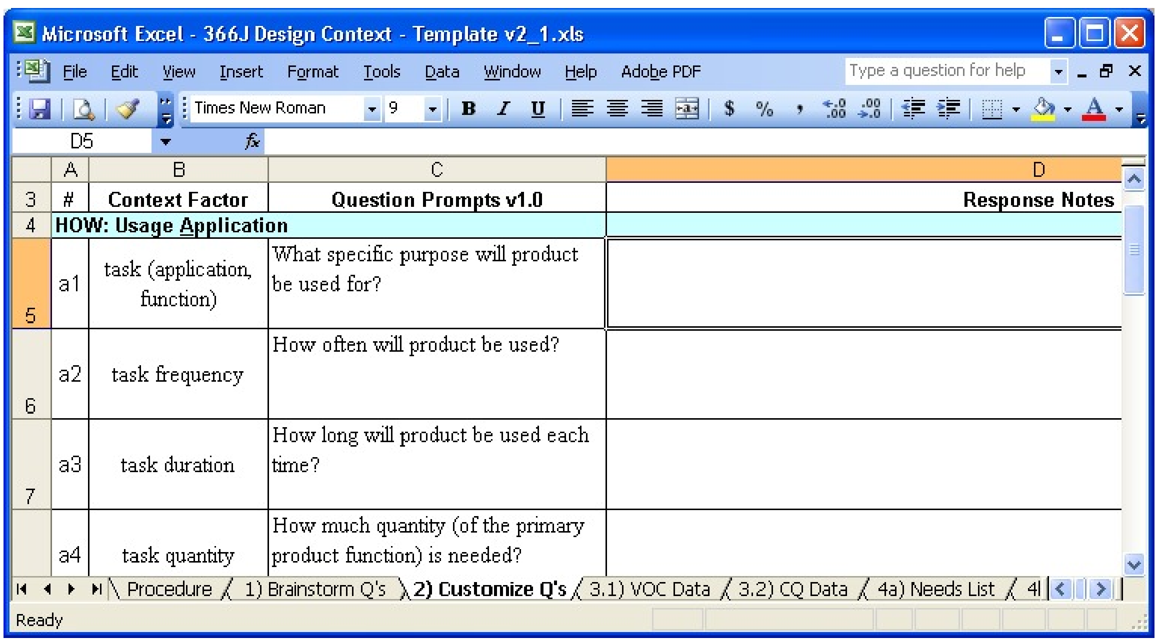


Figure 6.2: MS-Excel Template Supporting Contextual Needs Assessment

6.1.3 Methodology Results – Customized Context Questions

Fourteen out of 20 design teams voluntarily submitted their contextual needs assessment data for the study. Table 6.2 itemizes the products and the needs assessment methodology used by the participating teams. The table documents which elements of needs assessment each team employed and in what order (indicated by labels of 1st, 2nd, and 3rd). As shown in the totals at the bottom of the table, six teams performed articulated use interviews, ten performed like/dis-like interviews, all fourteen used context questioning (although one team's questions only contained 10% context and another team 40%), and four teams reported context scenario data. The number of customer needs in the team's lists ranged from six to 94, and all but two teams weighted their needs lists. Seven of the 14 teams exhibited an exceptionally effective understanding and customization of the context questions template, as indicated by the shaded cells.

Table 6.2: Summary of Design Team's Use of Context Needs Assessment

ID	Product	Articulated Use	Like/ Dis-like	Context Questions[31]	Scenario Formation	Needs List	Weighted
1b	Auto-juicer		1st	2nd		21w	✓
2b	Pizza Oven		1st	2nd		10w	✓
3c	Chiller/warmer			1st		25w	✓
4a	Bread maker		50%	10%		20	
5a	Hand Vacuum		1st	2nd		39w	✓
6c	Toy Auto-pitcher[32]	1st		2nd	3rd	28w	✓
7b	Amphibicar	1st		2nd		6	
8c	Auto Dog Feeder		1st	2nd		17w	✓
9c	Hand Vacuum	2nd	2nd	1st		30w	✓
10a	Kitchen Assistant	2nd	1st	40%	4th	37w	✓
11a	Vacuum Sealer			1st	2nd	94w	✓
12b	Shower Power	1st	2nd	3		39w	✓
13c	Auto-stirrer		1st	2nd	3rd	29w	✓
14a	Swiffer-Vacuum	2nd	1st	3rd		30w	✓
	TOTAL	**6**	**10**	**14**	**4**		**12**

The contextual needs assessment data submitted by the teams was analyzed in detail to assess patterns and insights into how the teams customized the context questions template. A major purpose of this assessment was to glean insight to improve the generalized template for future use. Virtually all of the customized questions the teams wrote took one of the four forms listed in Table 6.3. Modifications which departed from form #1, although helpful for the team's specific project, were often not appropriate for a template intended to be generalizable across products and types of design other than reverse engineering and re-design. A number of changes to the general template are indicated from careful analysis of the data, and these are summarized in the three-part

[31] Shading indicates exceptionally effective customization of the template.
[32] Deployed a customized survey before using the context questions template.

Table 6.4 with changes underlined. More detail is provided in Table B.1 through Table B.3, including examples of the customized template questions from which the changes were derived.

Many teams included suggested responses at the end of a question to facilitate both correct interpretation and consideration of multiple possibilities. This type of information occurs in the template (an earlier version of Appendix A) only in item e8 "What is the cost & availability of possible energy sources (human, battery, gas, electric, biomass)?" Listing suggested responses in the customized template clarifies the question and can make it more specific to the design problem. The drawback is potentially biasing the interviewee with suggested responses to the point of suppressing an actual response.

The use of a scale was included in one team's data ("rate needed durability on a scale of 1-10"). Although a numerical scale is limited, the use of a semantic scale such as those discussed in Chapter 5 has great potential, and is listed in the future work section.

Table 6.3: Four Forms of Context Elicitation Questions

1. *Question Form: What is _______ (context factor)?* *Example: What is the cost & availability of possible energy sources?* This question is the most basic and direct type of elicitation prompt, and is the form of almost all of the elicitation questions in the generalized template. 2. *Question Form: How satisfactory is the current product for (context factor)?* *Example: Are you satisfied with how long the current product's batteries last?* This question bears similarity to a like/dislike interview technique and in the same way it is most effective when the current product (or solution) is similar to the future product such as is the case with reverse engineering. 3. *Question Form: How will (or does) the future (or current) product interact with the context?* *Example: What energy sources would you use to power the product?* This question bears similarity to an articulated use interview, and requires a clear mutual understanding the solution being discussed between the customer and interviewer. 4. *Question Form: What product attributes are needed in light of (context factor)?* *Example: How long should the batteries last for jogging?* Although accurate answers to this question are very valuable, they are often difficult to obtain from customers. Sometimes it is necessary, however, as in the case of customer expectations such as costs.

Table 6.4: Summary of Template Changes Derived from Team Data

#	Context Factor	Template Questions With <u>Modifications</u> (Underlined)
HOW: Usage <u>A</u>pplication		
a0	task (application, function)	What specific purpose will product be used for? <u>How will the product be used?</u>
a3	task quantity	How much quantity <u>of the product's performance</u> is needed?
a6	<u>task interactions</u>	<u>What are objects and substances the product will interact with?</u> <u>What are their characteristics?</u>
a7	<u>operator position</u>	<u>What physical position will the user be in (standing, sitting, hands occupied)?</u>
a8	<u>task quality</u>	<u>What quality of performance must the product provide?</u>
a9	<u>cleaning</u>	<u>How and where might the product be cleaned?</u>

Table 6.4 (Cont.): Summary of Template Changes Derived from Team Data

WHERE: Usage Environment		
e0	surroundings	Where and in what type of surroundings will product be used? What characteristics of the surroundings affect what the product must be like?
e4	space (storage)	How and where will product be stored? How much space is available for storing product?
e5	aesthetics of surroundings	What do the product surroundings look like? How should the product interact w/ the surrounding aesthetics?
e9	noise acceptability	How much noise is acceptable where the product will be used?
e10	environment amenities	

Table 6.4 (Cont.): Summary of Template Changes Derived from Team Data

WHO: Customer Characteristics		
c0	user	Who will use the product? What user characteristics affect what the product must be like?
c1	user skills & education	How skilled/experienced is the user with this task? What is the user's education level?
c2	physical ability	Does the user have any physical conditions that may cause difficulty performing the task? (strength, control, range-of-motion, vision).
c3	user tolerance for complexity	What is the most complex product the user is comfortable using? Must this product be less complex? How long is user willing to spend learning the product?
c8	time expectations: setup & operation	About how much time is the user willing to spend to setup this product? To operate this product? How valuable is saving time?
c9	safety expectations	What is the most dangerous product familiar to the user? Must this one be less dangerous? What product safety concerns does the user have?
c11	purchase context	Who would purchase the product? Where and how might they purchase it? How would the buying decision be made (research, referral, impulse)?
c12	performance expectations	What specific features or qualities are expected?

6.1.4 Survey Results – Designer Perceptions of the Method

An online survey was deployed to measure designer perceptions of the contextual needs assessment method. The survey collected data on: participant background, perceived value of the methodology and re-use likelihood, and perceptions of the usability and usefulness of the methodology. Survey results were extremely positive in all aspects.

Study Participant Background

The response rate was 57 students, 61% of the class of 94. The survey participants self-reported demographics indicate 84% are male and 16% female with an average age of 22.1 (ranging from 21-31) and an average GPA of 3.4 (ranging from 2.5-4.0). Table 6.5 indicates most respondents and their teams were very involved in using the contextual needs assessment method. Table 6.6 shows participants have a high level of previous design experience except for needs assessment and most believe in the importance of design in both education and engineering practice.

Table 6.5: Involvement Using Experimental Method

	Strongly disagree	**Disagree**	**Neutral / Undecided**	**Agree**	**Strongly agree**
I was personally very involved in using the above method.	0% (0)	5% (3)	14% (8)	**54% (31)**	26% (15)
My teammates were very involved in using the above method.	0% (0)	4% (2)	18% (10)	**68% (39)**	11% (6)

Table 6.6: Previous Design Experience and Design Attitudes

Design Experience and Perceptions	**Strongly disagree**	**Disagree**	**Neutral / Undecided**	**Agree**	**Strongly agree**
I have had previous experience with design outside of my UT classes.	9% (5)	26% (15)	12% (7)	**39% (22)**	14% (8)
I have had previous experience with defining project constraints and requirements outside of my UT classes.	5% (3)	30% (17)	9% (5)	**51% (29)**	5% (3)
I have had previous experience with design needs assessment outside of my UT classes.	12% (7)	**42% (24)**	16% (9)	25% (14)	5% (3)
I believe design classes are an important part of the engineering curriculum.	0% (0)	2% (1)	4% (2)	32% (18)	**63% (36)**
I believe design is important in engineering practice.	0% (0)	0% (0)	2% (1)	28% (16)	**70% (40)**
I like design.	2% (1)	4% (2)	18% (10)	**39% (22)**	**39% (22)**

Perceived Value of Methodology and Re-Use Likelihood

Figure 6.3 compares the perceived value of the contextual needs assessment methodology with other "benchmark" methodologies shown in Figure 6.4. It is not possible to benchmark perceptions against traditional needs assessment methods since students do not have either a clear understanding of or experience base with alternative methods. For this reason other aspects of design methodology familiar to the students are used as a comparison. The figures combined show that the new methodology has an equal or higher perceived value than benchmark methods used in the comparison. Both figures distinguish between perceived value for the respondent's actual class design project and the perceived value for a foreign product. The data shows, virtually without exception, that students believe design methodology has even more value for products in a foreign context than for those in a familiar context. The graphs additionally show a level of re-use likelihood averaging midway between neutral and likely.

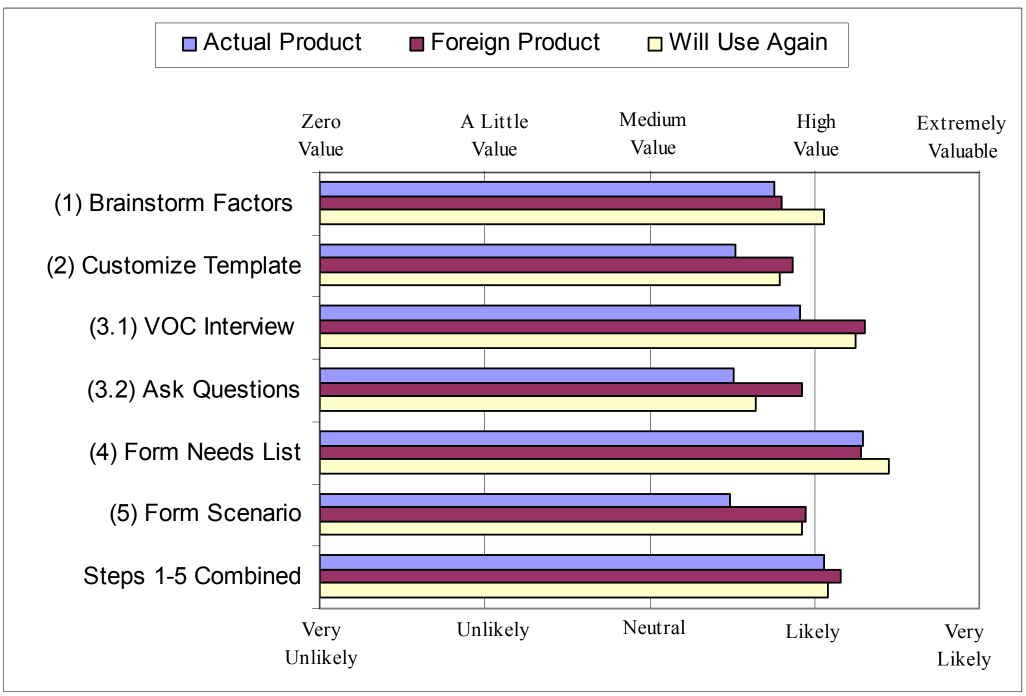


Figure 6.3: Experimental Methodology – Perceptions and Re-Usage Likelihood

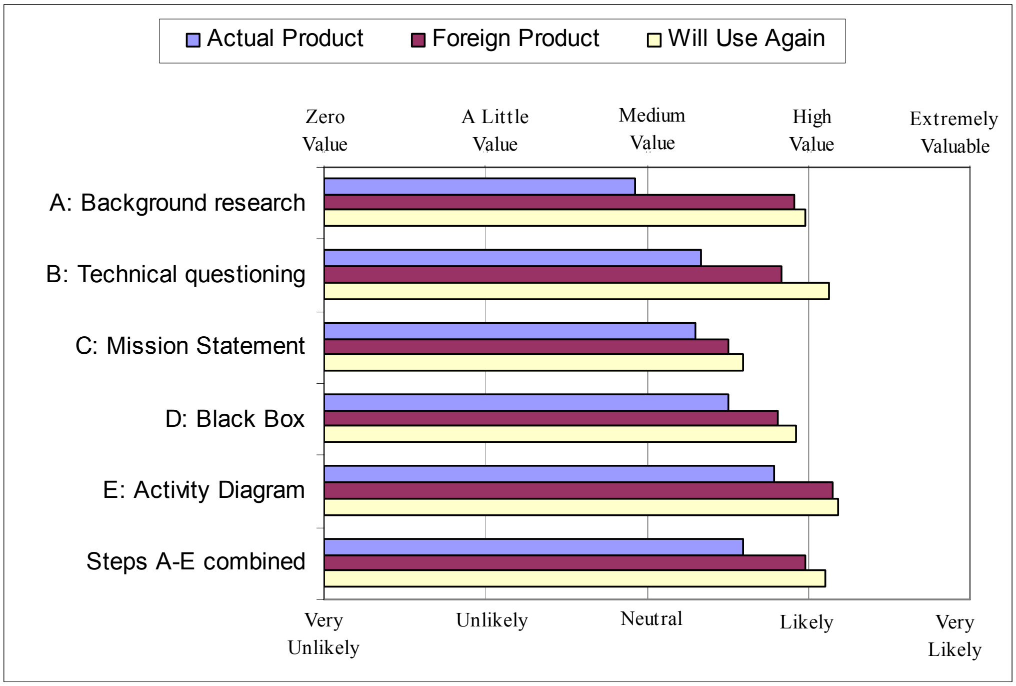


Figure 6.4: Benchmark Methodologies – Perceptions and Re-Usage Likelihood

Perceived Usability and Usefulness of Methodology

Table 6.7 presents survey data rating the perceived usability of the contextual needs assessment method. The data shows a high level of agreement with all statements related to usability, and neutral agreement on whether the method needs improvement. Table 6.8 similarly shows a high level of agreement for the perceived usefulness of the method.

Table 6.7: Perceived Usability of Experimental Method

	Strongly disagree	Disagree	Neutral / Undecided	Agree	Strongly agree
I understand how to gather information using the above method.	0% (0)	2% (1)	2% (1)	**81% (46)**	16% (9)
I like using the above method. [33]	0% (0)	14% (8)	28% (16)	**49% (28)**	9% (5)
The above method does not need improvement. [33]	0% (0)	24% (13)	**49% (27)**	22% (12)	5% (3)
The above method is not difficult to understand and use. [33]	4% (2)	12% (7)	18% (10)	**58% (33)**	9% (5)

Table 6.8: Perceived Usefulness of Experimental Method

	Strongly disagree	Disagree	Neutral / Undecided	Agree	Strongly agree
Using the above method helped me understand the design need.	0% (0)	4% (2)	12% (7)	**66% (37)**	18% (10)
I would consider using the above method again in the future.	0% (0)	0% (0)	14% (8)	**68% (39)**	18% (10)
After using the above method, I do not still feel uncertain about the design need. [33]	0% (0)	14% (8)	28% (16)	**46% (26)**	12% (7)
Using the above method will/did help our re-design provide better customer satisfaction.	2% (1)	5% (3)	21% (12)	**47% (27)**	25% (14)
Our re-design will/would not have been the same even without the above method. [33]	4% (2)	19% (11)	**39% (22)**	32% (18)	7% (4)
I am likely to use the above method again in the future.	0% (0)	2% (1)	25% (14)	**59% (33)**	14% (8)

***Participant Free Response Comments Regarding Methodology*[34]**

The free response comments in the online survey were generally very positive regarding the contextual needs assessment methodology. Sample characteristic responses are listed below, with analysis comments included in italics.

- "[The method] really helps in organizing all of the data … [i]t is very effective in identifying our customer needs." *Some students commented positively on the effortless organizational structure the template provides.*

[33] Opposite question asked and responses reversed for consistent data interpretation (better is to the right).
[34] This section was prepared in collaboration with Julie Linsey.

- "I felt like we overdid the contextual information. A lot of questions we developed had no use for the customer. Some but not all data was used for our CN." *Perceived redundancies of the method were noted; however the needs assessment philosophy is a very thorough coverage because the cost of missing needs is so great.*

- "The method allows for a clear definition of customer needs. Knowing the importance and most vocalized needs helps spotlight the areas of the product that could benefit from redesign."

- "Though it was tedious going through the entire process, I do feel like it ensured the results we were looking for. It would be difficult to make it any more concise." *In the beginning of a project students may find this method very tedious but will see its benefits later.*

The free response results also show that a number of students did not understand or apply the method correctly. The misconceptions evident in their comments suggest that more in-class instruction and instructional materials are needed. It is notable that the survey results were very positive despite these misunderstandings, and plausible that better instruction would lead to even better results and more favorable student perceptions of the method.

- "Don't give such a well done template for the context questions. I felt that one of the best parts of the likes dislikes methods was brainstorming questions to ask in that. So as students when we are given such a defined sheet we loose some of the learning by not thinking of these questions ourselves." *Brainstorming questions is part of the method.*

- "Minimize context questions and let interviewer feel more free to ask questions based on how the interview is flowing." *This is a part of the method. The interviewer is encouraged to stray from the context questions for clarification and to probe more deeply.*

- "The design context process almost needs to be led by the like/dislike method in order to allow the costumer to voice their own thoughts before being prompted by questions." *The method specifies that the like/dislike interview technique should be used prior to the context questions.*

6.1.5 Conclusions

Case 1 demonstrates that within an undergraduate reverse engineering setting, the contextual needs assessment methodology can be realistically deployed and well received, and result in significant improvement in needs assessment. Data analysis identifies eight new context factors and eighteen question revisions to improve the generalized template. Survey results show students rated the contextual needs assessment methodology of medium-high value for their product and high value for a foreign product, comparable to the perceived value of benchmark methodologies such as a black box and activity diagram. The majority of students rate the proposed methodology as usable and useful. Free response comments are favorable towards the method, but reveal misunderstandings indicating the need for more thorough teaching.

6.2 Case 2: Original Design - Assistive Technology

6.2.1 Design Team Background

The second case study was conducted within the graduate Product Design and Prototyping class at UT Austin, which culminates with students delivering fully functional prototypes to local "customers" with physical disabilities. Table 6.9 (from Publication 2) summarizes this course (Green, et al., 2002). The basis of the course is product design, development, and prototyping. Product design projects are the focus of the student efforts, with emphasis on functional, working designs as opposed to the common ink-paper concepts. Students must produce a working, tested, and robust design by the end of a semester, delivering the result to the customer. This focus provides graduate students from mechanical engineering, social work, and special education with a unique opportunity to work with hardware, in contrast to the theoretical focus of most graduate-level courses. Thus, the intent of the course is to produce functional designs based on real product/humanitarian needs. The course includes other innovative pedagogies such as experiential learning with hands-on in-class activities, instruction in drawing for design, and experiential walls as a medium for team presentations.

Table 6.9: Graduate Product Design and Prototyping Class (UT Austin)

Project Source	Local schools with students that have special needs
Funding	Foundation funding, endowment funding, and course fees
Tools	Design methods, Traditional engineering methods, Prototyping lab
Deliverables	Working prototype and manufacturing plan

Projects are selected which require the novel synthesis of low to medium technology (not high technology), and involve $100-$300 of funding. Projects are solicited from facilities that include persons with disabilities: the Austin State School and two local school districts. Interdisciplinary design teams of 4-5 graduate students from engineering, social work, and special education are formed using team selection algorithms (Jensen and Wood, 2000) based on MBTI, Six Hats, and technical/hands-on skills. The teams work with supervisors, teachers, and the students (customers) at the schools to refine project ideas into electromechanical design problems related to the customers' occupations and learning environments. These projects present a unique challenge to the design teams in that most of the problems admit solutions that provide assistive technologies for the tasks currently performed by the customers. Table 6.10 shows examples of projects completed since the course's inception.

Table 6.10: Examples of Past Design Projects in the Graduate Product Design Class.

- Assistive bowling device (Figure 6.5)
- Key turner usable with limited strength and range of motion (Figure 6.6)
- Switch activated ball thrower (Figure 6.7)
- Visual phone interface for deaf persons
- Device to wrap baking potatoes in foil using only one hand
- Letter labeler to assist persons with disabilities on a job site
- Sand-bagging system to assist persons with disabilities on a job site
- Electro-mechanical can crushing system
- Sensory-stimulation system for persons with disabilities
- Décor chip sorter to assist persons with disabilities on a job site
- Accessible shelving system for persons with disabilities

After initial project choices and visits to their customer locations in Austin, the students systematically follow the product development process (Otto and Wood, 2001) taught in the class. Design teams produce a proof-of-concept, an alpha prototype, and a beta prototype at key milestones. Students are required to deliver a package at the end of the semester to the customer that includes: a working device or system that satisfies the customer needs, a brief report documenting the project results and chronological decisions, a Bill-of-Materials, an illustrated manufacturing plan, and a brief user's manual. Each team also submits a 3-page article and a 5-minute videotape to the annual Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) international student design competition (2005i). Since 1994, twelve teams from UT Austin have been selected to present their designs at the annual RESNA conference.

For illustration, Figure 6.5 through Figure 6.7 show three RESNA winners that have been used in Austin schools. The assistive bowling project focused on the design of a bowling device that would allow people, especially children, with disabilities to bowl with more autonomy and normalization than current wheelchair bowling ramps offer. The innovative design enhanced accessibility for children with many types of disabilities and greatly increased the performance of the bowling ball ramp. The adaptive key handler (Figure 6.6) allows a wheel-chair user with severely limited strength and range of motion to use key-operated elevators and doors. The device was designed to be compact, portable and lightweight for use by an 11-year-old student with rheumatoid arthritis. His use of a wheelchair requires riding the elevator to attend classes. The switch activated ball thrower (Figure 6.7) is a portable device enabling students with limited mobility, strength, and coordination to participate in ball throwing activities integrated with their peers. Publication 1 is the RESNA paper reporting the design, prototyping and testing of the switch activated ball thrower (Green, et al., 2000).

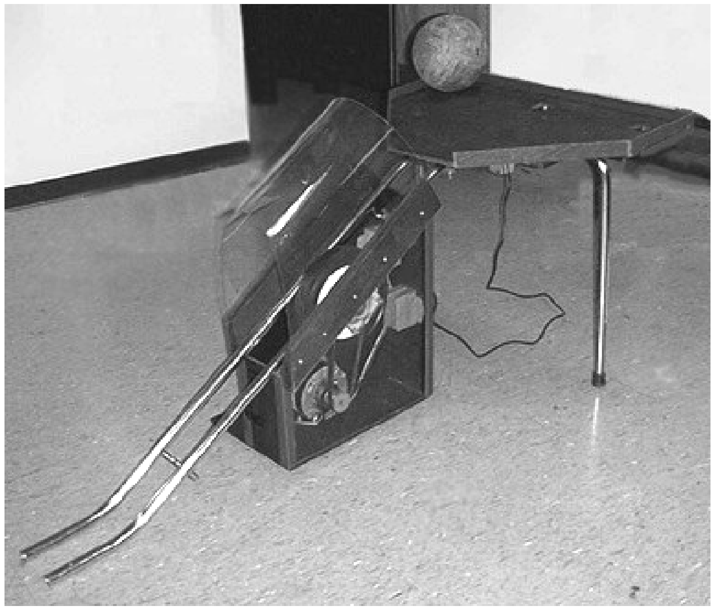


Figure 6.5: Assistive bowling device (Cox, et al., 1999).

Figure 6.6: Assistive key handler (Shimek, et al., 2001).

Figure 6.7: Switch Activated Ball Thrower (Green, et al., 2000).

6.2.2 Classroom Delivery of the Methodology

The contextual needs assessment methodology was delivered for the graduate prototyping class in essentially the same way as for the undergraduate reverse engineering course. Details are contained in Section 6.1.2.

6.2.3 Methodology Results – Customized Context Questions

The class is divided into three teams of 5 to 6 students each, and all three teams submitted their contextual needs assessment data for the study. Table 6.11 itemizes the design needs addressed by each team.

Similar to the reverse engineering undergraduate teams, virtually the entire customized template questions in the Case 2 study took one of the four forms listed in Table 6.3. Again modifications which departed from form #1, although helpful for the specific project, were often not appropriate for a template intended to be generalizable across products and types of design other than reverse engineering and re-design. Changes to the general template indicated from careful analysis of the data are summarized Table 6.12 with changes underlined. More detail is included in Table C.1

through Table C.4 (Appendix C: p. 207), including examples of the customized template questions from which the changes were derived.

Table 6.11: Summary of Graduate Teams for Case Study 2

Team	Design Need Statement
AutoFold [AF]	Prepare clean laundry for storage with portability and switch activation.
AutoRocker [AR]	Automatically provide a rocking motion to a chair to sooth students with cerebral palsy and other disabilities.
Stimulation Nation [SN]	Provide rehabilitative stimulation to visual and other senses when activated by visually impaired students in a classroom.

Table 6.12: Summary of Template Changes Derived from Team Data

#	Context Factor	Template Questions With Modifications (Underlined)
HOW: Usage Application		
a1	task application	What specific purpose(s) will product be used for?
	task function	What major function(s) should the product provide?
	task process	How will product change the current task process? (What is the current process)?
	task rate	At what rate should the primary function be provided?
a6	transportation type & amount	How often, how far, and in what way will product be transported?
	task quality	What quality of the primary function is needed?
WHERE: Usage Environment		
	surroundings (sound)	How noisy are product surroundings? How much noise from the product is acceptable?
e5	space (storage)	How will product be stored? How much storage space is available?
e9	energy availability & cost	What is the cost & availability of possible energy sources (human, battery, gas, electric, biomass)? How should product be powered?
WHO: Customer Characteristics		
c0	user	Who will use (choose, and buy) the product?
c8	time expectations: setup & operation	How much time is acceptable for setup? How much time and attention can be provided for operation?
c9	safety expectations	What is the most dangerous product familiar to the user? Must this one be less dangerous?

		What safety features are you expecting? What dangers must be avoided?

6.2.4 Survey Results – Designer Perceptions of the Method

An online survey was deployed to measure designer perceptions of the contextual needs assessment method, essentially identical to the one discussed in Section 6.1.4. The survey collected data on: participant background, perceived value of the methodology and re-use likelihood, and perceptions of the usability and usefulness of the methodology. Similar to Case 1, survey results for Case 2 were extremely positive in all aspects.

Study Participant Background

The response rate was 16 students, 94% of the class of 17. The survey participants self-reported demographics indicate 75% are male and 25% female with an average age of 23.3 (ranging from 21-26). A number of the respondents are first semester graduate students, and did not report an average GPA. A significant number of students recently came to the US to attend graduate school, but virtually all are fluent in English. Table 6.13 indicates most respondents and their teams were very involved in using the contextual needs assessment method. Table 6.14 shows participants have a high level of previous design experience and virtually all believe in the importance of design in both education and engineering practice.

Table 6.13: Involvement Using Experimental Method

	Strongly disagree	Disagree	Neutral / Undecided	Agree	Strongly agree
I was personally very involved in using the above method.	0% (0)	0% (0)	12% (2)	**50% (8)**	38% (6)
My teammates were very involved in using the above method.	0% (0)	0% (0)	12% (2)	**75% (12)**	12% (2)

Table 6.14: Previous Design Experience and Design Attitudes

Design Experience and Perceptions	Strongly disagree	Disagree	Neutral / Undecided	Agree	Strongly agree
I have had previous experience with design outside of my UT classes.	6% (1)	12% (2)	0% (0)	**56% (9)**	25% (4)
I have had previous experience with defining project constraints and requirements outside of my UT classes.	0% (0)	31% (5)	0% (0)	**69% (11)**	0% (0)
I have had previous experience with design needs assessment outside of my UT classes.	6% (1)	19% (3)	6% (1)	**62% (10)**	6% (1)
I believe design classes are an important part of the engineering curriculum.	0% (0)	0% (0)	0% (0)	25% (4)	**75% (12)**
I believe design is important in engineering practice.	0% (0)	0% (0)	6% (1)	25% (4)	**69% (11)**
I like design.	0% (0)	0% (0)	0% (0)	44% (7)	**56% (9)**

Perceived Value of Methodology and Re-Use Likelihood

Figure 6.8 compares the perceived value of the contextual needs assessment methodology with other "benchmark" methodologies shown in Figure 6.9. It is not possible to benchmark perceptions against traditional needs assessment methods since students do not have either a clear understanding of or experience base with alternative methods. For this reason other aspects of design methodology familiar to the students are used as a comparison. The figures combined show that the new methodology has an equal or higher perceived value than benchmark methods used in the comparison. Both figures distinguish between perceived value for the respondent's actual class design project and the perceived value for a foreign product. The data shows virtually without exception that students believe design methodology has even more value for products in a foreign context than for those in a familiar context. The graphs additionally show a level of re-use likelihood averaging midway between neutral and likely.

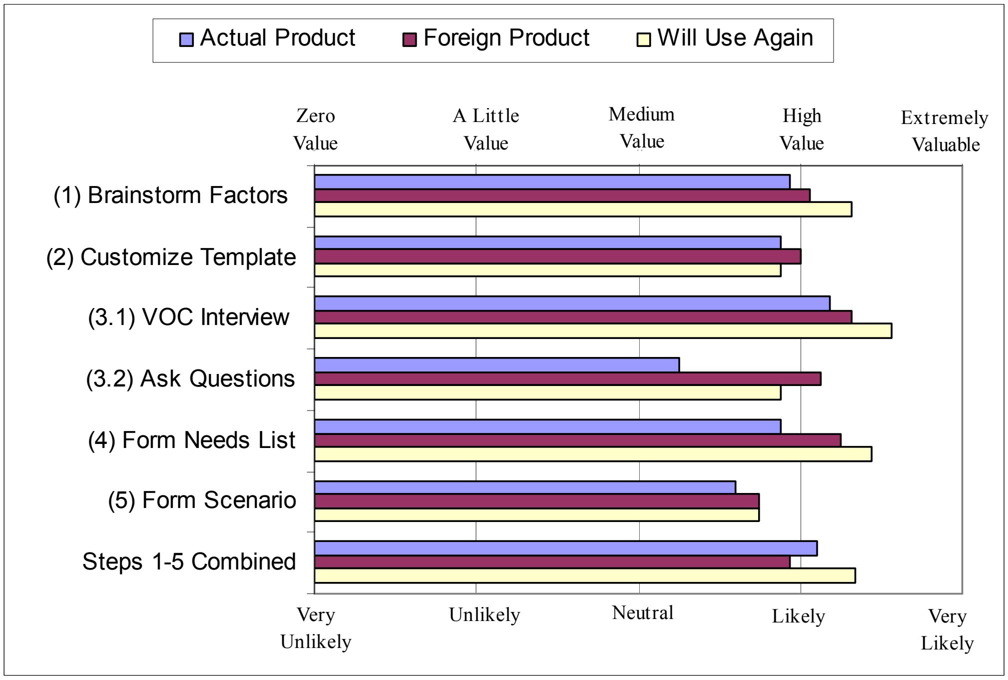


Figure 6.8: Experimental Methodology – Perceptions and Re-Usage Likelihood

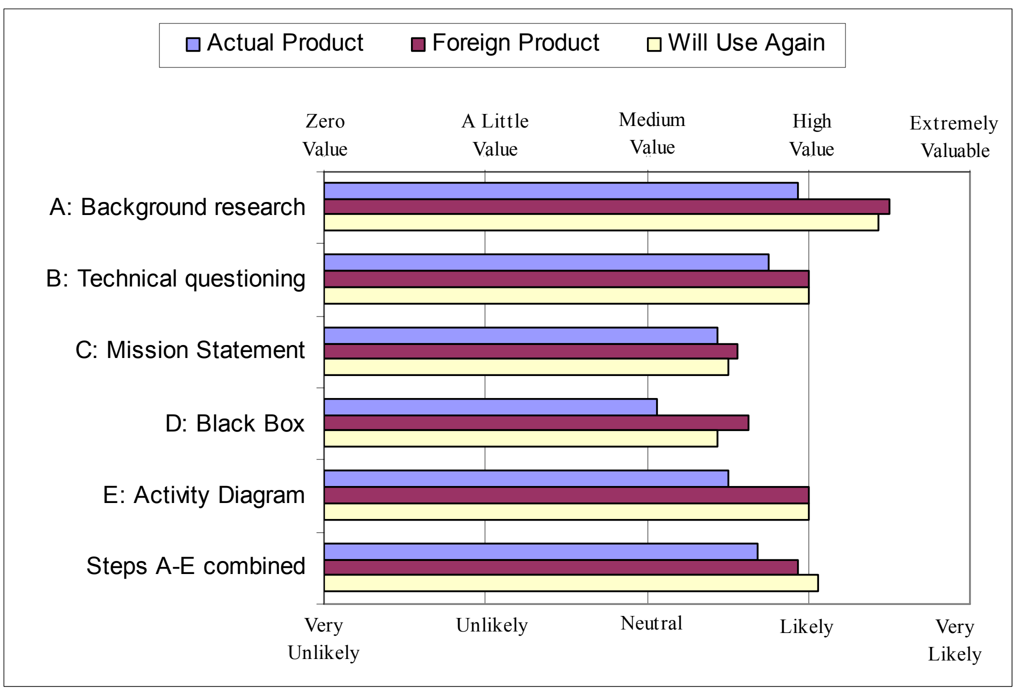


Figure 6.9: Benchmark Methodologies – Perceptions and Re-Usage Likelihood

Perceived Usability and Usefulness of Methodology

Table 6.15 presents survey data rating the perceived usability of the contextual needs assessment method. The data shows a high level of agreement with all statements related to usability, and neutral agreement on whether the method needs improvement. Table 6.16 similarly shows a high level of agreement for the perceived usefulness of the method.

Table 6.15: Perceived Usability of Experimental Method

	Strongly disagree	**Disagree**	**Neutral / Undecided**	**Agree**	**Strongly agree**
I understand how to gather information using the above method.	0% (0)	0% (0)	6% (1)	**69% (11)**	25% (4)
I like using the above method.[35]	0% (0)	0% (0)	6% (1)	**62% (10)**	31% (5)
The above method does not need improvement.[35]	6% (1)	19% (3)	**62% (10)**	12% (2)	0% (0)
The above method is not difficult to understand and use.[35]	0% (0)	0% (0)	19% (3)	**69% (11)**	12% (2)

Table 6.16: Perceived Usefulness of Experimental Method

	Strongly disagree	**Disagree**	**Neutral / Undecided**	**Agree**	**Strongly agree**
Using the above method helped me understand the design need.	6% (1)	0% (0)	6% (1)	**69% (11)**	19% (3)
I would consider using the above method again in the future.	0% (0)	0% (0)	12% (2)	**50% (8)**	38% (6)
After using the above method, I do not still feel uncertain about the design need.[35]	0% (0)	12% (2)	6% (1)	**75% (12)**	6% (1)
Using the above method will/did help our re-design provide better customer satisfaction.	0% (0)	0% (0)	19% (3)	**69% (11)**	12% (2)
Our re-design will/would not have been the same even without the above method.[35]	0% (0)	6% (1)	**62% (10)**	19% (3)	12% (2)
I am likely to use the above method again in the future.	0% (0)	0% (0)	12% (2)	**69% (11)**	19% (3)

[35] Opposite question asked and responses reversed for consistent data interpretation (better is to the right).

Participant Free Response Comments Regarding Methodology

The free response comments in the online survey were very positive regarding the contextual needs assessment methodology. Sample characteristic responses are listed below, with analysis comments included in italics.

- The method is very effective at capturing customer/design needs in frontier design scenarios and was heavily used by my team to build the basis of our entire customer interview activities.

- I feel very confident that we asked all the questions we needed, due in large part to having such a complete checklist.

- This method is extremely effective. If I had only used the like/dislike method my team would have very little information about the customer needs of our product. The like/dislike method is very difficult to use when designing a very innovative and different product.

- [My team discovered] 'extra' information from the customer by using the 5-step procedure. There is no doubt in that.

- This method helps us gather the data for the frontier design [context] easily; in a normal design method it will take a lot of interviews to get the data.

Some criticisms of the contextual needs assessment method and suggested improvements are as follows:

- … this method is very good [and efficient], but it takes a lot of time …

- There's the assumption that the customer knows what he needs.

- At times what a customer communicates [is inaccurate] … observation and interaction point those discrepancies out and can be useful in the design process. *This is a classic weakness of customer reported information. The articulated-use portion of the interview prescribes observation, but this is limited to observing the environment when no comparable product exists.*

- … some customers who do not think of a product in such detail and tend to get annoyed or bored. *Some teams prioritize questions and adapt the list to the customers attention span.*

- Brainstorming questions … after an initial discussion with the customer … may facilitate forming a much more effective questions template.

- More clearly define some of the template questions …
- I think the method should involve the manufacturing part of the design process too.
- [Provide] more generic context questions … to capture an even wider sphere of customer/design needs. [Provide further guidance] in generation of specific questions for peculiar design needs from the [template]. *Increasing the breadth of the template is one result of these case studies, and continues as future work.*
- Most times when the customer is asked to give quantitative values … the values are very [far from practical]. It is always better to perform such interviews … using an existing product or compare the expected values with some analogous product … *This is an important avenue for future work, and can be addressed in large part by the development of semantic inquiry scales as proposed in the future work section.*

6.3 Case 3: Controlled Interview Study - Village Cooking System

Observing interviews conducted under controlled conditions allows for a quantitative evaluation of the effectiveness and efficiency of the contextual needs assessment methodology. For this purpose an interview study was designed in which participants with traditional customer needs gathering training (without contextual assessment) interviewed an experimenter role-playing a customer. The experimenter answered interview questions based on a reference set of information prepared in advance[36]. The information gathered by study participants during the interview was recorded and later compared with the reference information to determine how effectively the interview elicited the reference information. The experimental group gathered significantly more contextual information (with a high statistical confidence level) than the control group using traditional needs assessment methods. Additionally, surveys measuring participant perceptions of the methodology showed equal or greater acceptance and confidence in the experimental methodology than in the control methodology.

[36] The assistance of Uma M Namasivayam and Abiola M Ajetunmobi is gratefully acknowledged.

6.3.1 Study Participant Background

An email to senior capstone design students offering extra credit for participation in the study resulted in 10 (out of 59) students volunteering for the study; 3 female and 7 male. All students recruited for the study had previously received classroom instruction for traditional customer needs assessment and project practice in the context of a reverse engineering project. The self-selected volunteers for this study are believed to disproportionately represent both students highly motivated by an interest in customer interviews as well as students highly motivated by the extra credit. Table 6.17 presents aggregate self-reported background data on the study participants showing some participants had previous design experience and all placed a high value on design both in education and in engineering practice.

To control against bias from previous exposure to the control methodology, two additional questions were asked regarding familiarity with contextual needs assessment (possibly gained from students learning the method in other courses, for example) and familiarity with the details of the experiment (possibly learned from previous study participants). No study participants recalled seeing the method before and none reported learning of the experiment from other students (they were asked not to disclose details to other students until the study was complete).

Table 6.17: Interview Study Participant Background

#	Statement	Mean Rating (Strongly Disagree / Disagree / Neutral / Agree / Strongly Agree)
	Previous Familiarity with Design Need	
1	I have used a stove or oven (other than a microwave) many times.	4.6
2	I am somewhat familiar with cooking in remote areas such as on camping trips.	3.9
3	I am somewhat familiar with cooking practices in remote villages.	3.1
	Previous Design Experience	
4	I have had previous experience with design outside of UT classes.	3.5
5	I have had previous experience with defining project constraints and requirements outside of UT classes.	3.6
6	I have had previous experience with design needs assessment outside of UT classes.	3.3
	Perceived Importance of Design	
7	I believe design classes are an important part of the engineering curriculum.	4.5
8	I believe design is important in engineering practice.	4.6

6.3.2 Interview Study Protocol Description

Table 6.18 provides an overview of the interview study procedure, with more detail contained in Table 6.19 and Table 6.20. After completing a background information survey, study participants interview the researcher role-playing a villager from an area in India needing an improved cooking system. Participants are given as much time as needed for the interview, and encouraged to use any interview technique desired (they have received training in traditional needs assessment interviewing in a previous course). After the first interview, participants complete survey A1 to indicate their perceptions of the effectiveness and usability of the first interview and give written comments if desired. Participants then complete answers to the contextual template questions (an earlier version of Appendix A) based on the knowledge gained during the interview. They then complete survey A2 to indicate any changes which may have occurred in their perceptions due to filling out the template. The answers given in the template and survey A2 are taken as the "control" data.

After completing part A, in part B of the experiment the participant is first informed of the importance of contextual information in design illustrated with examples. The participant then completes the second part of the interview, this time using the contextual template as a guide. Since the template is already partially completed from part A, a different pen color is used to add and/or modify information recorded from the first interview. Finally, participants complete survey B (with identical questions to the surveys in part A) and have the opportunity to write suggestions or comments. The completed template (in two colors) and final survey information are taken as the "experimental" data. Note that the experimental method encompasses both parts A and B, thus experimental participants complete both parts.

Table 6.18: Controlled Interview Study: Overview

		Control	**Experiment**	**Step**	**Data Collected**
Part A	1	✓	✓	Survey 0	Demographics, Design experience, Design problem domain knowledge
	2	✓	✓	Interview 1: Freeform	Interview technique used Time to complete
	3	✓	✓	Survey A1	Method effectiveness and usability Comments
	4	✓	✓	Contextual Template	Information gathered in interview
	5	✓	✓	Survey A2	Method effectiveness and usability Comments
Part B	6		✓	Participant Training	N/A (Learn about use of context factors)
	7		✓	Interview 2: Contextual	Information gathered in interview (cumulative) Time to complete
	8		✓	Survey B	Method effectiveness and usability Comments

Table 6.19: Controlled Interview Study: Detailed Protocol Part A

<u>Part A: Freeform Interview</u>

1. <u>Informed consent</u> form review and sign.

2. <u>Survey 0</u>: Fill out the short survey to give us some background information we'll need for the study data.

3. <u>Introductions</u>: Meet [customer], read the introductory problem statement and ask any questions it raises.

4. <u>Interview #1</u>: "Interview [customer], recording responses on paper. You may take some time to collect your thoughts if needed, and you may ask questions as long as you wish. Keep in mind that [customer] is not an engineer, and you will probably find that specific questions yield better results than vague prompts."
   Record Interview Approach: ______________________________

5. <u>Survey A1</u>: Fill out the short survey on how effective you believe the interview approach was, and how confident you are in your understanding of the design need.

6. <u>Contextual Template</u>: Fill in the "Context Questions Checklist" form (to be provided). ([customer] is no longer available to answer questions). PLEASE READ directions.

7. <u>Survey A2</u>: Fill out the short survey on how effective you believe the interview approach was, and how confident you are in your understanding of the design need.

Table 6.20: Controlled Interview Study: Detailed Protocol Part B

<u>Part B: Contextual Interview</u>

1. <u>Review information</u>: Review information (to be provided) discussing context factors that influence what customers want in a product.

2. <u>Interview #2</u>: "Interview [customer] again, this time using the *context questions checklist* as a reference to help insure that important factors are not overlooked." Use a **different color pen** to modify and add to your previous answers. Don't be afraid to keep re-phrasing the questions until you get a good answer. PLEASE READ directions. Provide a quick example.

3. <u>Contextual Template</u>: Complete any remaining answers to the questions about the design need on the form to be provided.

4. <u>Survey B</u>: Fill out the short survey on how effective you believe the interview approach was, and how confident you are in your understanding of the design need.

6.3.3 Results: Information Scores, Efficiencies, and Survey Responses

Contextual Information Scores

Table 6.21 summarizes the percentage of contextual information recorded by study participants following the first and second phases of the study, and detailed per-question scores are presented in Appendix D: (p. 211) Table D.1 through Table D.3. The right-most column of the table labeled "Δ" represents the contextual information increase reported between the end of the control interview and the end of the experimental interview. The percentages represent the portion of the reference information recorded, rated according to the scale shown in Table 6.22 and dividing each score by 3 such that 100% corresponds to the maximum theoretical score. An example of how participant answers were scored is given in Table 6.23. The summary table breaks the contextual information scores down into three categories corresponding to the major contextual categories of how, where, and who. For the freeform interview, participants scored significantly better on the "how" questions than the other categories, but showed much less improvement in this category when using the contextual interview. In every case the average score showed an increased of at least 28% points, and the average over all questions (weighted according to the number of questions in each section) increased by 49% points. Although these scores are sensitive to the contextual questions included on the template and the scoring rubric, the results strongly support the value of the methodology for increasing contextual information gathered.

A number of factors could explain why contextual interview scores do not average above 70%, including loss of information in the experimenter answering the question, in the participant's interpretation of the answer, and in transcribing the answer to paper. These results indicate that some information loss is inevitable in the interview process. Additionally, it was noticed during the interviews that many participants tended to ignore second questions in the elicitation prompts. There is value in splitting compound questions into separate questions for clarity (for example, "How and where would …" becomes "How would …? Where?). However, the advantages are offset by this tendency of some interviewers to overlook the second question, and this could also be a contributor to scores lower than 100%.

Table 6.21: Contextual Information Scores – Summary

	Freeform Interview	Contextual Interview	(A+B) – (A)
	A	**A+B**	Δ
HOW: Usage Application	37%	65%	28%
WHERE: Usage Environment	15%	61%	46%
WHO: Customer Characteristics	16%	79%	63%
Average[37]	**20%**	**69%**	**49%**

Table 6.22: Contextual Information Data Scoring Rubric

Score	Assessment of Answer
-1	Incorrect or misleading
0	Blank (unknown)
1	Major information omissions
2	Minor information omissions
3	Complete and correct (within reason)

Table 6.23: Contextual Information Data Scoring Example

Context Question: "How valuable is it if the product saves 1 hour of the user's time? (What could they do with that time?)"

Reference Answer: "Villager can earn ~$0.10/hr. Could do more farm work."

Score	Sample Participant Answers
-1	Time is abundant in this culture.
0	[Blank]
1	Could do more work.
2	Could earn ~$0.10/hr.
3	Could earn ~$0.10/hr. Could do more farm work.

[37] The average is weighted by the number of questions in each section (6, 11, and 11, respectively).

The statistical confidence of the contextual information scores in Table 6.21 may be evaluated with a paired student T-test using the difference of each participant's scores giving a sample (n=10) with an average of 48.8% and a standard deviation 15.0% (Table 6.24). The hypothesis that the contextual interview (A+B) averages at least a 30% greater absolute value of contextual information compared to the freeform interview alone (A) is supported with a confidence level of 98.5%.

Table 6.24: Contextual Information Scores – Statistical Confidence

Sample Size (n)	**10**
Δ Avg.	**48.8%**
Δ StdDev	**15.0%**
Confidence Δ ≥ 0%	**99.99%**
Confidence Δ ≥ 30%	**98.5%**

Interview Efficiencies

Although perhaps the greatest objective of needs assessment is the amount of useful information gathered, the realities of time and budget constraints require consideration of efficiency as well. In some cases the greatest constraint may be the availability and attention span length of eligible interviewees, making a high-efficiency assessment method extremely valuable by enabling more thorough information gathering. Table 6.23 summarizes interview efficiency scores for the freeform interview (A), the entire contextual needs assessment process (A+B), and the context template alone (Δ). The results show that from the perspective of gathering contextual information, the context template yields twice the information per minute than freeform interviewing (2.8 compared to 1.4). However, it is important to note that the freeform interview offers important aspects: it gathers more information than just context, it is preparatory for use of the context template, and it has the potential to uncover contextual issues that may have been missed with the template alone. For these and other reasons, the freeform interview remains a critical first phase of the proposed contextual needs assessment methodology.

Table 6.25: Interview Efficiency Scores

	Freeform Interview	Contextual Interview	(A+B) – (A)
	A	**A+B**	Δ
Time (minutes)	13.8	31.3	17.5
Ratio [%Context / Time]	1.4	2.2	2.8

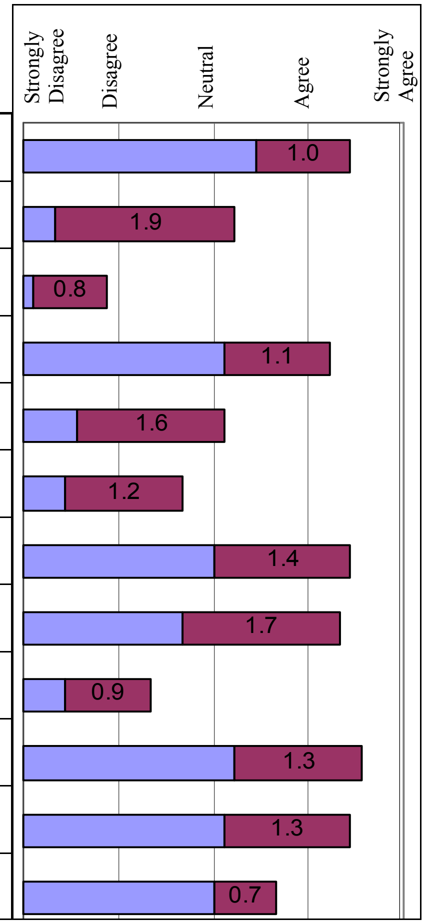
Survey Responses

Participants filled out two identical surveys, one after the freeform interview and answering the contextual questions and one after the contextual interview. The survey measured participant perceptions of the method (either freeform or contextual, depending on which time). Prompts addressed the usefulness, usability, and re-use likelihood of the methodology. Table 6.26 shows the average responses[38] graphically, with the leftmost bar representing the answer after the freeform interview and the rightmost bar showing the change in the average answer after the contextual interview. On a 1-5 scale, the average increased from 0.7 to 1.9 for all questions, indicating that in every case the contextual interview method has greater perceived usefulness, usability, and re-use likelihood than the freeform method.

[38] One participant's survey data was omitted due to gross answer inconsistencies indicating question confusion, resulting in n=9 for the survey data.

Table 6.26: Survey Responses

1	This interview approach helped me understand the design need.
2	This approach to interviewing was effective.[39]
3	This approach to interviewing does not need improvement.[39]
4	I understand how to gather information using this approach.
5	I like this approach to interviewing.[39]
6	This approach is not difficult to understand and use.[39]
7	I would consider using this approach again in the future.
8	I am likely to use this approach again in the future.
9	... I do not feel uncertain in my overall understanding of the design need.[39]
10	This approach uncovered important information for design.
11	This approach helped me understand the design need.
12	A design project would not be about the same even without … this method.[39]



In order to guard against experimenter induced bias, the subject posing as a customer for the interview was instructed to give the same reference answers to certain questions whenever they were asked, whether in part A or part B. To assess whether consistency in responses was achieved, two questions were included in the survey to measure participant perceptions of whether the "customer" was withholding information during part A. The survey question provided an agreement scale to respond to two prompts, "The person I interviewed answered the questions I asked effectively" and, "The person I interviewed was difficult to obtain information from." In all parts of the experiment participant responses agreed that questions were answered effectively and the

[39] Opposite question asked and responses reversed for consistent data interpretation (better is to the right).

person interviewed was *not* difficult to obtain information from. Although response averages differed from part A to part B, the difference was minor (±0.2), suggesting that the experimental "customer" was consistent throughout the interviews.

Survey Free Response Comments

Each survey included a free response section inviting participants to write comments or suggestions related to the contextual needs assessment process. Table 6.27 presents samples of comments characteristic of those received. The vast majority of comments further supported the inadequacy of the freeform interview and the high perceived value of the context template. One participant noted before seeing the context template (comment 5-a1) that there was a need for "general questions or guiding statements to spark thoughts."

Table 6.27: Sampling of Survey Free Response Comments

	Participant Comments Following Part A (Freeform Interview)
1-a2	This approach did not find all of the customer requirements or important engineering specifications.
3-a2	… I feel I missed a lot of things I need to know … to produce and effective design
5-a1	[Need] some general questions or guiding statements to spark thoughts

	Participant Comments Following Part B (Contextual Interview)
3-b	The list seems to cover all bases … using this method will be very beneficial to engineers … in a wide array of situations.
4-b	The [template] allowed for a more effective systematic approach to interviewing

6.4 CASE 4: ORIGINAL FRONTIER PRODUCT DESIGN – PERSONAWARMTH

The original design case study illustrates the application of the contextual needs assessment methodology within the context of a design process complete from need identification to prototyping[40]. The case study illustrates key insights derived from the application of the methodology to design for a frontier design need. The following

[40] The PersonaWarmth design project was performed in collaboration with George Malinoff.

sections present results of the design process organized according to the design process shown in Table 6.28.

Table 6.28: PersonaWarmth Design Process

1. **<u>Task Clarification (Section 6.4.1)</u>**
    1.1. Need Identification - Exploratory Interviews
    1.2. Need & Customer Definition - Mission Statement
    1.3. Product Family Research
    1.4. Black Box
    1.5. Technical Questioning
    1.6. Contextual Needs Assessment
        1.6.1. Brainstorm & Customize Templates
        1.6.2. Conduct Interviews
        1.6.3. Form Customer Needs List
        1.6.4. Form Context Scenario
    1.7. Activity Analysis

2. **<u>Concept Development (Section 6.4.2)</u>**
    2.1. Functional Model
    2.2. Solution Generation - Brainstorm/Mind Map
    2.3. Morphological Matrix
    2.4. Concept Variant Formation
    2.5. Concept Selection - Pugh Chart
    2.6. Modeling and Estimation

3. **<u>Detailed Design and Prototyping (Section 6.4.3)</u>**
    3.1. Detail Design
    3.2. Prototyping and Experimentation
    3.3. Final Recommendations

6.4.1 Task Clarification Results

Need Identification - Exploratory Interviews

The desired problem characteristics in Table 6.29 guide the search for a design need. The "must" items correspond to the purposes of the case study, and the "should" and "nice" items correspond to issues that would enhance the purposes of the case study but are not critical. With these criteria in mind, an extensive search process including brainstorming, background research, and exploratory interviews is conducted to identify potential target frontier contexts, individuals with expertise in these contexts, and design needs within these contexts. Exploratory interviews include a visually impaired individual, a student who grew up in China, and a teacher who formerly taught at a university in China. The search process culminates in a decision to design a portable personal hand warming device, dubbed the "PersonaWarmth," for use primarily by Chinese university students as described in the next section.

Table 6.29: Desired Design Problem Characteristics

- *(Must)* Need is in a frontier design context (from designer's perspective)
- *(Must)* Need is anticipated to require product attributes specific to the context
- *(Must)* Reasonable scope: 10-40 functions; simple and small enough to prototype
- *(Should)* Dominated by mechanical engineering flows (e.g. energy, force, material)
- *(Nice)* Non-trivial operating principle
- *(Nice)* An actual customer who is invested enough to provide feedback
- *(Nice)* High impact on human-need

Need and Customer Definition - Mission Statement

The product need is defined as a: "portable, personal hand warming device for university students in China." Table 6.30 outlines the product mission statement. For the purposes of the case study, the scope is limited to focusing on the primary market (university students in China), and leaving exploration of secondary markets for future work. The possible use of phase-change materials and correctly identifying and meeting context-specific needs are both avenues for creative design. The existence and accessibility of context-specific needs can not be determined until after the task clarification phase is completed.

Table 6.30: Mission Statement: PersonaWarmth

Product Description: maintain hands at comfortable temperature, with portability **Key Goals:** • Functional prototype in two months • Address context-specific needs and achieve customer satisfaction **Primary Market:** • University students in China **Secondary Market:** • Teachers and non-university students in China • Rural villagers, commuters (by bus, foot, or bicycle), merchants, factory workers • People in other countries with similar socio-economic and climatic conditions **Assumptions:** • Must maintain comfortable temperature with portability in freezing temperatures • Minimal power consumption relative to US products • Minimal purchase and operating costs relative to US products **Avenues for Creative Design:** • Phase-change materials • Entering a growing market with possible unmet context-specific needs **Scope Limitations:** • Focus on primary market and explore secondary markets later • Must be small and simple enough to prototype

Product Family Research

Existing products analogous to the design need are researched, and those listed in Table 6.31 are purchased for exploration and use during interviews. These products are representative of chemical, solid fuel, liquid fuel, battery, and re-usable crystallizing warmers. Exploration of these products reveals certain key attributes, such as the danger of the fuel warmers, the minimal heat of the battery warmer, and the short duration of the crystallizing fluid.

Table 6.31: Product Family Exploration

Product	Cost	Fuel	Heating Description
Chemical Packet	$0.80/pair	7 hr/unit	Warms when opened
Liquid Fuel	$10	8 hr/few ounces	Hot – “burns” with no flame
Solid Fuel Stick	$2.50	2-3hr/stick	Toasty – smolders with no flame
Battery Socks/gloves	$16 (socks)	6-7hr/2 D cells	A little warm – electric element
Crystallizing Fluid	$3	¾ hour	Hot then warm; resets w/ boiling

Black Box

Table 6.32 presents a black box model of the PersonaWarmth product. From an energy balance perspective, the primary product function is to portably maintain hand comfort by limiting net heat loss. Material flows are significant and heavily dependent upon context environment and usage activity.

Table 6.32: PersonaWarmth Black Box

<table>
<tr><th>Flow Type</th><th>Input Flows</th><th rowspan="4">Portably Maintain Hand Comfort by Limiting Net Hand Heat Loss</th><th>Output Flows</th></tr>
<tr><th>Energy</th><td>• Electricity or Fuel
• Heat from hand</td><td>• Heat to hand
• Heat to atmosphere</td></tr>
<tr><th>Material</th><td>• Hand
• Objects and surfaces
• Debris and liquids</td><td>• Hand
• Objects & surface
• Debris and liquids</td></tr>
<tr><th>Information</th><td>• On/off
• Heat level control</td><td>• Warming / no warmth</td></tr>
</table>

Technical Questioning

To further clarify the design need, a modified form of technical questioning is presented here, adapted from Otto and Wood (2001), Chapter 3, p. 94.

Table 6.33: PersonaWarmth Technical Questioning

- **What is the problem really about?** Retaining and/or adding sufficient heat energy to maintain comfortable hand temperature in freezing conditions.
- **What implicit expectations and desires are involved?** Satisfy context-specific customer needs.
- **Are the problem statement and constraints truly appropriate?** Yes, based on exploratory interviews.

- **What avenues are open for creative design?** Phase-change materials. A Growing market with possible unmet context-specific needs.
- **What characteristics / properties must the product have?** Provide sufficient warmth with portability. Satisfy contextual expectations of safety, cost, and convenience.
- **What aspects of the design task can and should be quantified now?** Maximum comfortable hand heat loss, expected heat loss for various insulators in the target climate. Target operating and purchase costs.
- **Is the problem statement free from bias? Is it appropriately abstract?** Yes.
- **What are the technical and technological conflicts inherent in the design task?** Achieving sufficiently low net heat loss with acceptable first cost, operating cost, portability, and task flexibility.

Contextual Needs Assessment

In order to gain a clear understanding of the design need including the need context, the contextual needs assessment methodology presented in Chapter 4 is customized for this case study. The first two steps are to *Brainstorm Context Factors and Customize the Questions Template* accordingly. Brainstorming categories corresponded to the "How" (e.g. frequency, duration, tasks performed while using) "Where" (temperature & humidity, energy supply, animals or insects) and "Who" (hand size, softness preference, warmth needed) categories described previously. The third step of contextual needs assessment, *Conduct Interviews*, consisted of the procedure shown in Table 6.34. The data collected are the basis of step four, *Form Customer Needs List* (Table 6.35) and step five, *Form Context Scenario* (Table 6.36 through Table 6.38). The context scenario is very broad, and as the design process progresses it becomes clear that the target scenario should be limited to a primary market of university students in southern China (Chapter 5).

Table 6.34: Adapted Interview Procedure

1. Gather background information: name, personal description, most familiar solution, experience in China
2. Explain design scope: portable personal hand warmer for Chinese University students
3. Ask for typical uses of such a product, then prompt from list
4. Simulated articulated use interview with the “most familiar solution”
5. Like/Dislike/Suggestions-style interviews on most familiar solution plus two products from the family (Table 6.31)
6. Ask any remaining unanswered questions from customized context questions template.

Table 6.35: PersonaWarmth Customer Needs List

Heat Adequately	
Heat adequately/actively	5
Heat long-lasting (pref. day)	3
Heat distributed (fingers)	3
Heat continuous	3
Heat adjustable	1
Heat consistent	1
Heat instant-on	1
Un-encumbering	
Wearable	3
Un-encumbered grip	3
Flexible	3
Easy/Ergonomic interface	3
Easy to carry	5
Easy to store	3
Compatible w/ lifestyle	3
Portable	
Compact	3
Attachable - in use	1
Attachable - off	1
Fits pockets	3
Lightweight	3
Setup & Usage	
Easy to use	3
Convenient to use	3
Easy/simple to setup	3
Fast setup	3
Easy to re-energize/re-use	3
Automatic operation	1

Safety	
Safe - low risk to user	5
Safe appearance	5
Child-proof	3
Secure container	3
No flame	1
Environmentally friendly	1
Safe accessories (e.g. fuel)	1
Unexposed	3
Operation	
Customizable (detach fingers)	1
Dual function (e.g. hot drink)	1
Easy to find	1
Reliable	3
Durable	3
Limited accessories	1
Low-maintenance	3
Maintainable	1
Rain & snow compatible	3
Low Cost	
Low-cost	5
Re-usable	3
Aesthetics	
Aesthetically pleasing	5
Stylish	3
Trendy	3
No smell	1
Interesting device	1
Compatible (no leaks)	3

Table 6.36: PersonaWarmth Context Scenario – "How" Factors

#	Question Prompts	Combined Context Scenario
HOW: Usage Application		
a1	How will hand warmer be used? What will the person be doing? How will they be using their hands?	To keep hand warm while: Writing, riding bike, bus, classroom activities, walking, sports. (Also, see activity list)
a2	How often will warmer be used? (Times/day? Days/week?)	North: on walks 4-5x/day * 5 days/wk S: up to all day (possible for sleep too), 5-7 days/wk
a3	How long will warmer be used each time?	N: just walks (5-10 min) Continuously or enough to stay warm. (Maybe less when sun is out - nice to have on/off).
a3a	What part of the year (and how much) will warmer be in use?	3-6 mo
a4	[RESEARCH] How much heat is needed? What temperature?	Low temp ~30F, varying humidity.
a5	How roughly will warmer be handled/treated? Will the warmer be treated and stored gently?	Reasonable care from older students, except if used in sports. (Children may be rough). Storage in backpack or pocket.
a6	How will warmer be transported & how much? How much transport is usage vs. storage?	Usually in-use. Backpack or pocket.
a7	How might customers transfer heat from warmer to their hands?	If active: must be wearable. If walking, holding it is fine.

Table 6.37: PersonaWarmth Context Scenario – "Where" Factors

WHERE: Usage Environment		
e1	What type of surroundings will warmer be used in?	Outside, dorm, classroom. Clasroom – plain, cold, drafty.
e1a	Will there be flammable materials present?	Paper, clothes, backpack (Fire hazard is a concern)
e2	What weather/climate will warmer be exposed to? Windy? Rainy? What temperatures and humidity will it be exposed to (average & extremes?)	Snow, varying humidity, windy, some rain. As low as -30F (N China). Some concern for snow & rain proof.
e3	Will warmer be exposed to any unusual substances or conditions?	None thought of.
e3a	Will there be any insects or animals present?	No animals, some insects.
e4	How much space is available for using warmer?	Easy to hold. Fit in pocket or backpack (usually room).
e5	How much space is available for storing warmer? (Transit & at home).	Little but adequate space for small product. May store under bed or on shelf.
e6	How will warmer interact w/ the surrounding aesthetics? What kind of styling is desired?	College students: colors, simple, elegant, small. Unique style important. Feel good on skin. Easy to hold … maybe exercise while holding.
e6a	Scent and sound "aesthetics"?	Important to not smell (or at least good). Little or no noise; esp. in classroom. (Some students enjoy scent or sound).
e7	How much ventilation is available during warmer use? How confined are the places of use?	Bus is confined. Try to minimize airflow in buildings, but not sealed well. Concern over CO problem with stoves.
e8	What is the cost & availability of maintenance & parts?	Must require minimal maintenance (perception=few parts)
e9	What is the cost & availability of possible energy sources? (e.g. human, battery, gas, electric, biomass)	Electricity affordable; but intermittent and no heating elements allowed in dorms. Gas not perceived well. Batteries cheap but poor quality. Water inconsistent, though hot drinking water OK but costs.

Table 6.38: PersonaWarmth Context Scenario – "Who" Factors

WHO: Customer Characteristics		
c0	Who will use the warmer? Age range (hand sizes)? What is the user's education level?	Chinese university students. [children, everyone if affordable] Smaller hands.
c1	How familiar is the average user with active heating elements?	Students familiar with electric kettles.
c1a	How familiar with any hand warmers (gloves, heavy socks, etc)?	Students: mostly gloves, water bottle-type devices, some active warmers. Students may be acclimated; may not think to try something new, though current generation is interested in new/western things.
c2	Does the user have any physical conditions that may make it difficult to perform this task?	
c3	What is the most complex warmer familiar to the user? Must this warmer be less complex? How simple would you imagine it should be?	Must be simple. (One respondent objected to the Jon-e).
c4	Are there any cultural practices or expectations related to this warmer?	Single child families; keeping up with neighbors. Students financially depend on parents who may be conservative. Possibly higher cold tolerance.
c5	About how much is the buyer willing to pay to purchase this warmer?	$2-4
c6	How much is the user willing to pay/work to operate & maintain this warmer (per use or per month)?	Very low - $0 is preferable. $0.25-$0.50/wk or use (?)
c8	About how much time is the user willing to spend to setup and operate this warmer?	<1-3 min. (Maybe more if it lasts all day). Desktop PCs left on, do turn off lights in PC lab.
c8a	How much additional material/equipment to activate?	Minimize. Match or lighter OK. Many men have lighters. Make use of other common products?
c9	What is the most dangerous warmer familiar to the user (burning)? Must this one be less dangerous? How dangerous?	Some students may be concerned about safety if wearing. College officials concerned with dorm safety.
c10	How long does the user expect warmer to last?	Last through one cold season.

Activity Analysis

Identifying the various activities of use is critical to understanding the context of "how" the product is used and aids identifying special concerns with each usage step. The activities in Table 6.39 are generated through brainstorming, interview data, and asking interviewees to comment on the likelihood of prompted usage activities.

Table 6.39: PersonaWarmth Activity Analysis

- Purchase, Transport, Unpackage
- Store, Store in transit (unused) – backpack, pocket
- Prepare to use, Turn on, Turn off
- Refuel / Re-charge
- Usage Activities
    - Transportation uses: walking, biking, bus riding, carrying objects
    - Active usages: typing, writing, playing, eating, exercising
    - Passive usages: listening, talking
- Discard or recycle

6.4.2 Concept Development

Functional Model

The functional model in Figure 6.10 is general enough to capture the essence of a wide variety of hand warming products, including all the existing products studied and shown in Table 6.31. The energy input flow is stated generally as "energy" such that it captures the possibilities of human, chemical, thermal, electrical, and other energy sources. The "energy carrier" material input flow represents energy transfer media such as the human hand (human energy), a battery (chemical energy), or hot water (thermal energy).

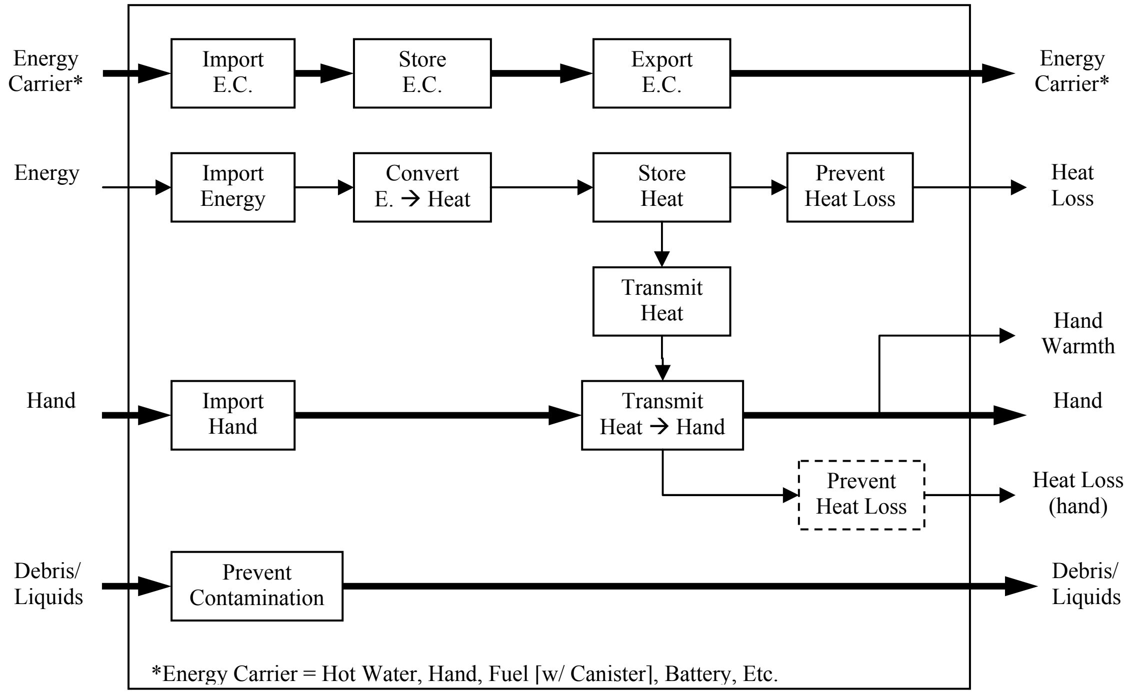


Figure 6.10: PersonaWarmth Generic Function Structure

Solution Generation - Brainstorm/Mind Map

Brainstorming personal warming solutions very naturally follows a functional organization, resulting in a mind map with very few levels of hierarchy. Partial results are shown in Table 6.40 for categories corresponding to the most dominate functions: "energy sources" in the first column (corresponding to "import energy" and "import energy carrier" functions) and "interface" in the second column (corresponding to "import hand" and "transmit heat → hand" functions). The third column lists analogous products generated to spawn creative problem solving by analogy.

Table 6.40: PersonaWarmth Partial Brainstorming Results Organized by Topic

Energy Sources	Interface	Analogous Products
• Battery / capacitor • AC gridpower • Solar • Chemical (single-use) • Chemical - re-chargeable • Hot water • Human - non-hand passive (armpit, breath) • Human - internal hand heat (exercise increases) • Human - hand motion/friction • Human - non-hand motion • Fuel • Human - shivering / muscle stimulation	• Glove • Velcro • Wrap-around: wide fabric, rope, string • Conductive gel • Rigid material w/ hand shape • Glove - fingerless / removable fingers • Hand Hat • Handle-cylinder • Fluid Pouch • Mitten • Pocket liner	• Elec. Blanket / heating pad • Paraffin bath • Active convective heater • Radiative heater • Passive conv. heat pipes • Oven / water heater • Microwave • Ultrasonic • Insulators - gloves, etc.

Morphological Matrix

Concept variants are assembled from the ideas generated in Table 6.40. These concept variants are decomposed into individual function solutions and entered into a morphological matrix format which serves as the basis for further idea generation. The complete results are shown in Table 6.41.

Table 6.41: PersonaWarmth Morphological Matrix

	a	b	c	d	e	f
General						
Import Hand (heat xfer)	glove w/ removable fingers	wrap-around fabric/ velcro	hand hat	pocket liner	gripped surface	glove inside surface
Store heat energy	hot fluid	hot H2O	small themal mass	large thermal mass (solid/liquid/p.chg)	small thermal mass (metal shell)	
Prevent heat loss	reflective	vacuum	air pocket	fatty layer	thin fabric	insulation (air / fabric)
Transmit heat (internal)	conductive metal shell	fluid transport /convection	heat pipes	heat conductive gel	heat conductive fabric	radiation
Transmit heat (to hand)	Convection via fan / airflow	Conduction thru gell	conduction thru shell & fabric	conduction thru t. mass & glove		
Prevent contamination	membrane	flexible-tough casing (mylar)	shell & cap	glove outer fabric	shell & fabric bag	
1,2: Hand Motion						
Import HE	crank/squeezable handle	accelerations (shake)	resist changing hand geometry	body motion / rubbing surfaces	breath heat capture	piezoelectric
Import Hand (energy in)	crank handle	gripped surface	squeezable handle	glove		
Convert HE -> heat	friction fluid	generator & heating element	rubbing friction surfaces			
Convert HE -> EE	linear generator	rotary generator				
3a, 3b: Heat Storage						
Import EE	cord					
Convert EE -> heat	peltier junction	heating element				

Table 6.41 (Cont.): PersonaWarmth Morphological Matrix

4, 5: Fuel, Battery						
Import fuel & container	pouring receptacle	injection capability	snap-in cartridge receptacle	battery pouch		
Store fuel & container	disposable cartridge	battery				
Export fuel container	snap-out cartridge receptacle					
Convert fuel to heat	flame	flameless platinum catalyst	heating element			
D: Hot H2O						
Import hot H2O	wick	canteen-style neck (pouring)				
Store hot H2O	flexible membrane (plastic bag)	thermos	soaked medium (wet rag)	cateen bottle/shell		
Export cold H2O	canteen-style neck (pouring)					

Concept Variant Formation

The final concept variants formed from the function solutions in the morphological matrix (Table 6.41) are presented in Figure 6.11. The datum concept, CV#0, is a hot water bottle currently used by some university students in China for personal hand warming. The major shortcomings of this product are short heat duration and the fact that it must be physically held in the hand, preventing other activities such as taking notes in class. Concept variant #1 is similar to a hand dynamo squeeze flashlight, but the human energy input converted into light is converted into heat and channeled into the hand when the product is switched to hand heater mode. In addition, the increased physical activity of the hand to pump the light increases the amount of natural hand warming by the body. CV#2a provides a high-friction surface enhancing the existing practice of hand rubbing for warming, and provides a highly conductive surface to transfer friction generated heat into the hand. CV#2b also employs human energy to both generate heat and increase warming by the body. The concept provides resistance to the hand gripping into a fist shape, and converts this captured energy into heat through friction. CV#3a is similar to the datum concept, but contains a phase change material to provide longer heat duration. This concept plugs in overnight to electrically heat and melt the phase change material. CV#3b is a similar concept housed in a wearable glove. The glove may contain a phase change material or some other type of thermal mass which must be heated before use. CV#4 is an adaptation of the existing flameless liquid fuel product in Table 6.31. The concept improves upon the existing pour-fill design by utilizing a disposable fuel cartridge to enhance safety, cleanliness, and convenience. CV#5a is a wearable glove heated by a battery, analogous to existing (but very expensive) products on the US market. CV#5b is also a battery powered warmer that is held in the hand.

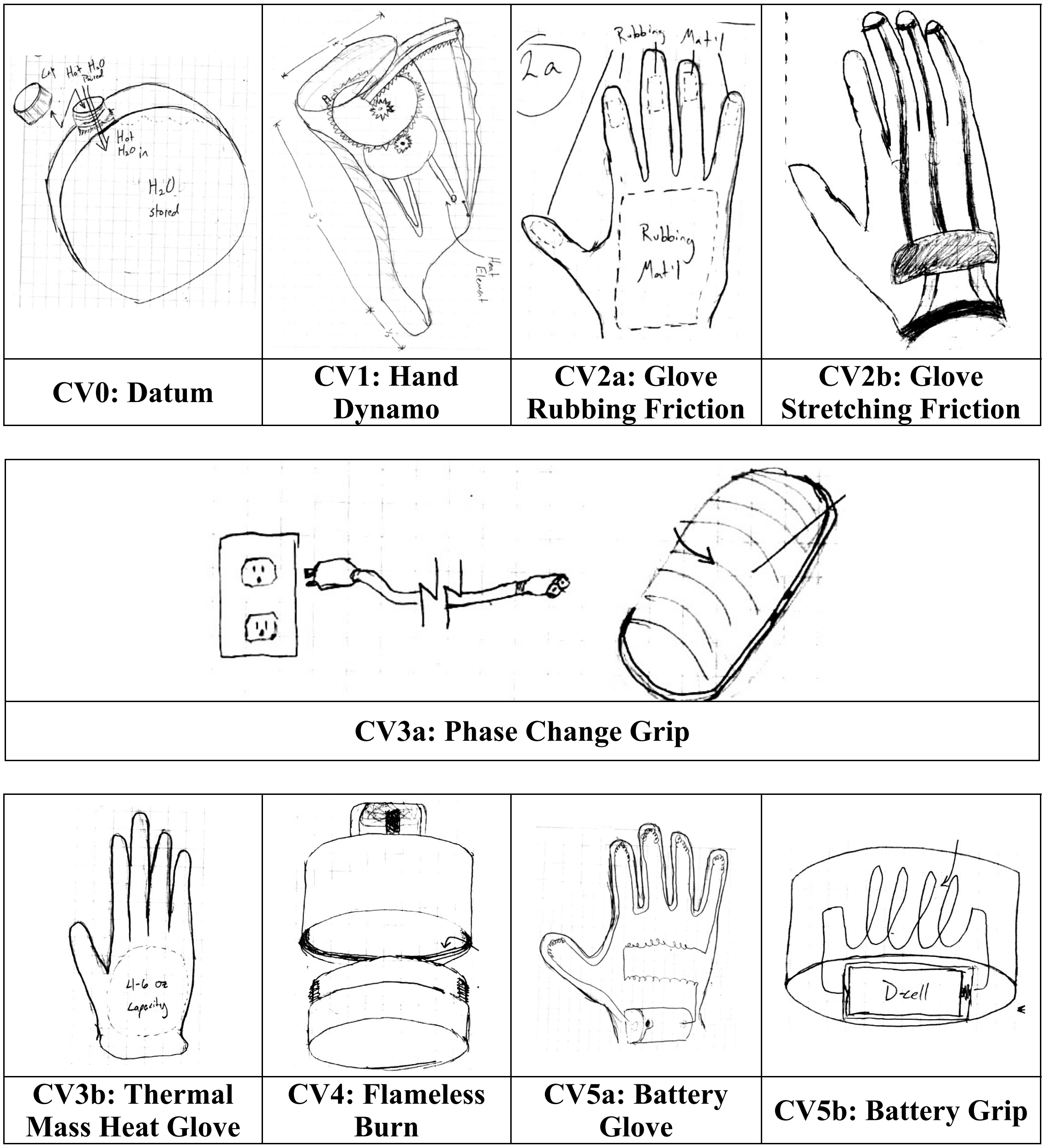


Figure 6.11: PersonaWarmth Concepts[41]

Concept Selection - Pugh Chart

All of the concept variants are rated in a Pugh Chart (Table 6.42) in order to choose one concept for further design. The criteria primarily consist of the potential of

[41] Drawings by George Malinoff

each concept to fulfill the top customer needs. Two additional factors include a "Wow!" factor, since innovation is important for the purposes of this case study and if the final product is to have market viability. Feasibility risk is also included due to the short timeline and tenuous feasibility of several of the concepts. The final scores do not strongly point to any of the concepts for further development in the scope of this case study, although further analysis and testing could reduce the feasibility risks of some of the concepts.

Table 6.42: PersonaWarmth Concept Selection Pugh Chart

	Hot H2O	Han-Dynamo	Hand Rubbing	Hand Stretch	PC Heat (Solid)	PC Heat (Glove)	TM Heat (Glove)	sansFire (cartridge)	Battery Glove	Battery (Solid)
	D	**1**	**2a**	**2b**	**3a**	**3b**	**3c**	**4**	**5a**	**5b**
Criteria										
Heat adequate (W)	s	s	-1	-1	s	s	s	+2	-1	-1
Heat long-lasting (hr)	s	+1	+1	+1	+1	s	s	+3	+1	+1
Heat on/off controllable	s	+2	+2	+2	s	s	s	+1	+2	+2
Un-encumbered grip (%)	s	s	s	+1	s	+1	+1	s	+1	s
Low purchase cost ($)	s	-2	-1	-1	-2	-2	-1	-2	-2	-1
Low operating cost ($/hr)	s	s	s	s	s	s	s	-1	-2	-2
Safe - (fire, injury, spill)	s	s	s	s	s	s	s	-2	S	s
Convenient (easy, fast)	s	-2	-3	-1	s	s	s	-1	S	s
Wow! Factor (Novelty)	s	+2	+2	+2	+1	+1	+1	s	S	s
Feasibility Risk	s	-1	-2	-3	-2	-3	-2	-1	-2	-1
# +'s	0	3	3	4	2	2	2	3	3	2
# -'s	0	3	4	4	2	2	2	5	4	4
SUM	**0**	**0**	**-2**	**0**	**-2**	**-3**	**-1**	**-1**	**-3**	**-2**

The findings of Table 6.42 call for the generation of additional concepts, as shown in Table 6.43. Concept #1' "Hot Writer" is a writing tablet which may be filled with hot water. In addition to enabling students to receive hand warmth simultaneously while taking notes, this concept can conveniently hold more water than the datum concept and thus provides greater heat duration. CV#2a' and CV#2b' are pen and chalk holders, respectively, with an outer shell containing a thermal mass. These concepts enable the user to write while receiving heat; however, due to the smaller size and mass required for a writing instrument the concepts suffer from a short heat duration in addition to feasibility concerns with the technology. Based on this analysis, concept #1' is chosen for further development since it has exciting potential to economically fill an important gap in current product offerings. In addition it is compatible with the current infrastructure and procedures of a product currently used, which increase the chances of new product success.

Table 6.43: PersonaWarmth Concept Selection Pugh Chart, Second Round[42]

	Hot H2O	**Hot Writer**	**Hot Pen**	**Hot Chalk**
	D	**1'**	**2a'**	**2b'**
Criteria				
Heat adequate (W)	s	s	-1	-1
Heat long-lasting (hr)	s	+1	-1	-1
Heat on/off controllable	s	s	s	s
Un-encumbered grip (%)	s	+3	+3	+3
Low purchase cost ($)	s	s	-1	-1
Low operating cost ($/hr)	s	s	s	s
Safe - (fire, injury, spill)	s	s	s	s
Convenient (easy, fast)	s	s	s	s
Wow! Factor (Novelty)	s	+2	+2	+2
Feasibility Risk	s	s	-2	-2
# +'s	0	3	2	2
# -'s	0	0	4	4
SUM	**0**	**6**	**0**	**0**

Modeling and Estimation

Modeling and approximation are used concurrently with concept generation and concept selection. Figure 6.12 depicts a generic heat transfer model which may be reconfigured through adjusting the parameters to model various aspects of many of the concepts. Figure 6.13 shows the thermophysical properties of various formulations of paraffin, a promising phase change material readily available in candles. Table 6.44 itemizes the relevant thermophysical properties of several materials considered for a thermal mass to store heat, and Figure 6.14 illustrates the total heat available from these materials as a function of total temperature change. Note that the materials which exhibit a phase change in the temperature range feasible for a hand warmer (~100-150^{o}F) are shown to have a very high heat release (the heat released when melting) even when virtually no temperature change occurs. From this analysis it is clear that paraffin and water are the two thermal mass materials of choice. However, experimentation with commonly available (and economical) paraffin revealed that the cooling behavior of the material is to form a skin on the outer (cooling) surface, gradually increasing the effective insulation value and slowly releasing the heat from the interior. Water, on the other hand, will maintain a more nearly uniform temperature throughout due to internal convection currents. From this analysis, water is selected as the thermal mass material of choice due to both thermophysical properties and the availability of very hot water (up to ~190F) in the target application environment.

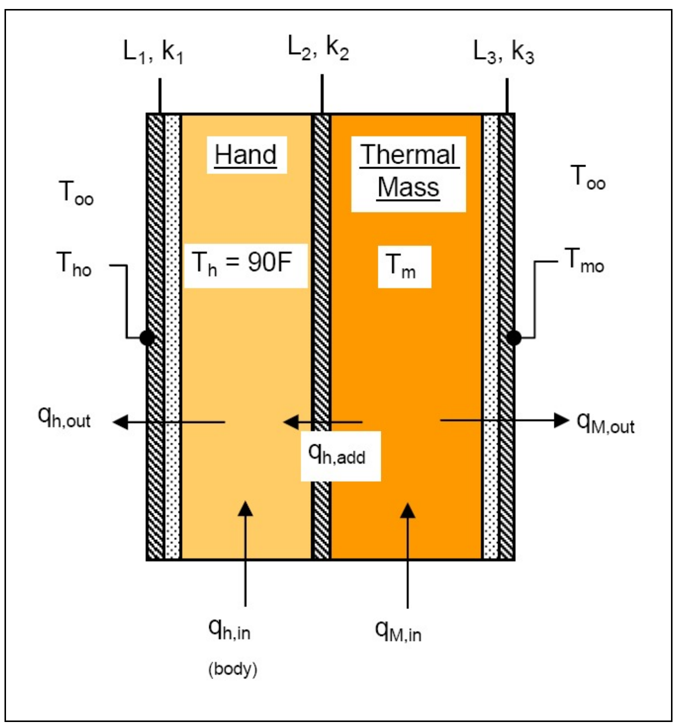


Figure 6.12: PersonaWarmth Generic Heat Transfer Model

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[42] The second round of concepts was generated in collaboration with Jennifer Green.

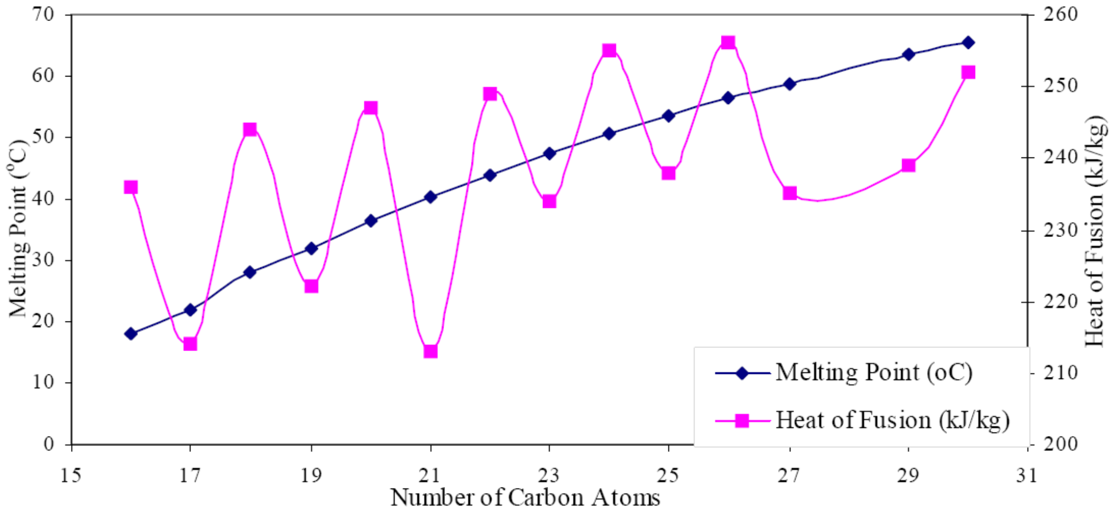

Figure 6.13: Thermophysical Properties of Paraffin (Khudhair, et al., 2002)

Table 6.44: Thermal Properties of Potential Heat Storage Materials

Material	T_{melt} (C)	Ht. Fusion (kJ/kg)	Spec. Heat (kJ/kgK)	K (W/mK)
Water[43]	0	NA	4.18	0.61
Paraffin[44]	20-50	~200	2.40	0.26
PlusICE A61[45]	61	202	2.22	0.22
PlusICE A39[45]	39	190	2.22	0.22
Aluminum[46]	660	NA	0.90	237
Pure Copper[46]	1085	NA	0.39	401

[43] MatWeb Online Material Data Sheet www.matweb.com http://www.matweb.com/search/SpecificMaterial.asp?bassnum=DWATR0

[44] A Multi-Functional Graphite/Epoxy-Based Thermal Energy Storage Composite for Temperature Control of Sensors and Electronics http://web.me.unr.edu/wirtz/Papers/AIAA2003%200513.pdf, (Khudhair, et al., 2002)

[45] Environmental Process Systems Ltd. - PlusICE™ Eutectic & PCM Solutions http://www.epsltd.co.uk/

[46] Incropera & DeWitt, Fundamentals of Heat and Mass Transfer, 4th ed.

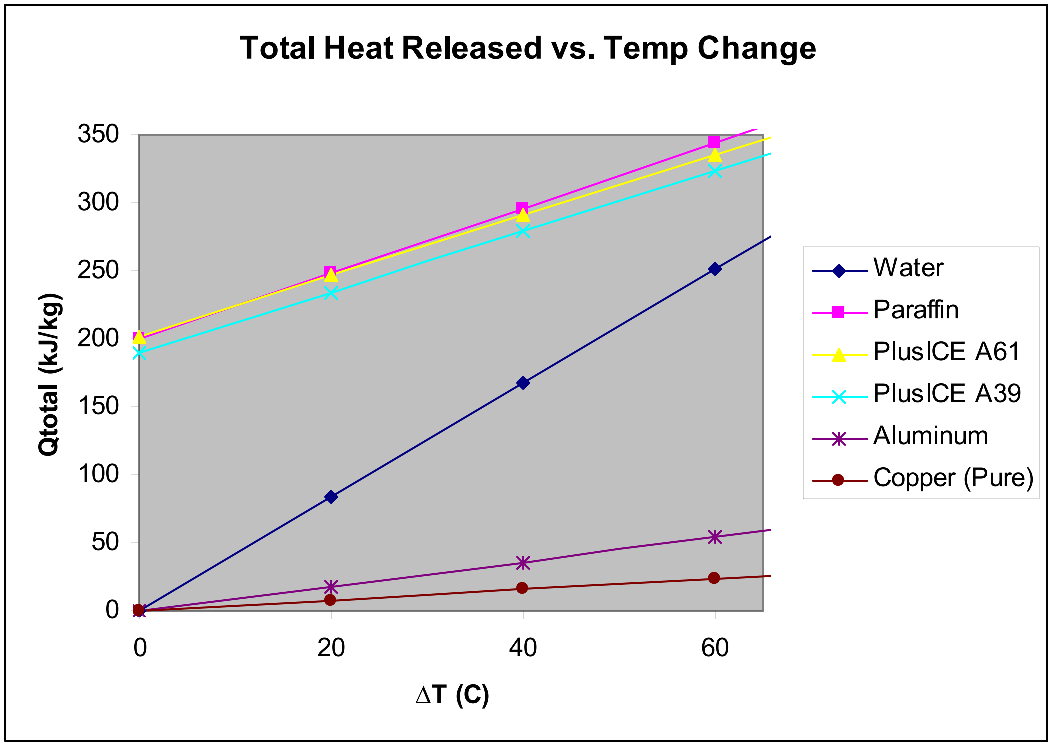

Figure 6.14: Total Heat Transfer from Heat Storage Materials

6.4.3 Detailed Design and Prototyping

Detail Design

The PersonaWarmth should be large enough to afford taking notes on the paper sizes commonly used in the target application environment. This is thought to be A5 paper (approximately 5 7/8×8¼ in.), but the larger A4 size should be accommodated as well (approximately 8¼×11¾ in.)[47] A prototype with outer dimensions of 10¾×12¾×¾ in. provides a balance between portability and accommodating both of these paper sizes when placed with the long dimension from left to right to accommodate both left and right hands. This size holds approximately 1L of water and thus has a weight slightly over 1kg. This size and weight is similar to a thin, tall book which would be familiar to students. The back side of the design should have a high insulation value to prevent

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[47] A4 Paper Format / International Standard Paper Sizes, http://www.cl.cam.ac.uk/~mgk25/iso-paper.html

reduce heat lost to the desk surface, and the front should have an insulation value such that the writing surface is the correct temperature (~120^{o}F or less) when the device is filled with very hot water.

Prototyping[48] and Experimentation

The prototype (Figure 6.15) is constructed from two layers of plastic fiberboard (similar to that used as an easily cleanable shower surface) and a frame cut from water resistant plywood. Two rubber stoppers and holes enable filling and draining the prototype for experimentation and testing, however the final design is intended to have a screw-on cap for convenience. Figure 6.16 shows water-proof caulk being applied to all inner surfaces of the plywood frame and between the wood and plastic cover surfaces to hold the pieces together.

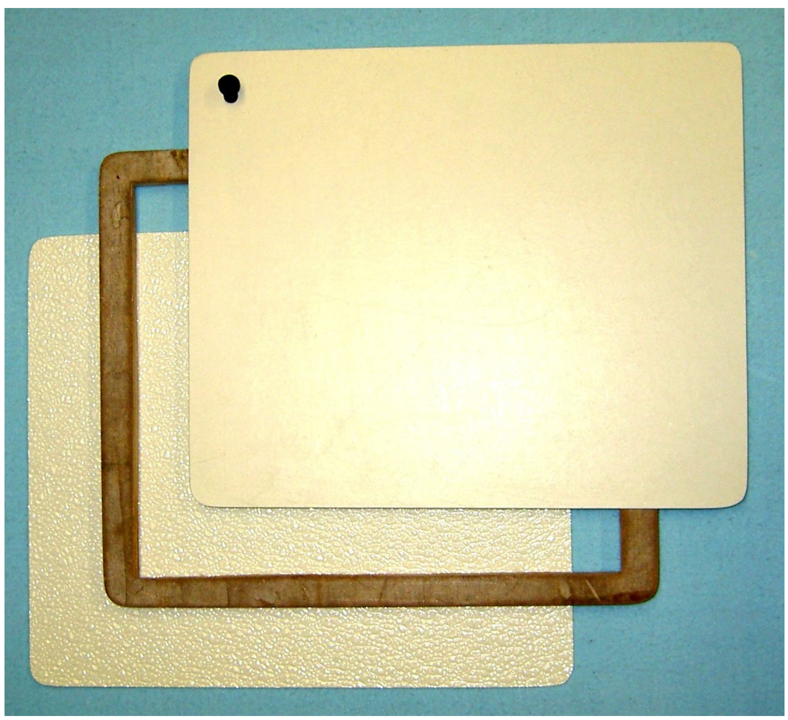

Figure 6.15: Prototype Materials Before Adhesive Caulk Application

[48] The prototype was planned and fabricated in collaboration with David Green.

Figure 6.16: Applying Adhesive Caulk to the PersonaWarmth Prototype

Experimentation shows the prototype provides significant hand warming and is convenient to carry. The prototype is tested (Figure 6.17) in the vegetable compartment of a refrigerator to simulate a classroom with ~50^{o}F ambient conditions[49] and no wind. A thermocouple is held on the surface of the prototype with a small piece of insulation and a rubber band. Figure 6.18 shows the temperatures recorded over time as the prototype cools. The green rectangle represents the highly usable window of the prototype when the surface temperature is between 120^{o}F to 90^{o}F, a range from the upper limit of usability to the lower limit which provides significant hand warming. However, compared to a 35°F desk, even a 70°F writing tablet represents a significant advantage, so the actual usable window for the prototype may be larger than shown.

Figure 6.17: Prototype Testing in a ~50°F Refrigerator Compartment

[49] This temperature is due to the capabilities of available equipment; a test at ~35 °F would more accurately simulate actual classroom conditions.

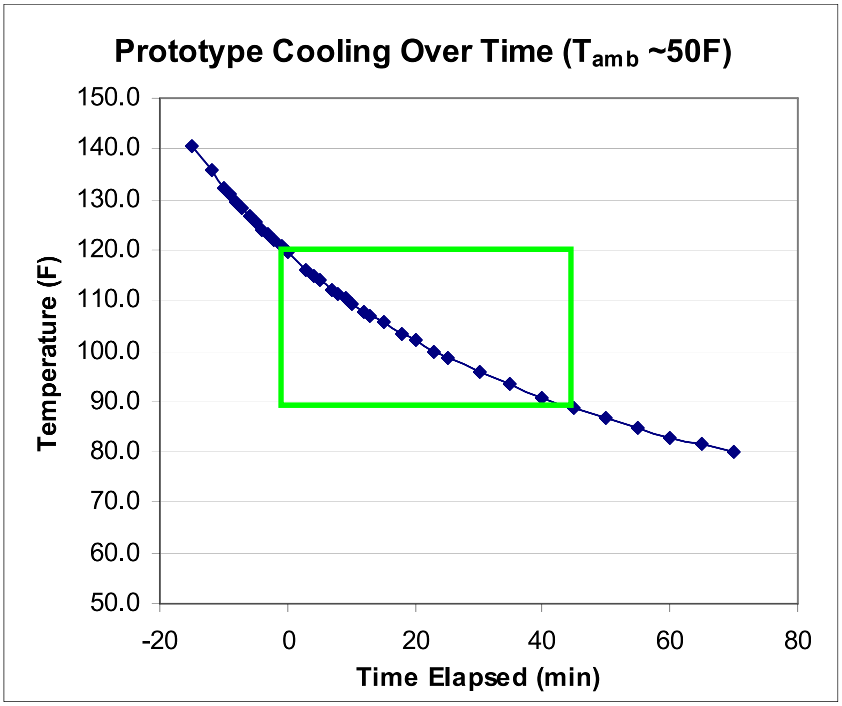

Figure 6.18: Prototype Surface Cooling Curve in a ~50^{o}F Test Environment

Final Recommendations

The final product may be manufactured inexpensively from sturdy plastic capable of handling the hot water temperatures. The prototype dimensions chosen (10¾×12¾×¾ in.) are suitable, although the size of the final design may be varied if needed. The insulation value of the back surface may be achieved through molding the plastic of the final device as two layers with a sealed air gap. The front surface should be a thickness such that the initial surface temperature is usable (~120^{o}F) when the device is initially filled with ~190^{o}F water. Using the maximum front insulation value will keep the cooling curve as flat as possible and provide the maximum usable heat duration. A surface insulation value approximately 150% greater than that of the current prototype is needed, which for a device containing 1L of water will provide over one hour of significant heating. The volume of water may also be significantly increased before weight becomes an issue, thus further increasing heating time. A drawing of the final product concept is shown in Figure 6.19.

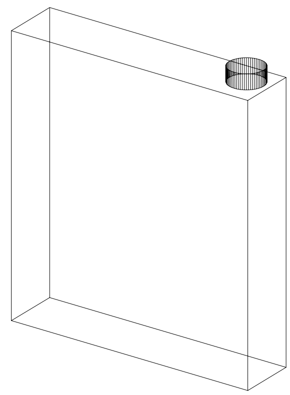

Figure 6.19: PersonaWarmth Final Concept

Influence of Contextual Information

One of the most important outcomes resulting from the application of the contextual needs assessment methodology in this original design case study is the enhanced ability for appropriate need identification and segmentation. The methodology enables organizing the needs, identifying an appropriate market segment, and scoping the mission statement. The knowledge of common tasks performed and classroom ambient temperatures helped highlight the critical insight of the need in southern china for a continuous heating solution which was unencumbering enough to enable the user to take notes. The interviewees indicated that in northern China classrooms are heated, indicating a personal warming product would be used for very different tasks (walking instead of note taking) and for much shorter lengths of time. The availability of very hot water as a potential heating source is another piece of contextual information which proved vital to enabling the successful PersonaWarmth design shown. Finally, a better understanding of customer expectations for cost, maintenance, and ease-of-use guided design decision making.

The amount of information gleaned from the relatively small number of interviews was vastly richer and fuller than would have been offered from only traditional like/dislike and simulated articulated use interviews. In the end, however, there is no true substitute for physical presence in the target context of use. The most valuable interview insights came from individuals with knowledge of both the target context and some principles of engineering design.

6.5 Conclusions

The four case studies in this chapter provide strong quantitative and qualitative support for the usability, usefulness, and designer acceptance of the contextual needs assessment method. The case studies further provide valuable illustrations of methodology application and numerous findings to continue improving the usefulness and generality of the method.

Case 1 demonstrates that within an undergraduate reverse engineering setting, the contextual needs assessment methodology can be realistically deployed and well received, and result in significant improvement in needs assessment. Data analysis identifies *eight new context factors and eighteen question revisions* to improve the generalized template. Survey results show students rated the contextual needs assessment methodology of medium-high value for their product and high value for a foreign product, comparable to the perceived value of benchmark methodologies such as a black box and activity diagram. The majority of students rate the proposed methodology as usable and useful. Free response comments are favorable towards the method, but reveal misunderstandings indicating the need for more thorough teaching. Case 2 demonstrates very similar results to Case 1 for graduate teams performing frontier context original design. Data analysis identifies *four new context factors and eleven question revisions* to improve the generalized template[50]. Case 3 quantitatively demonstrates the 3.5 times increase[51] (from 20% to 69%) in contextual information gathered using the method, and with a high information per unit time efficiency ratio. Case 4 demonstrates the impact the contextual needs assessment methodology can have on a frontier design project by making vital contextual information available to the entire design process. These case study results support the hypothesis of this research and provide strong justification for

[50] The Case 2 data set included three teams whereas Case 1 included fourteen teams.
[51] 98.5% confidence in a contextual score increase $\geq$ 30%.

the widespread dissemination of the contextual needs assessment approach in education as well as in field practice.

Chapter 7: Conclusions, Contributions, and Future Work

This work is based upon the central hypothesis that *engineers equipped with improved methods and tools for contextual design will show a measurable improvement in contextual understanding of design problems outside their experience and expertise*. Several objectives are completed towards the end of developing contextual design methods to facilitate discovering, documenting, and acting upon contextual information important for successful product design. A product design context framework is established, an empirical study is conducted to explore and demonstrate the importance of context in influencing customer satisfaction, a contextual needs assessment methodology and supporting techniques are developed, and four case studies are conducted to demonstrate and refine the method. The case studies provide strong quantitative and qualitative support for the usability, usefulness, and designer acceptance of the proposed contextual needs assessment method. The results support the research hypothesis and provide strong justification for the widespread dissemination of the methodology in education as well as in field practice. The following sections summarize conclusions, contributions, and future work.

7.1 SUMMARY CONCLUSIONS

7.1.1 Design Context Framework Definition

A foundational framework is defined for discovering, documenting, and acting upon contextual information important for successful product design. *Product design context* is defined as the collection of factors influencing product attribute preferences and divided into the categories of (Table 7.1): *usage context factors* ("how" and "where"), *customer context factors ("who"),* and *market context factors*. The empirical studies demonstrate that *product design context*, in addition to primary functional requirements, are fundamental causes which give rise to both customer needs and the resulting product requirements.

Table 7.1: Product Design Context Categories

Category	Sub-Category	Sample Context Factors
Usage Context (PUC)	HOW Application Context	• Application task • Usage frequency • Transportation mode • . . .
	WHERE Environment Context	• Infrastructure (e.g. energy supply and cost) • Weather and climate • Maintenance and parts availability • . . .
Customer Context	WHO Customer Context	• Physical Abilities • Skills and education • Cost expectations • . . .
Market Context		• Features of available products • Performance and quality of available products • Cost of available products • . . .

The context framework may be used to characterize a design need *scenario* through the identification of a value for each context factor of interest. As shown in Table 7.2, a "backpacking" context scenario may be partially described by assigning values to the usage factors of: storage mode, transportation, ventilation, weather, energy availability, usage frequency, and usage duty. The values shown define a specific instance of a "backpacking" context scenario, and ranges of values may also be used to capture the target contexts of a product design effort.

Table 7.2: Example Usage Context Scenario Decompositions

	"Backpacking" Context Scenario	"Heavy Domestic Use" Context Scenario
Usage Factors	**Usage Factor Value**	**Usage Factor Value**
Storage Mode	1 = backpack	5 = room
Transportation	1 = foot	3 = none
Ventilation	3 = outdoor	2 = some
Weather	3 = outdoor	1 = indoor
Energy Avail.	1 = no electricity	1 = no electricity
Usage Freq.	1 = infrequent	3 = heavy
Usage Duty	1 = light	3 = heavy

7.1.2 Empirical Study Approach and Results

The methodology shown in Figure 7.1 is developed and executed to empirically explore the influence of context factors on product attribute preferences. First, two functional families of successful, market-mature products are selected to allow cross-functional comparisons: eleven products that broadcast light with portability, and ten products that cook food through boiling. Second, customer interviews yield customer needs lists and usage contexts. Third, the products are measured across key attributes determined from the customer needs list. Fourth, interactive surveys show which products customers prefer for each usage context identified. Finally, the data are analyzed to investigate the relationship between product attributes and factors of the contexts for which they are preferred.

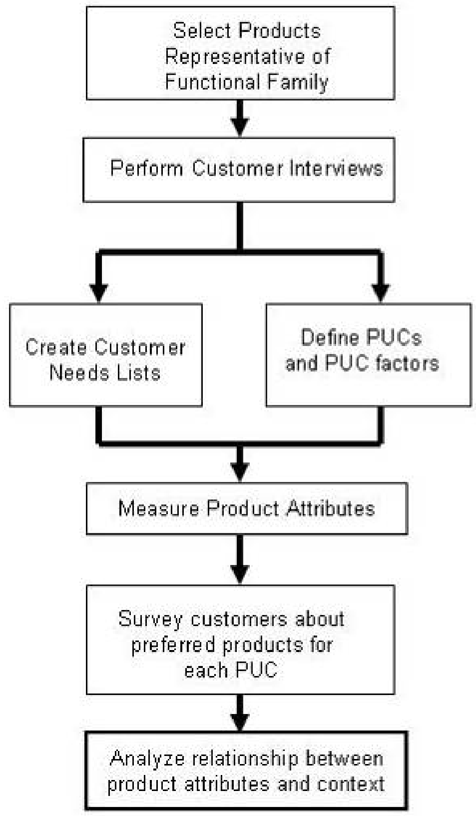

Figure 7.1: Usage Context Exploration Methodology

The results from the two product families studied show that: (1) different context scenarios exist within the same functional family and even the same products, (2) the customers surveyed prefer different products for different context scenarios, and (3) clear relationships exist between context factors and attributes of the preferred products. Figure 7.2 shows sample results from the empirical study. These findings give strong evidence that product attribute preferences depend, in part, upon factors of the intended usage context scenario. This result affirms the importance of accounting for contextual factors in product design processes intended to achieve customer satisfaction. Additionally, the empirical data establish a foundation for incorporating contextual information into the design process.

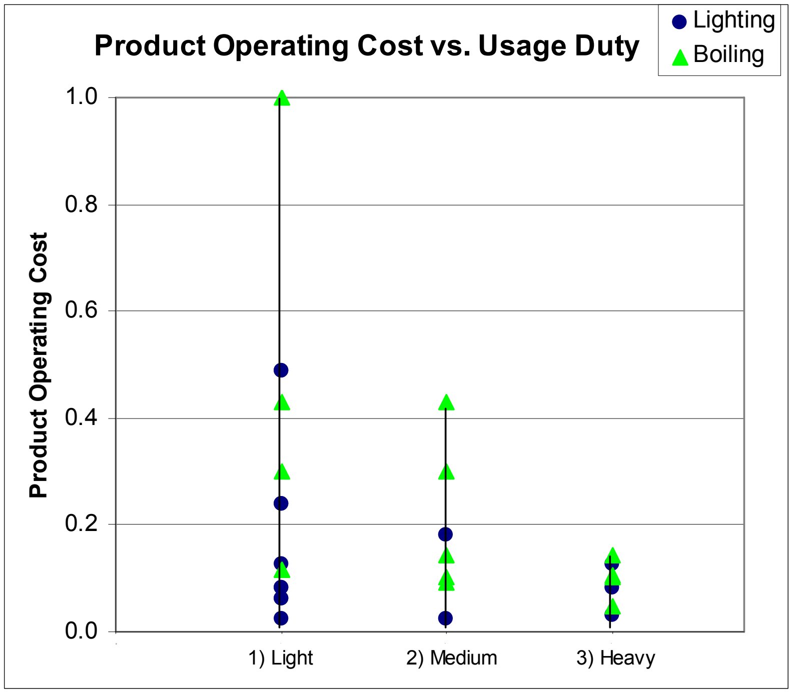

Figure 7.2: Empirical Study Data - Product Operating Cost vs. Usage Duty

7.1.3 Contextual Needs Assessment Method

The contextual needs assessment method shown in Figure 7.3 is proposed to improve task clarification through the formal support of discovering and documenting contextual information in a format readily applied throughout the design process. The method incorporates traditional customer needs methodologies, but extends significantly beyond these by formally incorporating contextual information. Step (1) calls for identification of as many of the relevant contextual factors as possible, and multiple supporting techniques are provided (Table 7.3). Step (2) involves translating each factor identified in Step one into the form of one or more questions. Step (3.1) may be fulfilled with established needs elicitation techniques. Step (3.2) involves answering the questions generated in Step two through customer interviews or research. Step (4) refers to standard needs aggregation techniques such as affinity analysis. Step (5) involves identifying the different factor values to be addressed by one or more products, noting any additional customer needs identified.

1. Identify relevant contextual factors
2. Generate list of contextual questions to be answered
3. Gather customer needs and factor values
    3.1. Gather customer needs
    3.2. Gather factor values
4. Aggregate customer needs into weighted list
5. Aggregate factor values into context scenario(s)

Figure 7.3: Contextual Needs Assessment Methodology

Table 7.3: Context Factor Identification Techniques

- Use context factor checklists, such as the template provided
- Translate customer needs and product reviews into factors
- Translate black box model into factors
- Translate activity diagram into factors
- Translate available data (e.g. physical characteristics) and experiences
- Identify functional family members, noting attribute distinctions

The contextual needs assessment methodology facilitates and directs the process of discovering, documenting, and applying contextual information and is easily adaptable to a variety of design needs. The straightforward method provides valuable structure and insight for organizing and driving the needs assessment process, and the templates place the power of contextual assessment in the hands of even novice engineers tackling a design need outside of their experience and expertise.

The basic contextual needs assessment methodology presented in Chapter 4 may be extended through the *context scenario hierarchical clustering* method from Chapter 5. The extended methodology provides additional guidance in forming context scenarios from interview data and identifying meaningful levels of distinction among context factor values. This guides the designer in grouping an appropriate breadth of context variation into a scenario suitable to address with a single product, or multiple scenarios corresponding to a multiple product offering.

7.1.4 Case Studies

Table 7.4 shows the four case studies of the contextual needs assessment methodology, and Table 7.5 itemizes the outcomes of each case study. The results of these case studies support the value of the contextual needs assessment method for design needs in all four quadrants of the context accessibility map, as well as indicating that the method is increasingly critical for the leftmost and upper-left quadrants. Design projects in the left quadrants of Table 7.4 are a challenge faced by organizations such as Engineers for a Sustainable World, Engineers without Borders, Engineering Ministries International, and other NGOs designing high human-impact solutions in frontier contexts.

Table 7.4: Case Study Examples Positioned by Customer and Environment Accessibility

<table>
<tr><th colspan="2"></th><th colspan="2">Environment Accessibility</th></tr>
<tr><th colspan="2"></th><th>Low</th><th>High</th></tr>
<tr><th rowspan="2">Customer Accessibility</th><th>Low</th><td>Case 4: PersonaWarmth Design</td><td>Case 2: UT Assistive Technology</td></tr>
<tr><th>High</th><td>Case 3: Controlled Interviews</td><td>Case 1: UT Reverse Engineering</td></tr>
</table>

The four case studies in this chapter provide strong quantitative and qualitative support for the usability, usefulness, and designer acceptance of the contextual needs assessment method. The case studies further provide valuable illustrations of methodology application and numerous findings to continue improving the usefulness and generality of the method (Table 7.5). Case 1 demonstrates that within an undergraduate reverse engineering setting, the contextual needs assessment methodology can be realistically deployed and well received, and result in significant improvement in needs assessment. Data analysis identifies eight new context factors and eighteen question revisions to improve the generalized template. Survey results show students rated the contextual needs assessment methodology of medium-high value for their product and high value for a foreign product, comparable to the perceived value of benchmark methodologies such as a black box and activity diagram. The majority of students rate the proposed methodology as usable and useful. Free response comments are favorable towards the method, but reveal misunderstandings indicating the need for more thorough teaching. Case 2 demonstrates the very similar results to Case 1 for graduate teams performing frontier context original design. Data analysis identifies four new context factors and eleven question revisions to improve the generalized template[52]. Case 3 quantitatively demonstrates the 3.5 times increase[53] (from 20% to 69%) in contextual information gathered using the method, and with a high information per unit time efficiency ratio. Case 4 demonstrates the impact the contextual needs assessment methodology can have on a frontier design project by making vital contextual information available to the entire design process. These case study results support the hypothesis of this research and provide strong justification for the widespread dissemination of the contextual needs assessment approach in education as well as in field practice.

[52] The Case 2 data set included three teams whereas Case 1 included 14.

[53] 98.5% confidence in a contextual score increase $\geq$ 30%.

Table 7.5: Case Study Outcomes Summary

Case Study	Outcomes
Case 1: UT Reverse Engineering	• Assessment of designer perceptions of usefulness, usability, and re-use likelihood → validation of method in undergraduate reverse engineering application • Analysis of template customization → template revisions to increase usefulness and generality
Case 2: UT Assistive Technology	• Assessment of designer perceptions of usefulness, usability, and re-use likelihood → validation of method in graduate original frontier design application • Analysis of template customization → template revisions to increase usefulness and generality
Case 3: Controlled Interviews	• Assessment of participant perceptions of usefulness, usability, and re-use likelihood → validation of contextual needs assessment method compared with traditional method • Analysis of participant data → quantitative demonstration of method effectiveness and efficiency
Case 4: PersonaWarmth Design	• Demonstration of method for frontier design problem • Demonstration of the importance of contextual information gathered with the method in influencing the design process

7.2 CONTRIBUTIONS SUMMARY

The key contributions from this work are as follows:

- Product context framework developed for discovering, documenting, and applying contextual information in the product design process
- Empirical study data illustrating the existence of context scenarios, the influence of context factors on customer product choice, and context correlations with product attributes
- Contextual needs assessment methodology and supporting techniques
- Classroom lectures and templates to support teaching the contextual needs assessment methodology
- Case study data validating and improving the method:
    - Case 1 validates the method within an undergraduate reverse engineering application, identifies new context factors and question to improve the generalized template, and reveals the need for more thorough teaching.
    - Case 2 validates the method within a graduate original frontier design application, and identifies new context factors and question to improve the generalized template.

- Case 3 qualitatively and quantitatively validates the method compared to traditional needs assessment methods, showing a 290% increase (from 24% to 69%) in contextual information gathered using the method.
- Case 4 demonstrates the importance of contextual information gathered through the method in influencing the design process.

7.3 FUTURE WORK

Many exciting avenues remain for continued work to enhance the formal incorporation of contextual information into the design process. Potential future work falls into the categories of: expanding the breadth and depth of the empirical studies, developing additional methodology and techniques, expanding the case studies, and dissemination of the method. Each of these categories is detailed in the following sections.

7.3.1 Expanding the Empirical Studies

This work is grounded in empirical product studies, and the expansion of these studies is one category of potential future work (Table 7.6). An empirical study of a third product family has the potential to add additional insight, particularly if the family is in a significantly different domain such as a water supply *system*. Although such studies are not expected to significantly alter the basic structure and philosophy of the methodology, the data gained can potentially inform the selection of appropriate context factors for the specific domain, lead to additional generalized context factors, and provide additional data to understand and model the relationship between context factors and attribute preferences. However, increasing the breadth of empirical studies alone has limited promise to enable modeling of attribute preferences unless additional depth is added as well. Whereas the work reported here focuses on products as a complete unit, future work could explore preferences for individual attributes[54] and the sensitivity to contextual influences, especially environmental or "where" factors. However, this requires caution since attribute preferences are inter-dependent. Additional, international development literature may be data mined to uncover additional insight into contextual factors, and in

[54] Existing techniques such as conjoint analysis could serve as the basis for this work.

particular additional factors may be discovered to include in the questions checklist template.

Table 7.6: Future Work – Expand Empirical Studies

• Broaden to additional product families and different domains • Include families of systems, such as water supply • Deepen to product attribute level (rather than whole-product level) • Data mining of frontier environment products to gain context-specific insights

7.3.2 Expanding and Refining the Contextual Needs Assessment Method

The contextual needs assessment method is central to the contributions here, and expansion and refinement of the method is both a realistic and desirable avenue of future work (Table 7.7). Avenues include improving the identification of context factors, the elicitation of factor values from customers, and the application of contextual information downstream from task clarification in the conceptual and embodiment phases of design.

Just as the case studies are used to expand and refine the context questions template based on team data, this process can be continued as additional data becomes available. In particular, the broad context factor of culture is covered in the template with only a few factors, and will benefit from increased subdivision and specificity as more cultural factors are identified. One technique given to identify additional context factors is to glean them from recorded data. An extension of this technique is to automate the process with data mining algorithms based on the contextual framework and understanding established here. Such algorithms could powerfully harness the vast data available through the Internet and digitized books. For example, the "Appropriate Technology Library" CD-ROM set contains a digital archive of over 1050 books with relevance to community development (2005a). The book page images are recorded in PDF format which is largely searchable through the optical character recognition capabilities built into PDF file reading software.

Additionally, although the context questions template and surrounding methodology guides the designer in asking the right questions, in many cases obtaining accurate answers from customers or even research remains problematic. A promising solution to this problem is the development of semantic scales (Otto and Wood, 2001 Ch4, p.129) for various context factors, and development of methodology to customize or create new scales for additional factors. For example, a semantic scale to elicit the context factor of user visual ability would include values of: “not applicable,” “can’t recognize a friend nearby,” “can’t recognize a friend across the room,” “full vision capability,” and additional points in-between (scale adapted from the Inclusive Design website (2005g)).

The contextual needs assessment methodology development stops at the completion of task clarification and, much like current benchmarking techniques for specification setting, correctly applying the information during the design process is left to the designer. Additional methodology development to guide the use of contextual information downstream has the potential to improve correct application and thus results. Methods are needed to apply contextual information to: increase the customer needs list specificity and breadth, to systematically inform specification setting with contextual information, to systematically inform concept selection or product selection, to interpret specification information from one context for use in a different context, and to document accumulated contextual domain knowledge for future re-use. Contextual knowledge documented in a database and linked to products could enable rapid identification of products from analogous contexts to facilitate context-appropriate design-by-analogy.

Table 7.7: Future Work – Expand and Refine Contextual Needs Assessment Method

- Expand and refine context questions template with further product and project data from specific frontier environments
- Develop semantic scales for context factor elicitation
- Develop method of using contextual information to increase customer needs list specificity and breadth
- Develop method to systematically inform specification setting with contextual information
- Develop method to systematically inform Pugh-chart concept selection (or product selection) with contextual information
- Develop method to use contextual information to interpret specification information from one context for use in a different context
- Develop procedures for using the template to document accumulated contextual domain knowledge for future re-use

7.3.3 Disseminating the Methodology through Teaching, Collaborative Application, and Publishing

Although many exciting avenues for future expansions remain, the methodology is already well suited for widespread implementation. The overwhelmingly positive student reviews and quantitative data from the case studies demonstrate the contextual needs method is not only classroom-ready, but also project-ready. As data is catalogued from a variety of institutions employing the method in varied project domains, the growing knowledgebase (database) can rapidly and effectively be transferred across projects and teams to continue improving the application of engineering design to frontier design contexts. Table 7.8 presents future work items for this purpose.

Table 7.8: Future Work – Disseminate through Teaching, Collaboration, and Publishing

- Develop refined and expanded teaching materials and templates based on accumulated classroom assessment
- Develop instructional modules and templates customized for ESW, EWB, and similar student teams, including a data reporting mechanism and fostering a community of collaboration
- Disseminate the methodology and case study to the target audience

The teaching materials and templates used in the case studies proved effective; however, the survey data also suggests that additional teaching would significantly improve performance of the methodology. Further, instructional materials customized to the unique needs of humanitarian design teams from organizations such as Engineers for a Sustainable World, Engineers without Borders, and Engineering Ministries International have an important role to play. The materials should include a data reporting mechanism (serving as an input to the data archiving discussed in the previous paragraph) and foster a community of collaboration. This community might loosely follow the example of the open source software community in which every individual may contribute, and central organization and quality control are provided (as in the case of Red Hat Linux). The methodology should be made accessible to those who need it and will build upon it through the appropriate publication outlets. Included in this community should be commercial interests which can both benefit from and contribute to the growing database.

Appendix A: Context Questions Template

Table A.1: Context Questions Template – "How" Factors

HOW: Usage Application			
#	**Context Factor**	**Question Prompts v2.0**	**Response Notes**
a0	task (application, function)	What specific purpose will product be used for? How will the product be used?	
a1	task frequency	How often will product be used?	
a2	task duration	How long will product be used each time?	
a3	task quantity	How much quantity of the product's performance is needed?	
a4	task ruggedness	How roughly will product be handled/treated?	
a5	transportation type & amount	How will product be transported & how much?	
a6	task interactions	What are objects and substances the product will interact with? What are their characteristics?	
a7	operator position	What physical position will the user be in (standing, sitting, hands occupied)?	
a8	task quality	What quality of performance must the product provide?	
a9	cleaning	How and where might the product be cleaned?	

Table A.2: Context Questions Template – "Where" Factors

WHERE: Usage Environment			
#	**Context Factor**	**Question Prompts v2.0**	**Response Notes**
e0	surroundings	Where and in what type of surroundings will product be used? What characteristics of the surroundings affect what the product must be like?	
e1	weather/ climate	What weather/climate will product be exposed to?	
e2	environment ruggedness	Will product be exposed to any unusual substances or conditions?	
e3	space (when in use)	How much space is available for using product?	
e4	space (storage)	How and where will product be stored? How much space is available for storing product?	
e5	aesthetics of surroundings	What do the product surroundings look like? How should the product interact w/ the surrounding aesthetics?	
e6	ventilation available	How much ventilation is available during product use?	
e7	maintenance & parts cost & availability	What is the cost & availability of maintenance & parts?	
e8	energy availability & cost	What is the cost & availability of possible energy sources (human, battery, gas, electric, biomass)?	
e9	noise acceptability	How much noise is acceptable where the product will be used?	
e10	environment amenities		

Table A.3: Context Questions Template – "Who" Factors

WHO: Customer Characteristics			
#	**Context Factor**	**Question Prompts v2.0**	**Response Notes**
c0	user	Who will use the product? What user characteristics affect what the product must be like?	
c1	user skills & education	How skilled/experienced is the user with this task? What is the user's education level?	
c2	physical ability	Does the user have any physical conditions that may cause difficulty performing the task? (strength, control, range-of-motion, vision).	
c3	user tolerance for complexity	What is the most complex product the user is comfortable using? Must this product be less complex? How long is user willing to spend learning the product?	
c4	relevant customs and practices	Are there any cultural practices or expectations related to this product?	
c5	cost expectations: (purchase)	About how much is the buyer willing to pay to purchase this product?	
c6	cost expectations: (operation)	How much is the user willing to pay/work monthly to operate this product?	
c7	cost expectations: (maintenance)	How much is the user willing to pay/work monthly to maintain this product?	

Table A.3 (Cont.): Context Questions Template – "Who" Factors

WHO: Customer Characteristics			
#	**Context Factor**	**Question Prompts v2.0**	**Response Notes**
c8	time expectations: setup & operation	About how much time is the user willing to spend to setup this product? To operate this product? How valuable is saving time?	
c9	safety expectations	What is the most dangerous product familiar to the user? Must this one be less dangerous? What product safety concerns does the user have?	
c10	durability expectations	How long does the user expect the product to last?	
c11	purchase context	Who would purchase the product? Where and how might they purchase it? How would the buying decision be made (research, referral, impulse)?	
c12	performance expectations	What specific features or qualities are expected?	

Appendix B: Case Study 1 Template Data

Table B.1: Template Changes Derived from Team Data – "How" Factors

HOW: Usage Application			
#	**Context Factor**	**Questions w/ Modifications**	**Sample Customized Questions from Team Projects**
a0	task (application, function)	What specific purpose will product be used for? How will the product be used?	• How will you use the product? • What is the primary reason for using this product? • What are typical uses of the product? What types of foods will be sealed?
a1	task frequency	How often will product be used?	
a2	task duration	How long will product be used each time?	
a3	task quantity	How much quantity of the product's performance is needed?	• How big is your pet that needs feeding? How many pets? • How much area do you vacuum? • How many and what size of rooms will be cleaned?
a4	task ruggedness	How roughly will product be handled/treated?	• On a scale of 1-10, how durable do you need this product to be?
a5	transportation type & amount	How will product be transported & how much?	
a6	task interactions	What are objects and substances the product will interact with? What are their characteristics?	• What types of foods will be sealed? How thick a mixture would you stir? • What floor types would you use it on? Would you use it on wet and dry floors? • What size pizza would you cook? • What are you picking up with the hand vacuum? What will be cleaned?
a7	operator position	What physical position will the user be in (standing, sitting, hands occupied)?	• When using the DustBuster in low areas, what posture will you use? (bending over, squatting, sitting on a chair) • Will you have two hands free? One hand?
a8	task quality	What quality of performance must the product provide?	• How would you rate the hand vac's ability to vacuum/pick up debris? • Are the pitches realistic?
a9	cleaning	How and where might the product be cleaned?	• How would you clean the product? (Dishwasher/handwash)

Table B.2: Template Changes Derived from Team Data – "Where" Factors

WHERE: Usage Environment			
#	**Context Factor**	**Questions w/ Modifications**	**Sample Customized Questions from Team Projects**
e0	surroundings	Where and in what type of surroundings will product be used? What characteristics of the surroundings affect what the product must be like?	• What surfaces will the DustBuster be used on? • Where will product be used?
e1	weather/ climate	What weather/climate will product be exposed to?	
e2	environment ruggedness	Will product be exposed to any unusual substances or conditions?	
e3	space (when in use)	How much space is available for using product?	
e4	space (storage)	How and where will product be stored? How much space is available for storing product?	• How and where will product be stored? • How would you store the pitching machine? Where will you store the pitching machine?
e5	aesthetics of surroundings	What do the product surroundings look like? How should the product interact w/ the surrounding aesthetics?	• Do you feel the pitching machine matches its surroundings? • How does the stirrer visually compare to your other appliances? • What do the surroundings look like?
e6	ventilation available	How much ventilation is available during product use?	
e7	maintenance & parts cost & availability	What is the cost & availability of maintenance & parts?	• If the product broke, would you fix it yourself or buy a new one? • Where would you get replacement parts? How much will they cost?
e8	energy availability & cost	What is the cost & availability of possible energy sources (human, battery, gas, electric, biomass)?	
e9	noise acceptability	How much noise is acceptable where the product will be used?	• Does the breadmaker need to be quiet? • How much noise is allowed? Tolerable? • How much noise does the kitchen permit?
e10	environment amenities		• Will there be a place to dispose of waste nearby? • Will there be a place to clean the juicer near by? • How much light will be available for use?

Table B.3: Template Changes Derived from Team Data – "Who" Factors

WHO: Customer Characteristics			
#	**Context Factor**	**Questions w/ Modifications**	**Sample Customized Questions from Team Projects**
c0	user	Who will use the product? What user characteristics affect what the product must be like?	• Who will use the dispenser? (Gender, age, size)?
c1	user skills & education	How skilled/experienced is the user with this task? What is the user's education level?	• Can a new user easily learn skills required to use the product? • How much cleaning experience would users have? • Are you in a little league (if so, what league)? How difficult is the task currently? Must the product make it less difficult?
c2	physical ability	Does the user have any physical conditions that may cause difficulty performing the task? (strength, control, range-of-motion, vision).	• How much strength and dexterity are available from the user? • Vision?
c3	user tolerance for complexity	What is the most complex product the user is comfortable using? Must this product be less complex? How long is user willing to spend learning the product?	• Is part of the current product too complex to use? • What is the most complex kitchen appliance familiar to the user? How long is acceptable to spend learning to use the product?
c4	relevant customs and practices	Are there any cultural practices or expectations related to this product?	
c5	cost expectations: (purchase)	About how much is the buyer willing to pay to purchase this product?	
c6	cost expectations: (operation)	How much is the user willing to pay/work monthly to operate this product?	• Is it hard to change the filter, and or to empty stored debris? • How long do you expect the battery to last?
c7	cost expectations: (maintenance)	How much is the user willing to pay/work monthly to maintain this product?	• Would you purchase a new hand vacuum if you notice performance loss, or will you keep this current vacuum for some time?

Table B.3 (Cont.): Template Changes Derived from Team Data – "Who" Factors

WHO: Customer Characteristics			
#	**Context Factor**	**Questions w/ Modifications**	**Sample Customized Questions from Team Projects**
c8	time expectations: setup & operation	About how much time is the user willing to spend to setup this product? To operate this product? How valuable is saving time?	• How busy is the user? How much is saving one hour of time worth? • What expectations are there for the product's assembly? • How long do you think it should take to make bread?
c9	safety expectations	What is the most dangerous product familiar to the user? Must this one be less dangerous? What product safety concerns does the user have?	• What do you think can be dangerous about this product? • What is the most dangerous aspect of a hand vacuum? • Can you leave your child alone with the pitching machine?
c10	durability expectations	How long does the user expect the product to last?	
c11	purchase context	Who would purchase the product? Where and how might they purchase it? How would the buying decision be made (research, referral, impulse)?	• Who would purchase the product? • How far would the user go to purchase this product? What research would they do beforehand? • If you were buying the Kitchen Assistant, either for yourself or as a gift, where would you expect to purchase it?
c12	performance expectations	What specific features or qualities are expected?	

Table B.4: Miscellaneous Specific Questions from Team Data

MISCELLANEOUS: (Non-contextual)		
#	**Context Factor**	**Questions w/ Modifications**
m1	current process	How is the task currently performed?
m2	current likes	What do you like about the current product used to perform the task?
m3	current dislikes	What do you dislike about the current product used to perform the task?
m4	suggested improvements	What suggestions do you have to improve the current way the task is performed?

Appendix C: Case Study 2 Template Data

Table C.1: Template Changes Derived from Team Data – "How" Factors

HOW: Usage Application			
#	**Context Factor**	**Questions w/ Modifications**	**Sample Customized Questions from Team Projects**
a1	task application	What specific purpose(s) will product be used for?	• What specific purpose(s) will product be used for? [AR] • Is product for: home to make students more independent? A work environment? At school? (What other applications?) [AF]
	task function	What major function(s) should the product provide?	• What item types should product fold, ideally and minimally? (towels, bibs, shirts)? • Item characteristics (cloth type, material, size, weight)? Are items completely dry? • Do items need to be folded in a particular way? (Could they be rolled instead)? • Final folded size/volume? (Where will these be stored)? [AF]
	task process	How will product change the current task process? (What is the current process)?	• What is the current laundry process? (Is it automated at all now?) • What part of the current laundry process do you want automatic? • Should the items be picked up from a pile? [AF] • What is the current laundry process? Advantages of current folding process? [AF]
a2	task frequency	How often will product be used?	• How often will the product be used (times/day, daily, weekly?) [AF]
a3	task duration	How long will product be used each time?	• How long should the product function each time it is activated by the user? [SN] • How long will each student be using the product at a time? [SN]
a4	task quantity	How much quantity (of the primary product function) is needed?	• How much laundry will be folded each time? How many towels at a time? [AF] • How many items should the machine fold before someone removes them? [AF]
	task rate	At what rate should the primary function be provided?	• How fast does the machine need to perform the task? [AF] • How fast should the rocking motion be? [AR]
a5	task ruggedness	How roughly will product be handled/treated?	
a6	transportation type & amount	How often, how far, and in what way will product be transported?	• How will product be transported & how much? • Will the product be moved frequently; stored frequently? [AF]
	task quality	What quality of the primary function is needed?	• How well do the items need to be folded? (This probably depends on the context: home, school or employment). [AF]

Table C.2: Template Changes Derived from Team Data – "Where" Factors

WHERE: Usage Environment			
#	**Context Factor**	**Questions w/ Modifications**	**Sample Customized Questions from Team Projects**
e1	surroundings	What type of surroundings will product be used in?	• Is there any additional overhead lighting? [AF]
	surroundings (sound)	How noisy are product surroundings? How much noise from the product is acceptable?	• Acceptable noise level of the machine? [AF] • How quiet is the surrounding environment? [AR] • How much noise does the environment permit? [SN]
e2	weather/ climate	What weather/climate will product be exposed to?	
e3	environment ruggedness	Will product be exposed to any unusual substances or conditions?	
e4	space (when in use)	How much space is available for using product?	
e5	space (storage)	How will product be stored? How much storage space is available?	• How much space is available for storing product? • Where will it be stored (indoors, outdoors)? [AF]
E6	aesthetics of surroundings	How will product interact w/ the surrounding aesthetics?	
e7	ventilation available	How much ventilation is available during product use?	
e8	maintenance & parts cost & availability	What is the cost & availability of maintenance & parts?	• What is the availability of someone to maintain the system? • With current products, how often are they maintained and what does this cost? [AF]
e9	energy availability & cost	What is the cost & availability of possible energy sources (human, battery, gas, electric, biomass)? How should product be powered?	• How should this be powered (battery, electrical outlet)? • If outdoors, what is the source of power? [AF]

Table C.3: Template Changes Derived from Team Data – "Who" Factors

WHO: Customer Characteristics			
#	**Context Factor**	**Questions w/ Modifications**	**Sample Customized Questions from Team Projects**
c0	user	Who will use (choose, and buy) the product?	• Who will use the product? (Will teachers intervene)? What is user's role? Who would be the buyer of this product? [AF] • How many people will operate the device? How many at one time? [AF] • Any noises, lighting, or colors that users do not like? [AF]
c1	user skills & education	How familiar is the average user with this task? What is the user's education level?	
c2	physical ability: strength, control, range-of-motion	Does the user have any physical conditions that may make it difficult to perform this task?	• Does the user have physical conditions that make the task difficult? • What can the user physically do? • What is typical: mobility, manipulative ability, working height, and lifting ability? • Types of interface switches used? [AF]
c3	user tolerance for complexity	What is the most complex product familiar to the user? Must this product be less complex?	• What cognitive tasks can the user do or not do? Could they distinguish whether one or two items were picked up by the machine? Could the user press a button to indicate what type of item was picked up? [AF] • Does the machine need to give an audio or visual signal indicating folding is done? Where should the machine display information for the user? [AF]
c4	relevant customs and practices	Are there any cultural practices or expectations related to this product?	• Does the laundry need to folded in a particular way? [AF] • How do students respond to existing products? [SN]
c5	cost expectations: (purchase)	About how much is the buyer willing to pay to purchase this product?	
c6	cost expectations: (operation)	How much is the user willing to pay/work monthly to operate this product?	• What are reasonable operating costs for this product? • Are there significant operating costs associated with existing products? [SN]
c7	cost expectations: (maintenance)	How much is the user willing to pay/work monthly to maintain this product?	• What level of maintenance by staff members is acceptable? (i.e. changing light bulbs, etc.?) [SN]

Table C.3 (Cont.): Template Changes Derived from Team Data – "Who" Factors

WHO: Customer Characteristics			
#	**Context Factor**	**Questions w/ Modifications**	**Sample Customized Questions from Team Projects**
c8	time expectations: setup & operation	How much time is acceptable for setup? How much time and attention can be provided for operation?	
c9	safety expectations	What is the most dangerous product familiar to the user? Must this one be less dangerous? What safety features are you expecting? What dangers must be avoided?	• What is the most dangerous product this user normally interacts with? • Must this one be less dangerous? [AF] • What will the students do to this product? Will they run into it? Will they put hands or other items in the machine (how frequently)? [AF] • What safety features are you expecting? What dangers must be avoided? [AR]
c10	durability expectations	How long does the user expect product to last?	

Table C.4: Miscellaneous Specific Questions from Team Data

- Should the folded items be collected in a container or basket? [AF]
- Is adjustability needed in the rocking motion? [AR]
- How will the user be placed in the chair? [AR]
- What are the preferable rocking positions? [AR]
- How will the device be activated? From how many different possible locations? [SN]
- How many total settings or configurations are necessary for the product? [SN]
- How often must the products settings or configuration be altered? [SN]
- How often will the students be supervised? How long will students be allowed to use the product at a time without being supervised?
- Are there concerns about affecting other studnets not using the product? [SN]
- What is the buyer's reaction to certain materials: wood, latex, metals, machine oils, plastics? [AF]
- How much time for setup? How much time & attention from the user? [AF]

Appendix D: Case Study 3 Itemized Score Data

Table D.1: Contextual Information Scores by Question – "How" Factors

HOW: Usage Application			**A**	**A+B**	**Δ**
a0	*task (application, function)*	What specific application or purpose will product be used for?	33%	43%	10%
a1	*task frequency*	How often will product be used?	63%	83%	20%
a2	*task duration*	How long will product be used each time?	67%	93%	27%
a3	*task quantity*	How much quantity (of the primary product function) is needed?	40%	70%	30%
a4	*task ruggedness*	How roughly will product be handled/ treated?	13%	53%	40%
a5	*transportation type & amount*	How will product be transported & how much?	3%	47%	43%
		Average:	**37%**	**65%**	**28%**

Table D.2: Contextual Information Scores by Question – “Where” Factors

WHERE: Usage Environment			**A**	**A+B**	**Δ**
e0	*surroundings*	What type of surroundings will product be used in?	37%	60%	23%
e1	*weather/climate*	What weather/climate will product be exposed to?	13%	80%	67%
e2	*environment ruggedness*	Will product be exposed to any unusual substances or conditions?	0%	40%	40%
e3	*space (in use)*	How much space is available for using product?	20%	87%	67%
e4	*space (storage)*	How much space is available for storing product?	17%	87%	70%
e5	*aesthetics of surroundings*	How will product interact w/ the surrounding aesthetics?	-3%	77%	80%
e6	*ventilation available*	How much ventilation is available during product use?	37%	70%	33%
e7	*maintenance & parts cost & avail.*	What is the cost & availability of maintenance & parts?	-3%	23%	27%
e8	*energy availability & cost*	What is the cost & availability of possible energy sources? (e.g. human, batt., gas, electric, biomass)	23%	53%	30%
e9	*labor availability & cost*	How valuable is it if the product saves 1 hour of the user's time? (What could they do with that time?)	17%	77%	60%
e10	*materials avail. & cost*	What is the cost and availability of local materials important for the product?	3%	13%	10%
		Average:	**15%**	**61%**	**46%**

Table D.3: Contextual Information Scores by Question – "Who" Factors

WHO: Customer Characteristics			**A**	**A+B**	**Δ**
c0	*user*	Who will use the product?	43%	97%	53%
c1	*user skills & education*	How familiar is the average user with this task? What is the user's education level?	40%	90%	50%
c2	*physical: strength, control, ROM*	Does the user have any physical conditions that may make it difficult to perform this task?	17%	53%	37%
c3	*user tolerance for complexity*	What is the most complex product familiar to the user? Must this product be less complex?	17%	83%	67%
c4	*relevant customs and practices*	Are there any cultural practices or expectations related to this product?	7%	63%	57%
c5	*cost expectations: (purchase)*	About how much is the buyer willing to pay to purchase this product?	17%	97%	80%
c6	*cost expectations: (operation)*	How much is the user willing to pay/work monthly to operate this product?	20%	63%	43%
c7	*cost expectations: (maintenance)*	How much is the user willing to pay/work monthly to maintain this product?	-3%	67%	70%
c8	*time expectations: setup & operation*	About how much time is the user willing to spend to setup and operate this product?	10%	90%	80%
c9	*safety expectations*	What is the most dangerous product familiar to the user? Must this one be less dangerous?	7%	73%	67%
c10	*durability expectations*	How long does the user expect product to last?	7%	93%	87%
		Average:	**16%**	**79%**	**63%**

Publication 1: Switch Activated Ball Thrower

Green, M. G., C. Anderson, C. Nguyen and S. Samad, 2000, "Switch Activated Ball Thrower," *Proceedings of the Rehabilitation Engineering Society of North America Annual Conference*, Orlando, FL

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SWITCH ACTIVATED BALL THROWER

Matthew Green, Clark Anderson, Chris Nguyen, and Shariq Samad

ABSTRACT

Occupational therapists often work to integrate children with disabilities into normal classroom activities. Gym activities that involve ball-throwing games pose a difficult challenge for children with mobility impairments. A mobile, switch-activated ball thrower has been designed and prototyped to facilitate the inclusion of children with mobility impairments into ball throwing activities. The device is adaptable to a variety of games, easy to use, and economical to reproduce.

BACKGROUND AND PROBLEM STATEMENT

This project started in response to a request from an occupational therapist who works with elementary school students with mobility impairments. She wanted to include her students in playing games with their classmates during gym time. Many of these games focus on ball throwing: basketball, dodge ball, and tossing games. Her vision was for a portable, simple device that could easily be moved alongside the child's wheelchair. She wanted the device to interface with the remote "big mac" switches the children were already familiar with. Since no device on the market fulfilled these requests, there was a need for the design of a new device. The purpose of this project was to design and build a switch activated ball thrower that was adaptable to a variety of games, easy to use, and economical to reproduce.

DESIGN METHODOLOGY

Gathering Customer Needs

The first phase of this project focused on understanding the needs of the children and teachers who would use the device. The goal was to discover "what" the customers really needed with an open mind without becoming pre-maturely locked into design solutions. The design team spent time with local schools gathering this information. A focus group was conducted in a round table format that allowed teachers and therapists to share their vision for the project. Observation and interaction with the children who would use the ball thrower revealed unspoken needs. The customer needs were prioritized, measured with House of Quality techniques, and then used as the basis for generating design concepts (1).

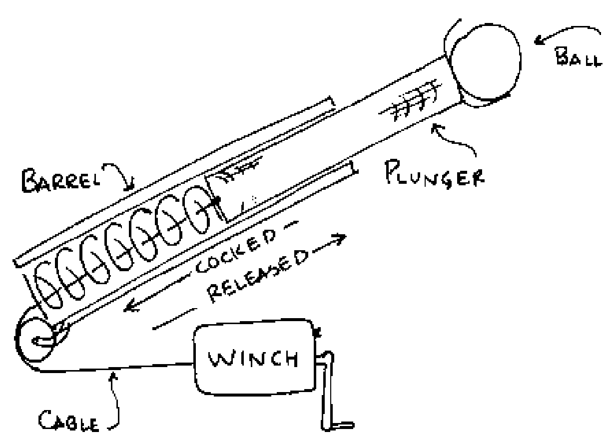

Figure 1: Compression Spring Concept

Concept Generation

The next phase of the project involved generating concepts to fulfill the customer needs. The problem statement was decomposed into sub-problems corresponding to functions that the device needed to perform. For example, the problems of holding the ball, triggering, and aiming were at first each considered independently. Ideas were generated using traditional brainstorming methods as well as newer idea generation techniques such as brain writing (1). Approximately sixty solution variants were identified. These partial solutions were then synthesized into design concepts. A sketch of one of these concepts is shown in Figure 1. The most promising of these design concepts were next evaluated during the concept selection phase.

Concept Selection

The concept generation phase resulted in four viable concepts that were considered for development: a catapult mechanism, rotating wheels, a slingshot device, and a compression spring concept. Several decision-making criteria were used to rank the concepts and select the most feasible one for development. The safety of students and therapists was of primary concern. Low maintenance was another customer need, which suggested that a simple design was preferable. The device needed to be economical to re-manufacture if it was to have widespread use. A subjective evaluation of the design's ability to capture the interest of students and teachers was also considered. This was dubbed the "Wow!" factor since it measured how likely the user was to have a positive first impression of the device. Based on these evaluation criteria, the compression spring concept (Figure 1) was selected to proceed with design and development. This selection was made based on the prediction that this concept could best fulfill the customer's needs.

DESIGN & DEVELOPMENT

The next phase involved developing the sketch of the selected concept into a working prototype. The decisions made during this stage were driven by the customer needs. Designing a safe device was a first priority. In order to score a basket from the free throw line, a basketball must leave the barrel at 20 miles per hour. This requires high forces and energy storage within the ball thrower. Therefore it was important to choose a design that adequately insulated the users from moving components. A five-gallon polymer bucket was selected to hold the ball in place and insulate the users from moving parts. A bucket was an economical choice that worked well. This is one example of a number of design decisions made to keep the device as simple and economical as

possible.

To enable the teacher to cock the device, a winch and cable arrangement was chosen to store energy in the compression spring (Figure 2). One advantage of this system is that it allows multiple power settings since the cranking distance controls how far the ball will shoot. A decision was made between a winch with a clutch ($125) and a normal winch ($20). The less expensive winch had the disadvantage that its handle would spin while the winch was being unwound during the release of the ball. The less expensive winch was chosen for economic reasons, and an electronic interlock was installed as a safety so that the device could not be fired until the user removed the winch handle.

Figure 2: Winch Mounted to Barrel

In order to make the ball thrower mobile, a rolling cart was chosen with wheel brakes. This allows the ball thrower to be mobile or stationary depending upon whether the brakes are set. Along with a variable shooting range, the device has a range of angle settings. It can be swiveled around to shoot in any direction without moving the cart. The ball thrower can also be aimed at any angle from horizontal to straight up.

EVALUATION & DISCUSSION

The children who first tested the device and the OT who requested it both enthusiastically received the ball thrower (Figure 3). It succeeded in meeting the design goals of being adaptable to a variety of ball games, easy to use, and economical to re-build. The device is adaptable to a variety of ball games due to its wide range of aiming angles and multiple power settings. At maximum power, the ball thrower will shoot a regulation size basketball up to 35 feet. It can also be used to gently toss a soft ball to a nearby classmate. The teacher can easily set the device to aim horizontally, vertically, or at any angle in between. It will also swivel 360 degrees for a wide target area. The ball thrower is mounted on a cart equipped with wheel locks. This allows it to be positioned securely in one location, or rapidly moved during gym activities.

Figure 3: Complete Ball Thrower

The ball thrower is also easy to use. An off-the-shelf winch allows the teacher to cock it by winding it three or four times. The winding force required is less than 10 pounds, a value consistent with accepted ergonomic standards (2). The child may use any remote switch with a standard 1/8” plug to trigger the device. Once the device is cocked and the switch plugged in, the child may fire at will by pressing the switch. A pair of long-lasting rechargeable batteries powers the ball thrower. The batteries used are calculated to last at least one month before needing recharging. A battery charger provided with the ball thrower can be plugged into recharging jacks mounted on the device so that the teacher does not have to handle the batteries. Due to lightweight construction, the complete ball thrower weighs less than 30 pounds. The device also disassembles into two parts within seconds to fit easily in a storage closet or a standard size car trunk.

Great care was taken during the project to insure that the device could be re-manufactured for other schools. Off-the-shelf parts were used whenever possible to avoid the costs of custom manufacturing. When the design was complete a detailed bill of materials was compiled along with exploded views to aid in duplication of the device. As testimony to the success of the project, another occupational therapist has already requested a duplicate of the ball thrower after witnessing a demonstration.

REFERENCES

1. Otto K, & Wood KL, (2000). Product design. Prentice Hall.
2. Sanders MS, McCormick EJ (1987). Human factors in engineering and design. New York: McGraw-Hill.

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Publication 2: Integrating Service-Oriented Design Projects in the Engineering Curriculum

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[1] Paper reformatted from published version to comply with dissertation formatting requirements.

Integrating Service-Oriented Design Projects in the Engineering Curriculum

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Abstract
Engineering curricula are undergoing continual advancements. Faculty seek to apply new techniques and strategies to interest students, to address their diverse backgrounds, and to achieve a balance between theory and practical, hands-on applications. One area of advancement is project-centered education. To provide students with realistic applications, projects are being used as an instructional vehicle. The extent of the projects depends on the type of course, ranging from support projects in analytical courses to backbone projects in design courses. No matter where a course falls in this range, a key question in project-centered curricula is the type of projects that should be used. In this paper, we propose a service-oriented strategy for choosing projects. This strategy provides a number of advantages to students and faculty. These advantages are described in the context of basic implementation principles and four case studies. Results are shown for an undergraduate design methods course, an undergraduate capstone design course, two graduate-level product development courses, and a Masters of Science research project.

Introduction
Project-centered education is becoming an emphasis of many engineering curricula. As part of this emphasis, unique opportunities exist to expose our students to a variety of design or open-ended projects. Service projects, or those that emphasize human need, represent one such opportunity. According to the NSPE Engineers' Creed, Professional Engineers are called upon to "place service before profit … and the public welfare above all other considerations." In this spirit, it is possible to create successful service projects that directly benefit a number of groups in our society: those marginalized by disasters, persons with disabilities, and the rural poor of developing countries. In the US, nearly 10% of the population copes with a severe disability[1]. Worldwide, many national economies have led to lifestyles with persons struggling for physical survival on a daily basis. A coarse measure of the distribution of technology indicates one-third of our world's population lacks access to electricity[2]. Engineering curricula should acknowledge these abundant opportunities for service-oriented design projects in our increasingly global society, and seek reliable methods for delivering and realizing such projects with our students.

This paper presents four approaches exemplifying the integration of human need projects into student design work. These approaches are: (1) an undergraduate design methods class in which teams design new concepts, such as a heat exchanger for medical relief teams; (2) an undergraduate capstone design class in which students deliver a working prototype, such as a wheelchair positioning unit; (3) two graduate prototyping classes in which students deliver a working prototype, such as an assistive lock-opener for persons with physical disabilities; and (4) an MS thesis research program for developing countries, with such projects as a handbook for selecting small-scale electricity generation technologies for use in remote areas. These approaches provide a framework for how "service-oriented design projects" can be implemented in an engineering curriculum. Four elements common to each of these approaches are: (1) a source of project ideas; (2) funding; (3) tools such as design techniques and prototyping facilities; and (4) deliverables with a service impact.

Benefits of service oriented design projects include intense student enthusiasm, a scope realizable as student projects, and broadening engineering horizons into international and philanthropic concerns. These projects address multiple ABET outcomes and produce deliverables serving those in need of medical relief, persons with disabilities, and the rural poor of developing countries. We present this framework using examples[*] from three US universities: The University of Texas (UT) at Austin, Brigham Young University, and University of Missouri-Rolla.

Case Study 1: Undergraduate Design Methods Class

A mechanical engineering design methods course at UT Austin includes the conceptual design of human-need projects. One month of the course is dedicated to producing a conceptual design by teams of three to five students. Teams select a project from descriptions provided by the instructor. Students employ the design methods[3] taught in the course to generate conceptual designs, and then select the most promising for fulfilling the customer needs. The conceptual designs include drawings showing geometry and materials, and a bill of materials with cost estimates. Only limited prototyping and experimentation are conducted by the teams, so no funding beyond the normal course fee structure is required.

The faculty and teaching assistants for the design methods class generate project ideas from personal experiences or contacts. Examples of previous projects include automatic pitching machines and pasta cookers. Other, service-oriented projects, such as a device for assisting people with disabilities in labeling envelopes, are obtained from local school districts, service organizations, and personal contacts. A teaching assistant, through contact with a medical relief organization, identified one such project with a service-oriented component. The project was for medical teams that make semi-annual trips into rural Mexico and establish a temporary clinic, hospital, and operating room. The design

[*] Syllabi available: http://madlab.me.utexas.edu/~mgreen/documents/service-oriented_syllabi.pdf

opportunity was to capture the waste heat from the exhaust of a 5kW diesel generator and use it to heat water for cooking, bathing, and medical purposes. Constraints from the relief workers included strict limitations on weight, volume, cost, and complexity.

Although the "waste heat water heater" project was only one out of five choices, approximately half of the student design teams selected the project. The unusually high interest resulted from a combination of the potential for implementation with a real customer, and the human need aspect. The high level of student interest and motivation also led to an unusual number of additional questions concerning constraints. The fact that the project originated as a need from an actual customer seemed to prompt the students to design for reality, rather than making assumptions for the sake of convenience.

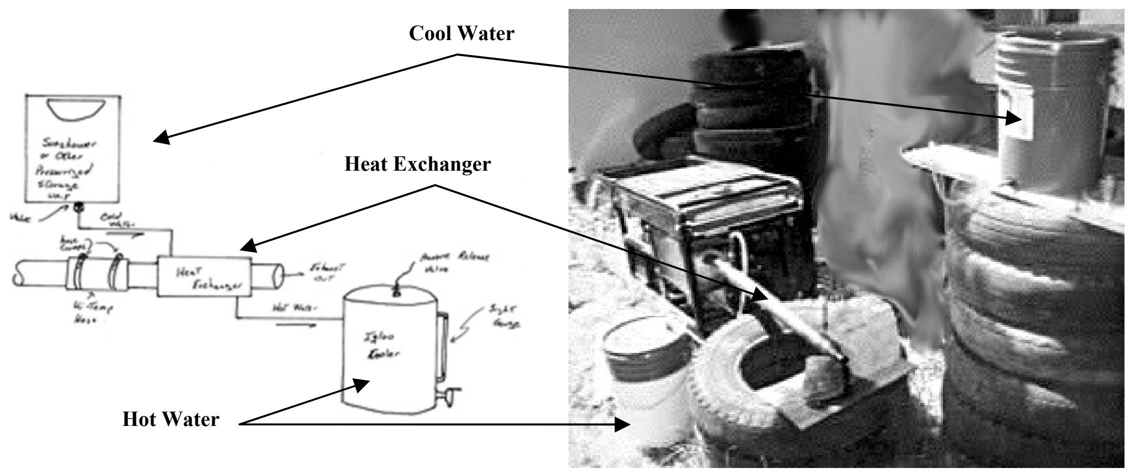

Figure 1: Water heater conceptual sketch[4]. Figure 2: Field-testing water heater prototype.

When the course was completed, the conceptual design reports were passed on to a graduate student for potential implementation. This student coordinated final design, prototyping, and field-testing of the device as a personal project. During a two-week operation in rural Mexico, the $50 device heated 5 gallons per hour of tap water to 150°F[5]. The prototype was light, small, and simple to operate and maintain.

Undergraduate Design Methods Class (UT Austin)

Project Source	Local school districts, service organizations, and personal contacts
Funding	Normal course fee structure
Tools	Design methods, Traditional engineering analysis
Deliverables	Culminates in conceptual design. Finalization and prototyping possible w/ outside work by graduate students.

Case Study 2: Undergraduate Capstone Design Class[6]

Brigham Young University (BYU) in Provo, Utah has included projects that address human need in their undergraduate capstone design course. The capstone course at BYU is a two-semester course in which student design teams, typically composed of five senior engineering students, design a product to satisfy the requirements of a project sponsor. Capstone projects generally include the design of a product as well as the construction of a working prototype. Most capstone projects are sponsored by industrial partners of the university. These industrial partners provide a liaison engineer for the student design team as well as a financial contribution to the capstone program. The cost structure of the capstone program is designed to accommodate a few "non-paying" projects each year.

Capstone projects that address human need are identified through potential sponsors, without active solicitation. These projects are either supported by an outside sponsor or else they fall into the "non-paying" category mentioned above. These projects can be either for an individual or for an organization. The student design team interacts directly with the individual or the organization in developing design solutions and a prototype. A student machine shop and wood shop are available for the construction of prototypes.

Design projects that address human need, including a multi-function wheelchair table and a tricycle merry-go-round for children with physical challenges, have been completed in the BYU course. A product that is currently being developed in the course is a mechanism for picking up and storing a wheelchair behind the seat of an extended-cab truck. The product will allow the driver with disabilities to enjoy greater independence by providing a means for loading the wheelchair in the truck without assistance from another person. The scope of the project fits well within the criteria for a capstone project and allows for both design and construction of a prototype.

Kurt Fackrell, a member of the student design team for the "wheelchair storing" device, noted two aspects of the project that are different from many other capstone projects. First, the project is for an individual, rather than for a corporation. The student design team interacts directly with the end user of the product, rather than with an assigned liaison engineer from a company. Second, the project involves every aspect of the design, rather than just a component of a larger system. The students will follow the project all the way from preliminary design concepts to installation of the final product into the truck.

Mr. Fackrell noted that, "*…working personally with the end-user has been very rewarding, especially when that user will gain so much from the project result. We have extra incentive to build a device that will serve beyond his expectations for years to come.*"[7] The incentive and satisfaction that come to students who are involved in such "human need" projects provide additional motivation for including such projects in the engineering curriculum.

The administrators of the capstone course at BYU plan to continue providing projects that address human need, although no formal structure has been established for soliciting such projects. A new center on campus called the Jacobsen Service Learning Center[8] has been established for identifying service-related opportunities for the university. This center has been identified as a potential source for additional project ideas for the capstone course.

Undergraduate Capstone Design Class (BYU)

Project Source	Capstone sponsors (individuals or organizations), service-learning center
Funding	Outside sponsor or covered by capstone projects budget
Tools	Design methods, Prototyping shop
Deliverables	Working prototypes delivered to customer

Case Study 3a: Graduate Design Course with Assistive Technology Products

At the University of Missouri-Rolla (UMR), assistive devices serve as the design projects for a graduate course: Modern Product Design. The goals of this course are to educate students in some recent research findings in the discipline of design as well as promote the engineering ideals of service to the community. The one semester course enrolls between 15 and 25. One aspect of special interest in the course is teaching the graduate students how to apply a "new" design principle or idea. To ensure students understand the material in a practical and applicable context, student teams design and develop fully functioning and usable prototypes. The critical challenge and learning in this course comes as students apply the design principles to their design projects. Topical coverage consists largely of recent research results from the design community along with basic approaches to product design. Since the majority of the course introduces new design research results, the previous scope of research applications is generally limited and perhaps not directly focused on product design. Creativity and innovation are required on the part of the students to apply a "new" idea, which is a critical aspect of an advanced technical education. In essence, the goal is not to teach the students something that is known, but to teach them how to extend current knowledge to a point where they can use it for the problem at hand.

The design projects are developed in cooperation with Rolla Public Schools Special Services Program. Our goal is to develop products that improve the educational climate of students with disabilities. Example products range from mobility assisting devices for students to educational assistive devices for teaching a specific skill or lesson to products that enhance the teacher's ability to control the classroom or prepare lessons more easily. In general, any product that helps is an acceptable design project.

In Fall 2000, three products were developed in the Modern Product Design class. One product assists teachers in teaching children to walk up and down stairs. Another product facilitates the teaching of fine motor skills such as ringing doorbells and manipulating latches. The third device moves students in a swinging motion, a twisting motion, or both to aid in calming students with autism.

In each case, the graduate students begin the product design by visiting the schools, interviewing students and teachers, and developing a focused set of customer needs. As the course progresses, students move through the basic stages of design; starting with clarification, conceptualization, and embodiment; and ending with fabrication of a usable prototype. One emphasis of the course is to explore new methods in concept generation. Figure 3 shows concepts for the swinging product that were generated using a method focused on developing modular product architecture[9].

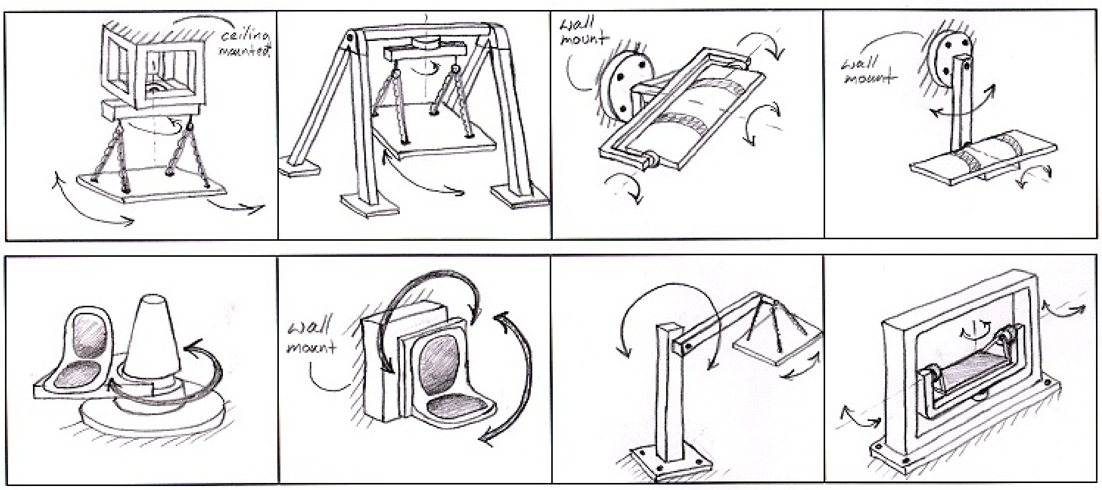

Figure 3: Concept sketches for a product to swing and rotate a student.

Shown in Figure 4 is the completed stair-step training product. In response to the teacher's need for compact storage, the steps stack inside the next taller step. The stacked steps store in the center section when not in use. The stair step trainer also features removable PVC railings to decrease storage space, and locking casters stabilize the stairs during stair step training.

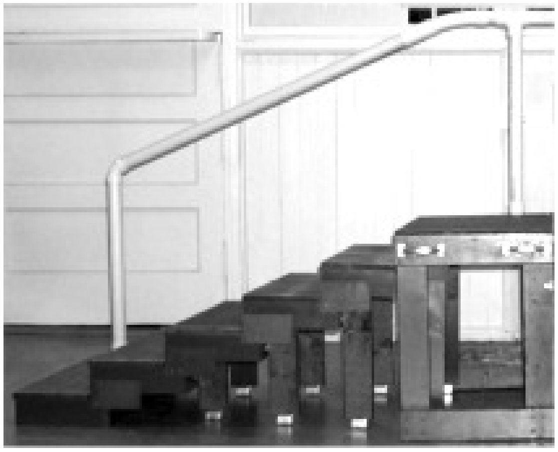
Figure 4: Stair step trainer product.


Figure 5: Activity board left view.

Figure 5 shows the final activity center prototype used to assist in the development of fine motor skills. The activity center has different activity modules that can be changed to feature different activities. One activity, for example, is used to train students to remove nuts from bolts. Training modules not in use are stored in the back of the activity center. The primary surface is curved to increase access to multiple activity modules for users who have limited reach and difficulty moving. The module mounting positions on the sides of the activity center enable simultaneous usage by three students.

To this point, the Modern Product Design course has been a significant success for the students of Rolla Public Schools, graduate students at UMR, and as outreach for the University of Missouri-Rolla. The activity center product won a RESNA award, the projects were featured in an article in the local daily newspaper, and the products are still in use at Rolla Public School campuses.

Graduate student sentiment on how the class could be improved echoes the needs of engineering design. In general, the graduate students felt better characterization and quality of customer needs, both in specificity and breadth, would have improved the projects. Also some technology, resource or method to reduce prototype effort and time would have allowed more time to have been spent on conceptualization and design analysis.

Graduate Design Methods Class (UMR)

Project Source	Rolla Public Schools, Individuals
Funding	University outreach support
Tools	Basic woodworking and hand tools with some rapid prototyping equipment
Deliverables	Working prototypes delivered to customer

Case Study 3b: Graduate Product Design and Prototyping Class

The graduate Product Design and Prototyping class at UT Austin culminates with students delivering fully functional prototypes to local "customers" with physical disabilities. The basis of this course is product design, development, and prototyping. Product design projects are the focus of the student efforts, with emphasis on functional, working designs as opposed to the common ink-paper concepts. Students must produce a working, tested, and robust design by the end of a semester, delivering the result to the customer. This focus provides graduate students from mechanical engineering, electrical engineering, social work, and special education with a unique opportunity to work with hardware, in contrast to the theoretical focus of most graduate-level courses. Thus, the intent of the course is to produce functional designs based on real product/humanitarian needs.

Projects are selected which require the novel synthesis of low to medium technology (not high technology), and involve $100-$300 of funding. Projects for initial offerings of the course were solicited from facilities that include persons with disabilities: the Austin State School and two local school districts. Interdisciplinary design teams of 4-5 graduate students from engineering, social work, and special education are formed using team selection algorithms[10] based on MBTI, Six Hats, and technical/hands-on skills. The teams work with supervisors, teachers, and the students (customers) at the schools to refine project ideas into electromechanical design problems related to the customers' occupations and learning environments. These projects present a unique challenge to the design teams in that most of the problems admit solutions that provide assistive technologies for the tasks currently performed by the customers. Table 1 shows examples of projects completed since the course's inception.

Table 1: Examples of design projects for persons with disabilities.

- Assistive bowling device
- Visual phone interface for deaf persons
- Device to wrap baking potatoes in foil using only one hand
- Switch activated ball thrower
- Key actuation device for persons with limited strength and range of motion
- Letter labeler to assist persons with disabilities on a job site
- Sand-bagging system to assist persons with disabilities on a job site
- Electro-mechanical can crushing system
- Sensory-stimulation system for persons with disabilities
- Décor chip sorter to assist persons with disabilities on a job site
- Accessible shelving system for persons with disabilities

Each week of the course employs a unique balance of one lecture, one lab or reverse engineering exercise, and one experiential presentation. Every class week begins with a lecture on a design method[11], assistive technology, or social work topic. The mid-week class includes a hands-on activity such as reverse engineering a product using a discussed design method, or completing a prototype construction lab to learn the use of fabrication equipment. The last session of each week is devoted to an experiential presentation wherein students are given a 10x10 ft^2 section of a wall to post team identity, background research, or project results. The instructors and other teams review the presentations and provide interactive feedback on the progress of the designs. In the last class meeting of the semester, students lead a feedback session that emphasizes critical and complimentary feedback for student progress.

After initial project choices and visits to their customer locations in Austin, the students systematically follow the product development process[12] taught in the class. Design teams produce a proof-of-concept, an alpha, and a beta prototype at key milestones. Up to 25 students a semester utilize a prototyping shop including over $40,000 in fabrication equipment (Figure 6). Students are required to develop a package at the end of the semester that will be delivered to the customer. This package includes a working device or system that satisfies the customer needs, a brief report documenting the project results and chronological decisions, a Bill-of-Materials, an illustrated manufacturing plan, and a brief user's manual. Each team also submits a 3-page article and a 5-minute videotape to the annual Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) international student design competition[13]. Since 1994, twelve teams from UT Austin have been selected to present their designs at the annual RESNA conference.

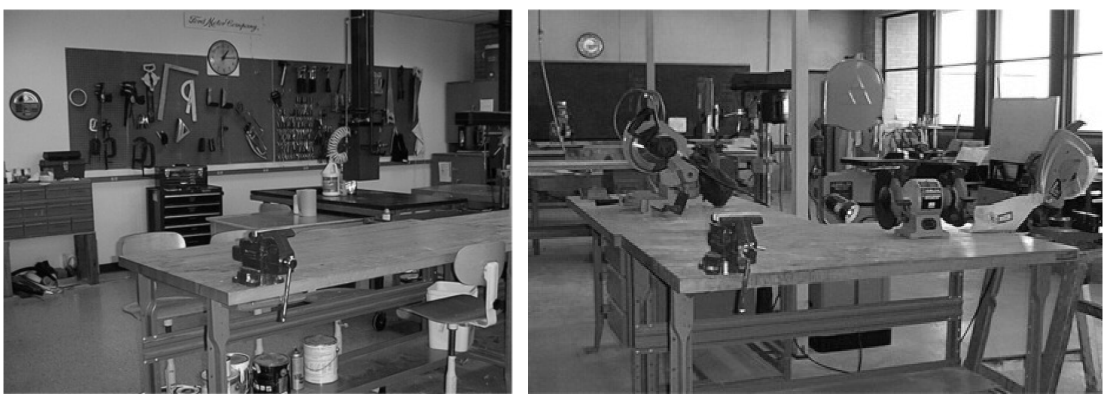

Figure 6: UT Austin Mechanical Engineering prototyping lab and cutting shop[+].

For illustration, Figure 7 and Figure 8 show two RESNA winners that are currently in use in Austin schools. The assistive bowling project focused on the design of a bowling device that would allow people, especially children, with disabilities to bowl with more autonomy and normalization than current wheelchair bowling ramps offer. The innovative design enhanced accessibility for children with many types of disabilities and greatly increased the performance of the bowling ball ramp. The adaptive key handler

[+] Sponsored by Ford Motor Company, National Instruments, the Keck Foundation, and Flour-Daniel.

(Figure 8) allows a wheel-chair user with severely limited strength and range of motion to use key-operated elevators and doors. The device was designed to be compact, portable and lightweight for use by an 11-year-old student with rheumatoid arthritis. His use of a wheelchair requires riding the elevator to attend classes.

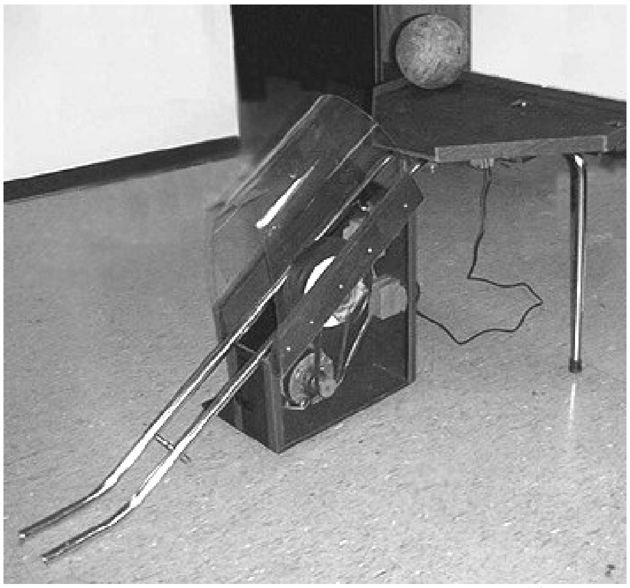

Figure 7: Assistive bowling device[14].

Figure 8: Assistive key handler[15].

Graduate Product Design and Prototyping Class (UT Austin)

Project Source	Local schools with students that have special needs
Funding	Foundation funding, endowment funding, and course fees
Tools	Design methods, Traditional engineering methods, Prototyping lab
Deliverables	Working prototype and manufacturing plan

Case Study 4: MS Thesis Research Program

Design research for use in developing countries has been integrated into graduate research at UT Austin. One such project culminated in a manual for selecting small-scale power generation technologies for use in remote areas. In this case, the student was specifically motivated to apply the principles of engineering design to needs of the rural poor in developing countries. Support for the graduate student was elicited from teaching assistantships and competitive fellowships. The research began with a hit-and-miss search of literature and organizations to uncover information and potential topics. Some of the most useful sources of literature were Non-Government Organizations[16,17] (NGO's), and hard-to-find literature was accessed through archival works[18,19] focused on developing countries. Travel to various NGO's was interspersed throughout the research to access physical libraries and consult with development experts.

The literature search and consultation with NGO's guided the selection of the topic, "Small-Scale Electricity Generation: Selecting an Appropriate Technology". The student wrote the thesis[20] as a manual minimizing technical terms in order to be "understandable to those who lacked engineering training, but not capability." The manual guides the reader through a seven-step selection methodology* for choosing among solar, wind, hydro, fossil-fuel generators, and utility grid extension.

The choice to develop a methodology for selecting among available technologies, as opposed to refining a single technology, was important for at least two reasons. First, it allowed the student to gain familiarity with multiple options to address a prevalent need. This type of expertise is often more in demand for applications in developing countries than specialization in a single solution. A common sentiment expressed by development workers is, "… what we need is not another new technology, but a resource for making an appropriate selection from what is already available." Secondly, a small research budget with no fieldwork possibilities was more conducive to developing a selection methodology rather than incremental development of a specific technology.

Effectively disseminating this type of research poses a challenging problem[21]. The approach taken in this case was to make the selection manual available for download[22] and pursue a non-profit publisher to provide a paper edition. Raising awareness of the research results among the target audience will include publicizing the work through contacts with NGO's and placing how-to articles in relevant periodicals.

MS Thesis Research Program (UT Austin)

Project Source	Literature review, NGO's
Funding	TA appointments, Competitive fellowships
Tools	Design methods, Non-traditional literature base
Deliverables	Publication of how-to manual

Benefits of Service-Oriented Projects

It is widely accepted that design projects address multiple ABET outcomes. The previous case studies, for example, include: the application of engineering knowledge, utilizing experimentation, designing systems, solving engineering problems, and communicating effectively. Achievement of these educational objectives is amplified by the student enthusiasm often accompanying a service-learning component. Service-oriented projects can serve those in need of medical relief, persons with disabilities, and the rural poor of developing countries. This leads to a high level of student motivation that facilitates educational objectives, particularly when students have direct customer contact. The motivating power of the student-customer connection in human need projects is apparent in a recent student's comments: "*Academic design exercises seemed*

* The steps are: understand the technologies, gather site resource data, assess the amount of power needed, estimate costs of viable options, select a technology, specify and install the system, and monitor and document performance..

so irrelevant; what difference did it make whether our design report was an order of magnitude off? The [UT Austin] prototyping class changed that. After we played with the kids and talked with their therapist, we knew we had to deliver a working product. We just couldn't disappoint them."

In addition to high student motivation, service-oriented projects provide other positive characteristics. They often provide a satisfying closure within the constraints of the academic calendar. A well-scoped project allows students to experience a complete product development cycle, from gathering customer needs to delivering a functioning prototype. Additionally, service-learning offers opportunities to broaden engineering education into a "global and societal context[23]," exposing students and faculty to new outlets to pursue humanitarian interests through research and career opportunities.

Principles of Implementation

The previous examples serve as case studies illustrating how "service-oriented design projects" can be implemented in an engineering curriculum, and highlight four necessary elements: (1) a source of project ideas, (2) funding, (3) tools such as design techniques and prototyping facilities, and (4) deliverables with a service impact. Table 2 suggests possible sources of service-oriented design projects, such as local schools or international design competitions. Funding is often a minor issue, since the low cost nature of many service projects allows integration into an existing design course with little or no addition to the existing course fee structure. In some of the previous examples, small amounts of funding were obtained through project sponsors. The existence of tools such as a prototyping facility is a more difficult issue, and projects must be designed to be realizable with the available facilities. Finally, there are numerous ways design projects can have a service impact. Conceptual designs can be passed on for prototyping and implementation, working prototypes may be delivered to the customer, or how-to manuals can be written and distributed. In the case studies above, integrating service-oriented design projects into the curriculum has proved richly rewarding to students, "customers", and faculty.

Table 2: Sources of service-oriented design projects.

• Local Resources Local schools with special needs Needs personally known to faculty and students
• Service-Learning Books on the implementation of service-learning[24] Websites of service-learning projects[25,26]
• Design competitions Rehabilitation Engineering Society (RESNA) www.resna.org Basic Utility Vehicle competition www.drivebuv.org Society Competitions, such as the 2001 ASME sip-and-puff[27]
• Technologies for Developing Countries Development by Design www.thinkcycle.org/tc-topics/ Development technology unit www.eng.warwick.ac.uk/DTU/

Bibliography

1 McNeil, John M. Americans with Disabilities: 1991-92. Data from the Survey of Income and Program Participation. U.S. Department of Commerce, Economics and Statistics Administration, Bureau of the Census. Accessed Oct. 2001. http://codi.buffalo.edu/graph_based/.demographics/.awd/AWD/Type.html

2 "Providing Energy Needs for Two Billion People," New Release No. 97/1313S, World Bank, Accessed Mar. 2002. www.worldbank.org/html/extdr/extme/1313.htm

3 Otto, K. N. and Wood, K. L., Product Design, Prentice-Hall, Inc., NJ, 2001.

4 Shimek, M., Holland, W., Kan, C., Rollins, J., Sanchez, C., "The Cleaners Project 2: `Waste Heat' Water Heater," ME 366J Conceptual Design Report, Dept. of Mechanical Engineering, The University of Texas, April 10, 2000.

5 "Field Test of a Waste Heat Water Heater Prototype," Accessed Jan. 2002. http://madlab.me.utexas.edu/~mgreen/water_heater

6 Communication with Robert Todd, professor of mechanical engineering, Brigham Young University, Dec. 2001.

7 Communication with Kurt Fackrell, member of the student design team, Brigham Young University, Jan. 2002.

8 www.byu.edu/jacobsencenter/findex.htm

9 Stone, R., Wood, K., and Crawford, R., "A Heuristic Method for Identifying Modules for Product Architectures," *Design Studies* 21(1):5-31, 2000.

10 Jensen, D.L., and Wood, K.L., 2000, "Incorporating Learning Styles to Enhance Mechanical Engineering Curricula by Restructuring Courses, Increasing Hands-on Activities, & Improving Team Dynamics," Proceedings of the 2000 ASME International Mechanical Engineering Congress and Expo., November 5-10, Orlando, Florida.

11 Otto, K. N. and Wood, K. L., Product Design, Prentice-Hall, Inc., NJ, 2001.

12 Otto, K. N. and Wood, K. L., Product Design, Prentice-Hall, Inc., NJ, 2001.

[13] "Rehabilitation Engineering and Assistive Technology Society of North America," www.resna.org

[14] Cox, D., Koshti, S., Jackson, B., Malish, A., Numan, M., Shipley, D., "Design of an Assistive Bowling Device," *Proceedings of the RESNA Annual Conference*, Summer 1999.

[15] Shimek, M., Van Wie, M., Kothawade, S., Subrahmanyam, R., Escobar, M., "An Assistive Technology Key Turning Device For Independent Entryway Access," *Proceedings of the RESNA Annual Conference*, Reno, Summer 2001.

[16] Intermediate Technology Development Group (ITDG) Homepage, Rugby, UK. www.itdg.org and www.developmentbookshop.com

[17] Educational Concerns for Hunger Organization (ECHO) Homepage, Ft. Myers, FL. www.echonet.org

[18] "Appropriate Technology Library," Available for purchase on-line. Accessed Jan. 2002. www.villageearth.org/atnetwork

[19] "Humanity Development Library 2.0," Humanity Libraries Project, Accessed Jan. 2002. www.humanitylibraries.net

[20] Green, M. G., "Small-Scale Electricity Generation: Selecting an Appropriate Technology," Masters' Thesis, Dept. of Mechanical Engineering, The University of Texas, Dec. 2001. http://madlab.me.utexas.edu/~mgreen/research

[21] Green, M. G. "Publishing Engineering Research on Appropriate Technology," Dec. 2001. http://madlab.me.utexas.edu/~mgreen/research

[22] Green, M. G., "How to Generate Electricity in Remote Areas – A Simple Guide to Choosing the Right Technology," Version 1.0. Feb. 2002. http://madlab.me.utexas.edu/~mgreen/seg/

[23] ABET. "Criteria For Accrediting Engineering Programs Effective for Evaluations During the 2001-2002 Accreditation Cycle," Engineering Accreditation Commission of the Accreditation Board of Engineering and Technology, 2000. www.abet.org

[24] Tsang, E., Projects That Matter: Concepts and Models for Service-Learning in Engineering, American Association for Higher Education, 2001. Preview: www.aage.org/service/series_new.htm

[25] "101 Ideas For Combining Service and Learning," Accessed Mar. 2002. www.fiu.edu/~time4chg/Library/ideas.html.

[26] National Service-Learning Clearinghouse Homepage. Accessed Mar. 2002. www.servicelearning.org

[27] "Student Design Contest Index" American Society of Mechanical Engineers. Accessed Jan. 2002. www.asme.org/students/Competitions/designcontest/index.html

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Publication 3: Product Usage Context: Improving Customer Needs Gathering and Design Target Setting

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[1] Paper reformatted from published version to comply with dissertation formatting requirements.

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PRODUCT USAGE CONTEXT: IMPROVING CUSTOMER NEEDS GATHERING AND DESIGN TARGET SETTING

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1 ABSTRACT

The early information-gathering stages of product design prove problematic for *frontier design environments*, or situations unfamiliar to the designer. This research provides a framework for gathering, documenting, and acting upon contextual information including the customer, market, and *product usage context*. This framework is validated through an empirical product study which shows that a chosen *functional family* of products, designed to fulfill the same primary function, exhibit significant differences in both customer needs and product requirement design targets. These differences are convincingly accounted for in terms of product usage context factors identified by the research. The functional family of "broadcast light and allow mobility" is selected, corresponding to a wide variety of candle and lantern-type products. It is shown that the products suited for long distance backpackers, for example, exhibit significantly lower volume and weight than the products intended for other usage contexts. The results presented provide a starting point to extend this research to other

product domains, and support the future development of methods and tools equipping design engineers to successfully design products for frontier design environments.

2 PRODUCT DEFINITION

Multiple texts have put forward formal design methods (Cagan and Vogel, 2002; Otto and Wood, 2001; Pahl and Beitz, 1996; Ullman, 2002; Ulrich and Eppinger, 2004), exhibiting some variations among definitions. For this reason, we present here our working definitions of: product definition, customer needs, and product requirements. The following two sections build on these by introducing and exploring the concept of product design context, with a focus on the context in which a product will be used.

The beginning stages of the product design process may be collectively referred to as the "front-end" of the design process (Cagan and Vogel, 2002), "understanding the problem" (Otto and Wood, 2001; Ullman, 2002), or the "product definition" phase. This beginning phase is characterized by extensive information gathering, and is considered foundational to creating successful designs. This paper uses the following definition:

Product definition - the first phase of the design process including: background research (often including competitive benchmarking), gathering customer needs, and formulating product requirements/engineering specifications.

Customer needs (sometimes called "customer requirements") combined with importance ratings show how important it is to the customer that certain expectations are satisfied. For example, the abbreviated product definition information shown in Table 1 indicates that "boil water" is a must (importance rating of 5) for satisfaction, whereas economical is desirable but negotiable. Product requirements (sometimes called "engineering specifications", "design requirements", or "functional requirements") define quantitative measures for satisfaction of each need. Design target values (or thresholds of satisfaction2) are defined in terms of metrics such as mass (kg) and cost ($). Quality Function Deployment (QFD) is a popular technique for mapping customer needs to product requirements, and specifying design targets.

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2 A *Kano diagram* represents the product requirement thresholds as the origin of the axes, the point at which degree of implementation becomes great enough to cross from negative to positive satisfaction. It also shows the effect of exceeding or undershooting the product requirement thresholds depending on whether a need is classified as basic, expected, or delighted.

Table 1: Partial Product Definition for Portable Stove.

Customer Needs	Importance[3]	Product Requirements
Boil water	5	Heat into water ≥ 1 kW
Portable	5	Total mass ≤ 20 kg Volume ≤ 5000 cm^3 Largest dimension ≤ 25 cm
Economical to buy	3	Total cost ≤ $20
. . .		

3 PRODUCT DESIGN CONTEXT

This research seeks to augment the product definition phase beyond current methods by accounting for the design context in which the product will be used.

> *Product design context - all environmental factors that may significantly affect the design of a product. These factors may be divided into three categories: customer context, usage context, and market context.*

The three groups of factors composing the product design context may be defined as follows: (1) *customer context factors* include consumer beliefs, values, practices, and demographics (e.g. wealth and age); (2) *market context factors*[4] include aspects of competing products; and (3) *usage context factors* cover the situation in which the product will be used such as weather and infrastructure (e.g. the state of roads, maintenance systems, central energy supply, and supply chains). Table 2 itemizes examples of product design context factors.

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[3] Scale is from 0-5 with: 5=product must satisfy the need, 3=important to satisfy the need if possible, and 0=unimportant.

[4] Customer needs capture what is required to satisfy customer expectations, which change over time with a changing market climate.

Table 2: Product Design Context Factors

Factors	Examples
Customer Context	• Wealth • Safety expectations • Convenience expectations
Market Context	• Features of available products • Performance level and quality of available products • Cost of available products
Usage Context	• Energy supply cost, availability, and characteristics. • Infrastructure (e.g. transportation) available • Harshness of environment

Based in part on the findings of this research, the authors believe that *product design context*, in addition to primary functional requirements, are fundamental causes which give rise to both customer needs and product requirements in the product definition phase (as illustrated in Figure 1). The term "primary functional requirements" is used here to refer to the functions a product is designed to achieve independent of the design context. For example, a radio must in some way achieve the function of receiving and playing a radio frequency, although how this is achieved may differ depending on whether the customer context factor of wealth is high or low.

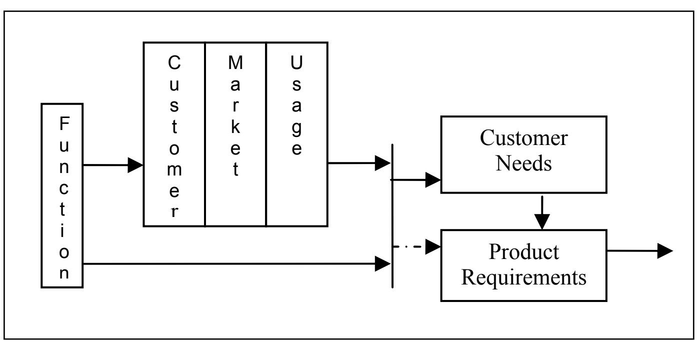

Figure 1: Model of Information Flow for Customer Needs Gathering and Product Requirements

Need for Understanding Context Factors.

Engineers are often called on to design for frontier design environments (those unfamiliar to the designer). This occurs by default because engineers are a sub-set of society. Engineers design products which will be used by business people, artists, children, the uneducated, and other groups not represented among design engineers. Additionally, the importance multi-national companies place on positioning products in a global marketplace calls on engineers to design for customers in other countries and cultures. A special case of global design occurs when engineers in affluent societies create life-improving designs for use in high human-need environments, such as the Freeplay Radio initially targeted at rural African customers. (A case study of the Freeplay Radio design is included in Cagan and Vogel (2002)). Human interest groups estimate approximately one-third of the world's population, or over 2 billion "customers" are preoccupied with basic needs such as food and shelter, representing a significant engineering opportunity to improve the quality of life (see [5], for example).

The product definition step is critical for the success of any new product, and particularly problematic for frontier design environments. An opportunity exists to increase the success of products designed for these markets through formalizing methods of discovering, documenting, and addressing the product design context during the design process. This research focuses on developing an understanding of the product usage context, leaving exploration of customer context and market context for future work.

4 PRODUCT USAGE CONTEXT (PUC)

The product usage context (PUC) refers here to all factors relating to the situation in which a product will be used that may significantly affect its design. As shown in Table 2, PUC is one of three elements of the larger definition of product design context, which also includes customer context and market context. Examples of PUC factors include: infrastructure (such as energy supply), how the product will be used (for what application), and the conditions the product will be exposed to (such as weather). Table 3

[5] "Providing Energy Needs for Two Billion People," New Release No. 97/1313S, World Bank, Accessed Mar. 2002. http://www.worldbank.org/html/extdr/extme/1313.htm

shows examples of differences in PUC factors which result in dramatic differences in the design of the product in question.

Table 3: Examples of PUC Differences

Need (Product)	**PUC #1**	**PUC #2**	**Differences**
Cook food (Stove)	Wilderness	Domestic kitchen	Size constraints, Energy supply
Loosen/tighten nuts (Wrench)	Space station	Garage	Ruggedness of use, Mass constraint
Store ink writing (Paper)	Office	Clean room	Allowable particle emissions
Harvest crop (Scythe/Tractor)	Rural village	Commercial farm	Maintenance, Prevailing wages

Benefits of Understanding PUC Factors

We anticipate numerous benefits from discovering how the PUC influences the product definition phase. It is expected that an improved theoretical understanding of the fundamental contextual causes giving rise to customer needs and product requirements will improve the product definition phase, and thus the success with which products satisfy and delight customers. Specifically, this research focuses on improving the understanding of product usage context (PUC). The following three benefits are expanded in the following paragraphs:

- Improved customer needs gathering
- Improved setting of target design values
- Leveraging the known to design for the unknown – attacking frontier design problems by using correlations to generate guess values

First, an improved understanding of PUC will facilitate and organize the customer needs gathering process. This understanding will improve the quality and quantity of information gathered within limited resource constraints, and illuminate latent customer needs which might be missed otherwise. Designers can more effectively select and interview customers, and better understand and classify the information received in interviews.

Second, a PUC framework will improve the task of setting target design values by clarifying for the designer how contextual factors influence such targets. Current techniques prescribe capturing the "voice of the customer", but provide insufficient guidance on how to translate this into quantifiable numbers (QFD is a excellent technique for this conversion, however it is left to the designer to determine what the customer means by "light-weight," for example, in terms of kg). The primary technique for forming design targets is benchmarking, but this can be very difficult in frontier design situations in which comparable designs are sparse. A PUC framework and the concept of a functional family (a group of products which solve the same primary need) will provide the designer with tools to maximize domain cross-over of benchmarking information, intelligently selecting and adapting information from existing products which may exhibit some similarities, but do not occur in the target context.

Third, a PUC framework will equip designers to leverage the known to design for the unknown. With an improved understanding of the similarities and differences among PUC's, design problems may be attacked through the use of correlations to generate guess values for design targets. For example, a documented understanding of the weight, size, and energy constraints of backpackers gained from common camping stoves and lights may provide a solid basis for beginning the design of novel devices for this application.

5 RESEARCH APPROACH

The approach of this research is to conduct an empirical product study to gain insight into the fundamental causes leading to differentiation among products that solve the same primary function. The working hypothesis is:

> *Hypothesis: Products which solve the same primary function exhibit differences in the product definition (customer needs and product requirements) which may be explained according to differences in the intended product usage context of each product.*

We have selected successful products in a mature market, and reverse engineered (Otto and Wood, 1998) them to re-create information which would have been part of the product definition phase for each product. We have chosen a functional family of products which solve the same primary need, in this case to "broadcast light for visibility of other objects, and allow mobility." The steps in the empirical study are as follows:

selecting appropriate products, gathering customer needs through interviews and research, measuring products (quantitative benchmarking), and analyzing the data for differences indicating the effects of PUC factors.

6 LITERATURE REVIEW

The current texts on design methods reviewed here all address the product definition phase to a greater or lesser extent. Cagan and Vogel (2002) prescribe a number of methods for understanding "the user's needs, wants, and desires" including: new product ethnography, customer scenario development, and lifestyle reference. The authors introduce SET Factors influencing the design of a product: social – culture and social interaction such as common hobbies or lifestyles; economic – the excess income people are comfortable spending; and technical – results of new discoveries. Otto and Wood (2001) discuss gathering customer needs and competitive benchmarking as part of "understanding the problem". They present supporting methods such as a: product mission statement, business case analysis, customer interviews and focus groups, activity diagram of product usage throughout the lifecycle, and Quality Function Deployment (QFD). Pahl and Beitz (1996) emphasize the importance of "clarifying the task" through a requirements list which itemizes demands and wishes, both qualitative and quantitative. The authors present lists of questions and suggested categories for the design engineer to reference in order to facilitate defining accurate and complete product requirements. Ullman (2002) organizes his discussion of the product definition phase around the QFD framework. Major steps include: identifying customers, identifying customer requirements through surveys and focus groups, benchmarking competing products, translating qualitative customer requirements into quantitative product requirements, and setting design targets. Ullman discusses the types of customer requirements and present a checklist to reduce the problem of the design engineer overlooking important product requirements.

None of the above design methods were found to give significant attention to exploring the fundamental contextual factors leading to customer needs and product requirements, or a framework for categorizing, documenting, and correctly applying this information to a variety of design problems. The following paragraphs review research bearing significance to a discussion of product design contextual factors.

Urban and Hauser (1993) provide a detailed discussion of numerous techniques for: customer measurement, perceptual mapping, and benefit segmentation. The results of these techniques facilitate identification of a product opportunity, design of a product to fill the opportunity, and product positioning (primarily through marketing and branding) to exploit the opportunity. Although contextual factors are not explicitly dealt with, the effects of context would presumably manifest as differences in customer needs and be identified as separate opportunities through benefit segmentation methods.

LaFleur (1992) proposes a general framework for describing engineering design problems in terms of fundamental variables. Included in these variables are "environmental constraints" and "environmental conditions." The engineering environment is divided into four categories, including the "Application Environment (APP)" described as the "actual situation the device will encounter; real conditions and constraints, actual tasks to perform and real behavior." The Application Environment is described as a large source of public domain information, which is "fuzzy due to real complexities." Additionally, this work mentions the role of experience in the design process, noting that this experience "can be tracked and represented as information," thus making an experienced designer's knowledge accessible to others.

Crawley et al. (2001) present the "Design, Development and Marketing of Solar Lanterns" for the rural poor of African countries. They specifically address Kenya, which has a large population without hope of access to electricity in the near future; more than 90% of households use kerosene lighting, and 70% also use scarce cash supplies to buy batteries. They employed focus groups and general discussions to gather information about what customers wanted in a solar lantern. They noted the importance of: (1) picking groups not dominated by a few dominant members, (2) holding surveys during the day for travel safety of participants, and (3) focusing on individuals with incomes similar to the target customers, who often had significantly different spending patterns than wealthier individuals. In general, the authors note that for companies in developing countries, product development is expensive and high-risk and conventional research techniques for gathering customer needs are often incomplete and inaccurate in accounting for lifestyles and culture for new products being designed for use in developing countries.

A chapter on international market research (1986) notes that unfamiliarity with a foreign country is a hazard faced by market researches which can cause ambiguity and false conclusions. Common blunders originate from unstated assumptions which may differ from one country and culture to another. Some kinds of market research in certain countries are not feasible. "… particularly in developing countries – it is virtually impossible to design an adequate quota sample …" due to lack of social structure definition, or lack of knowledge. Interviews do not work in some settings; for example, "Question-and-answer interaction with a stranger can sometimes seem strange, even uncomfortable or threatening." Therefore there is "no substitute for close familiarity with the local culture." Even in some developing countries the costs of market research have risen to nearly European levels, which increases the importance of economical solutions to overcome the listed problems.

Additionally, Chen et al. (2003) advise that when tapping global markets, multinational companies must be wary of errors on two extremes: attempting to standardize the product for significantly different markets, or excessive customization for significantly similar markets. A balance must be struck which properly accommodates real and important differences, without unnecessarily undercutting economies of scale through standardization. Examples of major differences faced when political and/or cultural boundaries are crossed include: language, ethnic, religious, social structure, tradition, literacy, income patterns, geography and climate, infrastructure, product distribution, advertising, and legal climate.

Chen et al. (2003) predict that "... multicultural factors are the most difficult issues for organizations to address … [and will be a] future direction in NPD." They address the need for research in this area, commenting "… there are few successful or effective techniques available for the evaluation of multicultural factors in customer requirements." This paper proposes a system employing laddering technique and radial basis function (RBF) neural network to address the problems of multicultural barriers to customer needs gathering. A mobile phone design case study is included. The cultural factors addressed are primarily dealing with the customer context.

Some design research addresses the consideration of "culture" in the design process. Culture may be defined as the customary beliefs, values, social forms, and material traits of a group of people that are learned from preceding generations (author's adaptation from [6]). Ellsworth et al. (2002) reports on the "effects of culture on refrigerator design." This paper does not define culture, but references the "needs and values" of customers which differ from place to place. The authors build a case for improved cultural understanding among design engineers, stating that products will be more successful worldwide as design engineers account for cultural needs. The authors propose the development of a Design for Culture (DfX) methodology, citing a lack of attention to the subject evidenced by a dearth of literature and suggesting that cultural considerations must include not only marketing but also design. They suggest studying the use of similar products across different cultures to begin development of such a method. Refrigerators were chosen for this study because they are in widespread use globally and the designs have stabilized with distinct differences in various countries. The paper itemizes a number of macro physical differences (such as volume, energy efficiency, and construction) in refrigerators used in the US, Europe, Japan, and Brazil, and comments on the apparent cultural reasons for these differences. The authors conclude by suggesting the following categories of cultural aspects to account for: aesthetic appeal, cultural habits (e.g. tendency to snack), traditions, available resources, physical environment.

Donaldson (Donaldson, 2002; Donaldson and Sheppard, 2001) proposes various items to improve product development for developing countries, and comments extensively on the particular barriers and problems associated with designing for this context. Some of Donaldson's findings may be generalized to other frontier design environments.

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[6] Merriam-Webster, 2002, "Merriam-Webster On-Line Dictionary", http://www.m-w.com, January 29, 2002.

The research reviewed here relating to product design context is far from complete, and often emphasizes the need for greater attention to this area. No research was found that distinguishes among the effects of market, customer, and product usage context on product definition. Further, no work was found to provide a framework for formally categorizing, documenting, and correctly applying contextual information to a variety of design problems.

7 SELECTION OF PRODUCTS FOR EMPIRICAL STUDY (HOW, WHY, AND WHAT)

In order to illuminate the effect of PUC on products, an empirical study was designed involving the selection of a "functional family" of products hand-picked to exhibit embodiment differences for the same basic functional need. We chose the need of "broadcast light for visibility of other objects, and allow mobility." In the product domain, this need translates into a variety of lanterns; lighting products intended for signaling or self-illumination were not included. Flashlights are not included because they primarily focus light, rather than broadcast light broadly within a space. Permanently installed lighting is not included because it does not offer portability. Proper identification of a functional family is important to the effectiveness of this research, in order to avoid product differences resulting from differences in the required primary function.

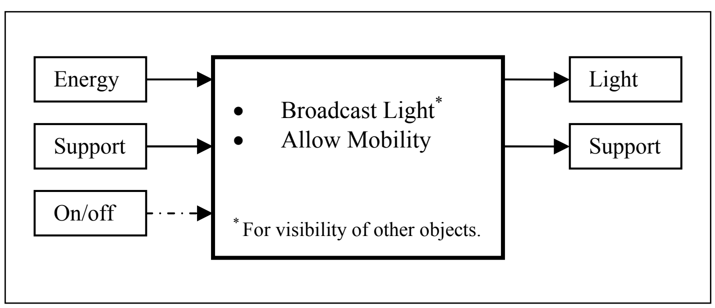

Figure 2: Simplified Black Box for Functional Family

This functional family was selected because it met the criteria of: a common need spanning multiple PUC's, a mature market, products of a reasonable size and cost for an empirical study, and consumer products dominated by energy flows.

Initially a wide range of consumer products were considered with narrowing decisions made as follows: products dominated by energy flows (as opposed to information flows and primarily static objects). Domains such as water supply, cooking, and transportation were considered. Lighting was chosen since it is a common need across many PUC's. Additionally, it represents a mature market which has had many years to stabilize, increasing the chances of finding a full suite of market-proven products relatively unaffected by transients from recent developments[7].

To discover what lighting products are available, we searched local retail outlets and internet sources: ePinions.com, amazon.com, and the Google directory. While studying the variety of lighting products, it was found that different sub-needs were being addressed under "provide light." Some of these differences were identified as follows (below). In order to compare apples to apples to begin with, it was decided to focus on lights which were designed for: portability, lighting a space, and moderate to continuous usage. The type of energy used was found to result in significant differences in product embodiment, and one or more products were chosen from each energy type sub-family.

- Energy type
- Portable vs. non-portable
- Aim-able vs. fixed
- Focused vs. light a space

From this initial survey of lighting products, the following classification was developed to organize the findings (Table 4). Products were grouped in rows according to the energy type used, and in two columns according to whether the light was broadcast or focused.

[7] Products utilizing LEDs were not included due to their relatively recent market entry.

Table 4: Classification of Products "Providing Light for Visibility of Other Objects"

Energy Import	Products that Focus Light	Products that Broadcast Light
AC (or fixed DC)	Permanent fixture: wall, ceiling Floor Desk: sitting, clamp-on Task: makeup, magnifier, endoscope Transport: Automotive, marine, ~bicycle	Permanent fixture: wall, ceiling, flood Floor: torchere
Batteries (Chemical)	Flashlight: regular, spotlight, micro, flex Headlamp: waterproof, arctic	Lantern (battery) Tap light (mounted)
Fossil Fuel		Lantern (fuel) Campfire Torch Candle
Renewable	Human energy flashlight	Lantern (solar) Security (solar)
Chemical (non-battery)		Glowstick Lightning bugs Flares (for area lighting)

Products fitting into the "lantern" category above fit into the chosen functional family, all addressing the same primary need. Products were selected from this category with one or two representatives from each energy domain (shown in Table 5). Most products chosen are from sub-families in the product market, sometimes included dozens or hundreds of similar products, such as kerosene lanterns.

Table 5: Products selected for the empirical study.

Product	Cost	Fuel	Fuel Run Time (hr)	Fuel Cost
1) Paraffin lamp	$0	Liquid Parrafin	20+	$2
2a) Candle	$0	Wax	9	$1
2b) Candle lantern	$17	Wax	9	$1
3) Kerosene lantern	$6	Kerosene	--------	$5/gal
4) Pump-up gas	~$25	Liquid fuel ("White gas")	3	$5/gal
5) Propane lantern	$20	Bottled propane	5	$1.50/bottle
6a) Battery – krypton	$10	4 alkaline "D" cells	12	$4 for 4
6b) Battery – fluorescent	$20	6 alkaline "D" cells	14	$6 for 6
7a) Solar – low-cost	~$80	10 hours of bright sun fully charges battery	4 (fully charged)	$0
7b) Solar – camping	~$150	12 hours of bright sun fully charges battery	5 (fully charged)	$0

Figure 3: Products Selected for Empirical Study

Table 6: Description of Products Selected

Product	**Description**
1) Paraffin lamp	A recycled bottle with a wick through a hole in the lid. Filled with 99% pure paraffin for clean burning.
2a) Candle	A long burning, low-drip candle.
2b) Candle lantern	A spring advances the candle into a glass shielded burn chamber for better all-weather performance. The shield nestles inside the base to decrease the candle stowage volume.
3) Kerosene lantern	Hollow and lightweight, an adjustable wick draws kerosene up from the base for a controlled burn.
4) Pump-up gas	A liquid fuel poured into the base is pressurized with the built-in hand pump. The fuel vaporizes inside an ash bulb (mantle) where it burns with a bright, yellow-white flame.
5) Propane lantern	A screw-on bottle releases gas into the mantles where it burns with a bright, yellow-white flame.
6a) Battery – krypton	Rugged and almost water-proof; a krypton bulb casts a soft, pleasant glow through the frosted white cover.
6b) Battery – fluorescent	Two bright (4W) fluorescent tubes are independently controlled for two brightness settings.
7a) Solar – low-cost	Similar light to 6b, but designed as a solar re-chargeable for rural African markets.
7b) Solar – camping	Similar light to 6b, but designed as a solar re-chargeable for recreational campers.

7a - Low-cost Solar Lantern | 7b - Solar Camping Lantern

Figure 4: Products Selected for Empirical Study

8 GATHERING CUSTOMER NEEDS: TECHNIQUE AND RESULTS

After selecting and purchasing the products for the empirical study, the next step was to gather customer needs. Gathering and understanding customer needs for each product was achieved primarily through two means: the researchers experienced the products through setup and usage, and interviews were conducted with potential customers. In a one-on-one interview, the potential customer was asked to examine and use each product, and then comment on prompts including "What do you like? … What do you dislike? … What would you like to see improved?" Initially the interviews were encoded by hand, however this was soon replaced by voice recording which was later played back and transcribed to text. Finding interviewees who understood the various situations in which each product might be used posed a major challenge. For those products intended for extremely low-cost rural applications, finding interviewees who had experienced the products in their target PUC was nearly impossible within the time and budget limitations. We believe this situation would be similar on a larger scale for a design firm seeking to design for such a frontier design environment outside their experience range – the cost and time involved may be insurmountable. This was partially overcome by recruiting a graduate student volunteer who had spent time visiting family members in poor rural areas of his home country and therefore could comment on the usage.

The interviews were recorded in the "voice of the customer" and later translated into inferred customer needs. These were gathered and assigned weighting based on the judgment of the researchers. Weightings were assigned based on a combination of how frequently the need was articulated, how forcefully it was articulated, and the researcher's assessment of the product and intended usage context based on the accumulated research and interviews. The chosen need grouping and assigned weightings are therefore subject to researcher bias.

Presenting the customer with multiple products seemed a very effective technique for eliciting responses, as features in one product stood out and lead to more comments on other products. Additionally, interviewees begin comparing and contrasting products. Through this process, an understanding was developed of the "functional family" of products selected for study, showing how a common need has been solved in different ways according to a sliding set of criteria (due to different usage contexts). This approach of "mapping a functional family" may hold value for preparing to position a new product design. Benchmarking is currently encouraged in reverse engineering techniques; however the formal recognition of PUC differences could allow benchmarking to be usefully extended further, to cover an entire functional family whereas it might otherwise be abridged to similar customer and PUC clusters.

As research and interviewing proceeded, it became evident that the functional family chosen addressed distinct usage contexts, relating to four PUC categories. Although these categories were not explicitly stated by many interviewees, they are largely based on a categorization of the various contexts they were collectively referring to. Most interviewee's appeared to reference only a subset of the four identified PUCs, and in some cases it was difficult to tell which they had in mind regarding specific comments. As the research progressed, questions were added to the interview format, asking each interviewee what context they could foresee using the product in, as well as what context they viewed each product as suitable for. No further verbal cues were given for this question other than the word "context" and the implication that it might vary from one product to another. The four PUC categories determined were: (1) Backpacking, (2) Camping near a car, (3) Intermittent domestic electrical outage, and (4) Heavy domestic use (no electricity). They imply respectively: (1) an outdoor adventure in which individuals carry all personal supplies and products on their backs for several days or more, (2) an outdoor adventure involving pitching a tent within walking distance of an automobile, (3) a domestic setting with regular and reliable grid supplied electric power with occasional outages of an annoying but infrequent frequency, (4) a domestic setting with no grid electricity such as a remote cabin. Initially PUC 4 was considered to indicate a rural village situation (and the often accompanying poverty), but it was later decided that it was desirable to hold the customer factors constant in the study. Since a rural village context also implied great differences in the individual customer, PUC 4 was modified to refer to customers who were economically similar to those in the first 3 PUC's, but who chose to live outside of the reach of established grid electricity. Table 7 shows which PUC's each product was determined to be the most appropriate for.

Table 7: PUC's Indicated for Each Product
(■ = strong, • = weak)

	Usage Context			
Product	**1**	**2**	**3**	**4**
1) Paraffin lamp			•	■
2a) Candle	•		■	
2b) Candle lantern	■			
3) Kerosene lantern			•	■
4) Pump-up gas		■	•	
5) Propane lantern		■	■	
6a) Battery – krypton		■	■	
6b) Battery – fluorescent		■	■	
7a) Solar – low-cost				■
7b) Solar – camping		■		
(1) Backpacking, (2) Camping near car, (3) Intermittent electrical outage, (4) Heavy use (no electricity)				

It is well established in the marketing literature that customers have needs which vary from one person to the next, and an accepted marketing and product development strategy is to "cluster" customers with similar needs into target groups of a size large enough to permit economy of scale and small enough to allow the product to satisfy the entire target group of customers. Perhaps this process can be used to implicitly account for difference in the context in which customers will use the product, or to use our terminology, in the intended PUC. However, in the course of our interviews we found that implicitly accounting for the PUC by clustering customers into groups was clumsy and unsatisfactory. It was clumsy, because valuable interview time was consumed during a search phase as the PUC's gradually became evident. During this time, data was collected from various interviewees without clarity as to which PUC they had in mind, leading to obscurity in results. More disconcerting was that without formal recognition of the importance, characteristics, and potential effects of PUC differences, it seems likely that some PUC's could be inadvertently (and mistakenly) combined, or missed altogether.

Further, we found that implicit accounting for PUC's by customer segmentation was unsatisfactory because it obscures the true fundamental causes which give rise to differing product definitions (sets of customer needs and product requirements), and may in fact be completely inadequate to describe such differences when identical customers are present in dissimilar PUC's. For example, if the same customer requires a lantern product for use in two distinct PUC's (e.g. "backpacking" and "car camping"), this will result in distinct product definitions which are due entirely to differences in the PUC, and not differences in the customer (the customer characteristics are identical). If different customers require different customer needs in the same PUC (for example, for a "car camping" lantern an elderly customer may require more accessible controls when compared to average customers), then this is an appropriate application of segmentation by customer.

In summary, it was found that multiple PUC's existed for the functional family under study, and the experience gained suggests it is desirable to formally account for the PUC before and during the customer need gathering process. Table 8 presents the differences found in customer needs which result from differences in the PUC (the customer context was held similar). These needs lists represent the authors' analysis based on the customer needs gathering process (research, experiencing the products, and customer interviews).

Table 8: High-level Customer Needs List for Functional Family Studied - Weights Differ Across Four PUC's

	Backpacking (on the trail)	Camping (near car)	Intermittent electrical outage	Regular domestic (no electricity)
Customer Need	**(1)**	**(2)**	**(3)**	**(4)**
Light				
Provide adequate light	5	5	5	5
Adjustable brightness	2	3	1	4
Ergonomic (no glare)	3	3	1	5
Pleasant light	1	1	1	3
Directable light	4	1	1	4
Value				
Low purchase cost	5	5	5	5
Low operating cost	5	5	5	5
Portable				
Mobile	5	5	5	5
Small	5	1	1	2
Lightweight	5	2	1	1
Hangable	3	3	1	5
Stable base	2	2	2	5
Safe				
Small chance of harm	5	5	5	5
Low O_2 consumption	4	0	5	2
Low gas emission	1	1	5	3
Low fire hazard	4	2	5	2
Low glass hazard	4	3	3	1
Operation				
Easy to use	2	4	4	2
Fast to light	2	4	4	2
Fast to setup	2	3	5	2
Durable	4	3	1	2

Product usage factors which account for differences in customer needs for this data across the four PUC's are itemized below and line itemed in Table 9.

PUC Factors Found to Affect CN's for Products Studied:

- Energy supply cost, availability, and characteristics (e.g. weight, safety, convenience of supply)
- Frequency and duration of product use
- Transportation available
- Activities (e.g. setting up a tent vs. playing cards)
- Enclosed vs. ventilated usage area
- Ruggedness of handling & conditions

Table 9: Comments on How PUC Differences Lead to Customer Need Differences

	Backpacking (on the trail)	Camping (near car)	
Customer Need	**(1)**	**(2)**	**PUC Differences (1) vs. (2)**
Light			
Provide adequate light	5	5	
Adjustable brightness	2	3	Extra functionality less expected
Ergonomic (not glaring)	3	3	
Pleasant light	1	1	
Directable light	4	1	More dependence on light for after-dark activities Often smaller light intensity, more important to focus
Value			
Low purchase cost	5	5	
Low operating cost	5	5	
Portable			
Mobile	5	5	
Small	5	1	Carrying in backpack vs. car trunk
Lightweight	5	2	Long hiking distance vs. short walk from car to campsite
Hangable	3	3	
Stable base	2	2	

Safe			
Small chance of harm	5	5	
Low O_2 consumption	4	0	More likely to be used in tent, whereas (2) primarily for outside
Low gas emission	1	1	
Low fire hazard	4	2	More likely to be used in tent, whereas (2) primarily for outside
Low glass hazard	4	3	Transported farther w/ more rugged conditions
Operation			
Easy to use	2	4	Convenience less demanded; trade-off for small & lightweight
Fast to light	2	4	Convenience less demanded; trade-off for small & lightweight
Fast to setup	2	3	Convenience less demanded; trade-off for small & lightweight
Durable	4	3	Transported farther w/ more rugged conditions

9 MEASURING PRODUCTS TO DETERMINE TARGET DESIGN VALUES

To understand how PUC influenced target design values required continuing the reverse engineering process by measuring metrics corresponding to product requirements. The metrics were estimated initially, and refined as customer needs gathering progressed in order to determine values for the appropriate product requirements. Table 10 shows product metrics for three major categories of customer needs: light, value, and portability. Future work includes defining and measuring metrics to quantify the remaining customer needs related to "safety" and "ease of operation."

The measurements are obtained from a combination of manufacturer data and direct measurement. Equipment cost is the retail price paid. Operating cost is determined by taking an average fuel cost (determined through searching retail and web sources) and dividing by the fuel consumption rate (determined by manufacturer specifications and experimental tests). The brightness was measured in Fc using a light meter placed one foot from the light source8 (resulting in the indicated readings of close to "1.0 Fc" for the candles measured, consistent with the definition of the Fc unit). Each product was weighed fully fueled, using an electronic scale. Height and diameter were

[8] A 60W incandescent light bulb measures approximately 70 *Fc* (Foot candles) by this testing method.

physically measured, twice for objects which change shape in an open and closed position. Approximate volume was calculated from the height and diameter.

Table 10: Product Measurement Data

	Equipment Cost ($)	Brightness (*Fc*)	Weight w/ Fuel (kg)	Operating Cost ($/hr)	Volume (mm^3)	Brightness / Op. (*Fc**hr/$)
1) Paraffin lamp	0	1.0	0.18	0.04	269	23.6
2a) Candle	0.80	1.1	0.05	0.09	57	12.1
2b) Candle lantern	18	0.5	0.19	0.09	216	5.5
3) Kerosene lantern	6	3.3	0.81	0.02	6923	157.4
4) Pump-up gas	25	41.0	0.90	0.10	1846	397.6
5) Propane lantern	20	43.0	1.91	0.26	5575	164.8
6a) Battery–krypton	10	3.3	0.99	0.33	1689	9.9
6b) Batt.–fluorescent	20	11.7	1.41	0.43	3313	27.4
7a) Solar – low-cost	80	~12	3.00	0.00	6011	∞
7b) Solar – camping	150	~12	0.93	0.00	4100	∞

The products vary widely in terms of the metrics chosen, indicating dramatically differing design target values during the product definition phase for each product. Figure 5 compares the normalized weights and volumes of the products, grouped according to PUC’s 1-4. Note that some products appear more than once, if they correlate with more than one PUC. The data are normalized by the largest value in the product set, and thus a low normalized value suggests significant design priority was given to reducing the value as compared with other products in the functional family. The figure reflects the strict weight and volume constraints that were observed for PUC 1 – backpacking. Figure 6 shows a wide variation in the economic efficiency of each product, in terms of brightness normalized by operating cost (*Fc*/$/hr). The solar powered lanterns perform off-the-chart in this case, since they have no direct fuel cost. The graph shows that the pump-up gas lantern is a much better investment than the equivalent 40 candles or paraffin lamps which would be required for the same amount of brightness.

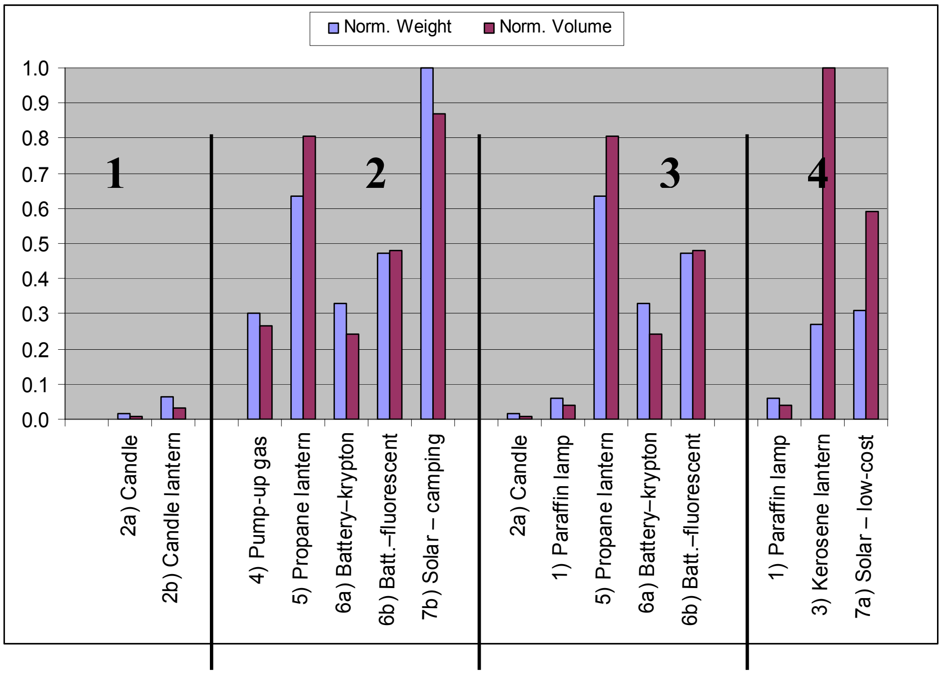

Figure 5: Product Weight, Volume Grouped by PUC

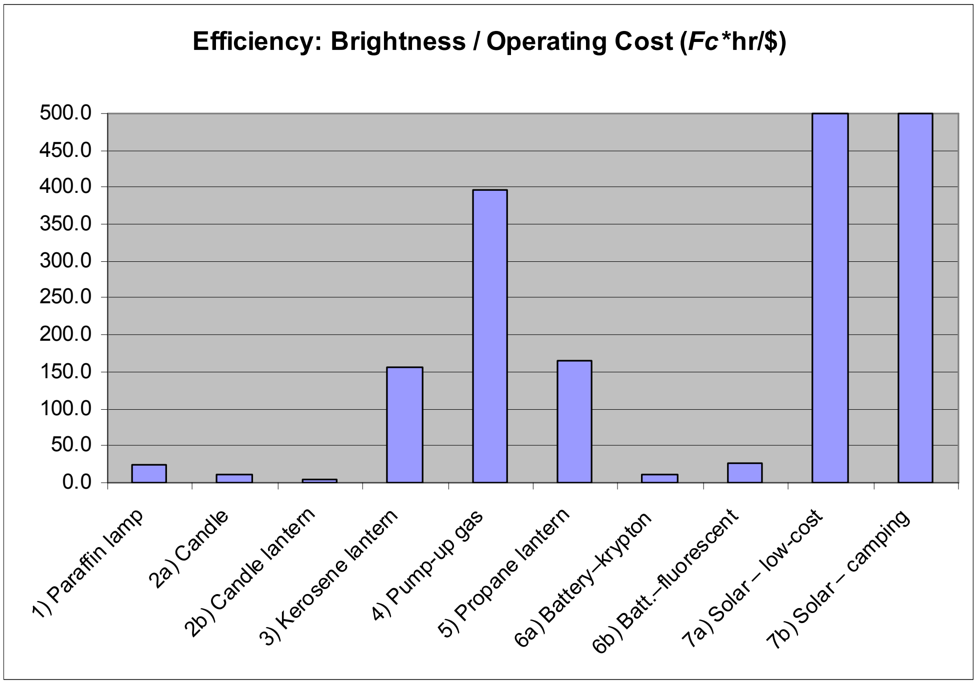

Figure 6: Product Economic Efficiency

10 CONCLUSIONS AND FUTURE WORK

The products studied perform the same primary function, to "broadcast light for visibility of other objects, and allow mobility." These products from the same functional family exhibit significant differences in product definition. The metrics measured show differences in product requirement design targets, and the customer needs that were gathered also show distinctions. Many of these differences have been convincingly explained according to differences in the product usage contexts, thus supporting the research hypothesis.

Future work will include extending the present study of lanterns with additional metrics to measure the remaining customer needs, and additional lantern products to further validate the PUC differences shown here. Customer perceptions will also be measured, as a method to verify the chosen metrics are correctly correlated to the customer needs. For example, customer perceptions of product size should correlate directly to actual volume, if low volume is in fact the customer's implicit intention when making the qualitative statement "it should be small."

Future work will also include extending this research approach to additional functional families such as: cook food, turn (plow) soil, and transport water for domestic consumption. As more PUC factors are discovered for different functional families, comparison and contrast among functional families can begin. This will lead to a generalized understanding of PUC, laying the foundation for improved design methods for the product definition phase.

The end goal of this work is to develop design methods explicitly addressing product design context, and thus equipping design engineers to more successfully address frontier design environments. It is expected that as additional products and functional families are studied, trends will be identified in the normalized key performance metrics. These trends would not provide strict prescriptions, but rather a frame of reference in which the designer can choose to either follow existing trends, or make an informed decision to depart through innovation. It is hoped that the development of such methods will increase the design of appropriate products for customers in high-human need environments who are traditionally less-served by technology.

References

1986, "Chapter 23: International Market Research," *Consumer Market Research Handbook* (R. Worcester and J. Downham, Eds.).

Cagan, J. and C. M. Vogel, 2002, *Creating Breakthrough Products: Innovation from product planning to program approval*, Prentice Hall, NJ.

Chen, C.-H., L. P. Khoo and W. Yan, 2003, "Evaluation of multicultural factors from elicited customer requirements for new product development," *Research in Engineering Design,* Vol. 14, No. 3, pp. 119.

Crawley, K., R. Holland and S. Gitonga, 2001, "Design, Development, and Marketing of Solar Lanterns," *Development by Design: 1st International Conference on Open Collaborative Design of Sustainable Innovation*, Boston, MA.

Donaldson, K., 2002, "Recommendations for Improved Development by Design," *Development by Design: 2nd International Conference on Open Collaborative Design of Sustainable Innovation*, Bangalore, India.

Donaldson, K. and S. Sheppard, 2001, "Modification of a Methodological Design Tool for the Developing Country Scenario: A Case Study in Product Definition," *ICED01 13th International Conference for Engineering Design*, Glasgow, Scotland. Professional Engineering Publishing, pp. 505-512.

Ellsworth, K., S. Magleby and R. Todd, 2002, "A study of the effects of culture on refrigerator design: Towards design for culture," Montreal, Que., Canada. American Society of Mechanical Engineers, pp. 415.

LaFleur, R. S., 1992, "Principal Engineering Design Questions," *Research in Engineering Design - Theory, Applications, and Concurrent Engineering,* Vol. 4, No. 2, pp. 89-100.

Otto, K. N. and K. L. Wood, 1998, "Product evolution: A reverse engineering and redesign methodology," *Research in Engineering Design - Theory, Applications, and Concurrent Engineering,* Vol. 10, No. 4, pp. 226.

Otto, K. N. and K. L. Wood, 2001, *Product design: techniques in reverse engineering and new product development*, Prentice Hall, Upper Saddle River, NJ.

Pahl, G. and W. Beitz, 1996, *Engineering Design – A Systematic Approach,* 2nd Ed., Springer, New York.

Ullman, D. G., 2002, *The mechanical design process,* 3rd Ed., McGraw-Hill, Boston, Mass.

Ulrich, K. and S. Eppinger, 2004, *Product Design and Development,* 3rd Ed., McGraw-Hill, New York.

Urban, G. and J. Hauser, 1993, *Design and Marketing of New Products,* 2nd Ed., Prentice-Hall, Upper Saddle River.

Publication 4: Service-Learning Approaches to International Humanitarian Design Projects: A Model Based on Experiences of Faith-Based Institutions

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Service-Learning Approaches to International Humanitarian Design Projects: A Model Based on Experiences of Faith-Based Institutions

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Abstract

Recent curriculum advancements in engineering education highlight the value of a healthy synergy from including applied mathematics and science, industrial work, and need-based projects. In light of the growing interest in globalizing engineering education, a service-learning approach to globally-based humanitarian projects is an effective approach to help in achieving this balance. The importance of integrating both globalization and social needs into the engineering curriculum is acknowledged by the ABET criteria. Human need is also a clear priority of engineering as a profession and of major world religions. It is not surprising, therefore, that faith-based institutions place a high value on such projects. This paper presents the methods and conclusions of design projects from four faith-based institutions that exemplify the successful integration of both globalization and humanitarian interests. The presentation focus is a model for conducting such projects. Particular results, within the context of these projects, include specific characteristics and insights for designing, selecting, and executing international humanitarian design projects within the undergraduate engineering curriculum.

Introduction

Engineering educators are increasingly recognizing the value of exposing students to need-based engineering problems and pedagogies [1, 2, 3, 4]. Another area of growing interest is the globalization of engineering education [5, 6, 7, 8]. These important topics may be concurrently addressed with a service-learning approach by involving students in international humanitarian (IH) design projects [9, 10, 11]. This approach addresses key ABET criteria by integrating both globalization and social needs into the engineering curriculum. Additionally, social needs are a clear priority of engineering as a profession (as indicated in the NSPE creed[ii]) and of major world religions (as indicated by their international outreach). It is not surprising, therefore, that engineering departments at faith-based institutions place a high value on such projects. This paper presents the methods and conclusions of design projects from four faith-based institutions that exemplify the successful integration of both globalization and humanitarian interests into the curriculum. The resulting model for IH design projects should be applicable to any accredited engineering program, from state to private universities, and from faith-based colleges to secular-based institutions.

To develop a model for international humanitarian projects, data are collected from the four participating institutions, where this data is presented in a common framework. Each of the four project examples from the four institutions is preceded by the general context of the host institution and design class, including the general approach to team formation, project selection, funding, deliverables, and teaching/mentoring. Following this general context are the specific details of each project. Projects presented include the design of (1) a women's hospital in Nigeria by senior engineering students at Calvin College, (2) a crop irrigation system in support of a Honduran community development organization by Dordt College students, (3) a modular and scalable solar power system providing economical power to remote areas by electrical engineering seniors at Grove City College, and (4) a water purification system in Guatemala by Messiah College students. The presentation focus is the development of an underlying model for successfully conducting such projects. Success in this context involves achieving goals that may be categorized as educational, humanitarian, and spiritual. The focus here is on educational and humanitarian objectives; spiritual aspects are discussed in a parallel paper to appear in the 2004 CEE conference [12].

Methodology for Developing an IH Project Model

Our educational research seeks to present guidance for the successful implementation of IH projects in engineering curricula. The research approach to address this goal includes the following steps: (1) selecting four exemplary projects, (2) reviewing design reports, publicity articles, and student responses, (3) compiling a summary of each project, (4) reviewing the project summaries and identifying a list of "key elements" thought to be instrumental to project success (team formation, project selection, funding, overcoming obstacles characteristic of IH design projects, deliverables, and teaching/mentoring), and (5) comparing similarities and differences of these common elements across the projects. Each example project description concludes with a table summarizing how the key elements were executed. The paper ends with a discussion organized around these key elements and suggests insights thought to be generally applicable for successfully designing, selecting, and executing IH design projects.

[ii] "As a Professional Engineer, I dedicate my professional knowledge and skill to the advancement and betterment of human welfare …" (NSPE Code of Ethics for Engineers)

The key elements compared across projects were chosen based on both previous experience with student design projects and a review of critical aspects across the four projects presented here. For example, the influence of design team formation on the success of a design projects is well documented. In the experience of the author's, selecting an appropriate project is important to project success, and presents a special challenge for IH projects. Funding is an important concern due to the greatly increased learning which often results when students build prototypes and delivery a working device to the customer. In the case of IH projects, international travel can be an important, and costly, element of a successful project. The category of "obstacles characteristic of IH design projects" was used to note special challenges which arose such as language barriers. Deliverables are critical to the execution of any service-learning or humanitarian project, since this is the only outcome the "customer" receives. A special challenge of IH projects is scoping deliverables that are realistic for a team to deliver with quality, while giving adequate attention to pedagogical objectives of the project. Finally, the aspects of how teaching/mentoring was carried out are noted for each project due to the importance this has to student learning.

Institution I: Senior Design at Calvin College

Calvin College offers a general B.S.E. degree with concentrations in chemical, civil, electrical & computer, and mechanical engineering. The program emphasizes the integration of religious faith and learning, the value of the liberal arts, and design. Approximately 70 students graduate from the program each year. Design projects are assigned starting with service learning projects in the first engineering course and culminating in a two-semester senior design projects course involving students from all concentrations. The senior design course has involved a number of international humanitarian projects.

Team Formation. For the senior design course, teams are self-selected with some guidance from the faculty. Teams usually have four members, sometimes all from the same concentration, but often multidisciplinary in nature. Some teams also work with students in other departments, such as business or computer science.

Project Selection. The teams are allowed to choose their own project, and many have already selected a project at the time the class officially begins. The faculty provide suggestions for teams that are looking for a good project. Projects must show significant design, i.e., they cannot be entirely analytical, nor simply an integration of off-the-shelf parts. Normally a prototype must be constructed to validate primary aspects of the design. Over the years, many of the teams have picked a humanitarian design project, such as a water supply system for a village in Ecuador, low cost modular housing using local materials for Haiti, or a solar-powered, battery-backed incubator for premature infants born in developing countries.

Funding. Teams are provided with $500 to use towards supplies, prototype parts, and so forth. If the project requires further funding, the team must obtain the funds through grants or donations. Many teams have been successful in obtaining additional funding from local industry, state or federal grants, or sometimes through humanitarian aid agencies when the project is mission-related.

Teaching and Mentoring. A group of four faculty team-teach the course, one representing each concentration. The faculty give lectures on various concepts important in completing successful engineering projects, such as team dynamics, conflict resolution, communication, project scheduling, etc. Each team is assigned one of the four faculty members as an advisor. The advisor guides team members with suggestions but requires the team to make all design decisions. A few major milestones are required of each team (such as a problem statement, task specifications, project schedule, feasibility study, and so forth), while other deliverables are specific to each team. Each team member is required to give an oral presentation to the class sometime during the two semesters. A public presentation is made in May during an open house project night, attended by 300-500 people.

Figure 1: Calvin Students Performing a Site Survey in Nigeria

Empirical Data Set I: Design of a Women's Hospital in Nigeria (Calvin)

During the 2002-2003 academic year, a senior design team worked with Engineering Ministries International[13] (EMI) and the Worldwide Fund for Mothers Injured in Childbirth[14] (WFMIC) to develop a women's hospital in Jos, Nigeria. The focus of this center would be to treat vesicovaginal fistula[iii] (VVF). Victims of VVF are often social outcasts because of the resulting urinary incontinence and associated infections. The goal of the project was to design a culturally appropriate, cost-effective hospital complex (including the hospital, patient hostels, and staff housing) capable of serving the needs of 1,000 to 1,200 women suffering from VVF per year. The hospital was designed to have a communal setting that would be open and inviting to the women coming for surgery.

A Nigerian hospital team of five students, all from the civil engineering concentration, was formed and had selected a project before the course officially began. Because they wanted to complete a mission-related design project, one of the team members contacted EMI three months before the class began in May, 2002 to discuss cooperation on a project. EMI had already made a preliminary investigation of the proposed location and worked with a local contact on preliminary specifications. The Calvin team then joined the effort in September, agreeing to produce structural, water, and wastewater design plans. Project deliverables were a project manual (detailed design specifications including a complete set of design drawings), a cost estimate, and design notebooks (providing design calculations). The team visited the site in October, 2002 for one week. The cost of the trip was covered by fund-raising the team carried out over the previous summer. During the trip, the team surveyed the site, tested soil samples, met with local contacts involved with the project, and interacted with local residents. Normally an off-campus experience by Calvin students would be supported by our Off-Campus Programs office, which helps with travel visas, passports, trip itineraries, and so forth. In this case, however, the US State Department had issued a travel advisory for Nigeria. College policy prohibited official college travel to locations under advisories. The course instructors assured the students that they could complete the project without the trip, but the students were intent on going, and the college asked them to sign liability waivers before they traveled to Nigeria. The college health services office provided the appropriate inoculations for the trip.

The student design team split up the project into various functional areas, with one team member responsible for each. They reviewed each other's work periodically. The design included basic engineering assessments of environmental conditions (soil, weather, elevations, water quality, etc.), engineering analysis (e.g., live and dead load computation, shear calculations, expected water demand, water pressure), and design decisions and implementation (e.g., material selection, truss design). The team advisor for the Nigerian hospital team was a licensed professional engineer with extensive civil engineering industrial experience. The team also received advice and guidance from an EMI project manager. An outside industrial consultant was brought in once each semester to review the team's design.

[iii] VVF afflicts around 2 of 1000 women after childbirth in developing countries. It sometimes occurs after prolonged labor, causing a small hole between the bladder and vagina.

The students emphasized the value of a large project as a way to put their technical learning into perspective. Here are some quotes from the team's final design report, emphasizing their reaction to a faith-based project in their engineering studies:

> *"The actual visit to the site location gave us the ability to fully grasp the Christian responsibility we have in designing this hospital complex."*
>
> *"Over the course of this semester there was a lot of time spent designing every civil engineering part of the complex. From the drawing of the plans, to doing the calculations to writing the specifications, to writing the report the team put in well over 1500 hours on this project and during that time we kept our focus on the overall purpose of our project. Our purpose was to help others…. We persevered because we remembered what we saw in Nigeria and what we saw in the eyes of those women and girls. We do not have it that bad and given the opportunity to make someone else's life better we took the opportunity with open arms."*
>
> *"From the details of designing a water storage tank to the structural design of a truss we can use our talents as Christians to serve the people of God's kingdom whether it be abroad or at home.*"

Table 1 summarizes the key elements extracted from this Calvin College project. This table includes important facts extracted from the Calvin College data. These data, in their elementary form, provide interesting clues to the successful result obtained from the project. For example, Calvin College formed a balance in responsibilities between student investment (Team Formation, Project Selection, Funding) and outside assistance (Mentoring & Teaching).

Table 1: Model Summary - Design of a Women's Hospital in Nigeria (Calvin)

Team Formation	Before the semester began, this team formed with the goal of carrying out a mission-related project. All team members were students in the civil engineering concentration.
Project Selection	The team contacted Engineering Ministries International, a non-profit international engineering and architecture firm.
Funding	In addition to the $500 provided, the team raised funds before the class started to cover a one-week trip to Nigeria.
Obstacles Identified	The US State Department had issued a travel advisory for Nigeria, and college policy prohibited official college travel.
Deliverables	Design specifications, drawings, and cost estimates addressing: structural, water, and wastewater aspects of the hospital.
Mentoring & Teaching	The faculty mentor was a Civil PE with extensive industrial experience. An EMI project manager also provided guidance. An industrial consultant provided end-of-semester reviews.

Institution II: Dordt College Engineering Program

Dordt College is a fifty-year old Christian liberal arts college located in Iowa. The engineering program was first implemented in the early 1980's with general engineering. This general engineering major offers mechanical and electrical emphases to an engineering student body of about 90 individuals across all levels (freshman to senior). About 20 seniors complete the program each year. Design projects play a role in many engineering courses, in freshman through senior years. The design curriculum concludes with a two-semester course sequence that allows teams of 3 or 4 students to work with a faculty mentor and a client on a selected project.

Senior Engineering Design Project Management. The two-course senior design sequence begins with a fall semester class in which the faculty member and students discuss design project management and teamwork principles, engineering economics, and statistics. Discussion of possible design projects also begins early in the fall, with a goal of having teams and projects identified by mid-semester. Project ideas come to the course instructor by way of industry contacts, department colleagues and the students themselves. As these ideas develop, project options are discussed and approved by the Engineering Department.

Team membership is somewhat self-selected based on individual student interest in the various projects. This team formation process can be somewhat chaotic at first, but generally works out well with some facilitation by the instructor.

An engineering department faculty member is assigned to mentor the project team into and through the second semester, where weekly written reports and meetings with the mentor are required. A design review session involving the whole class is conducted about 3-4 weeks into the second semester so that all classmates can ask questions and observe each team's progress. Most of the projects involve the construction and testing of some type of prototype. A written report and a public oral presentation of each project are required near the end of the spring semester.

Figure 2: Dordt Students Installing a Crop Irrigation System in Honduras

Empirical Data Set II: Design of a Crop Irrigation System in Honduras (Dordt)
Design Problem Statement and Project Initiation. The irrigation system project was an answer to the needs for greater food security and for improved health of the 300 indigenous Tolpan people in the village of San Juan in the Montana de la Flora region of Honduras. These needs were communicated to Dordt College via the Luke Society[15], a Christian society that builds and financially supports medical and dental clinics in disadvantaged areas of the U.S. and in developing countries around the world. The Luke Society also provided logistical support for the student team's investigation and construction trips.

Dordt College's involvement with the project began in the spring of 2000, when a member of the department became interested in the project through personal contacts with members of a Luke Society volunteer brigade that had recently traveled to the La Joya region of Honduras to build a clinic. While visiting Honduras, brigade members investigated other possible projects in the area, including irrigation of cropland for the Tolpan people living nearby. As a class design assignment, a faculty member asked his fluid mechanics students to study the problem and its constraints, and to create an initial plan that might be used as background if the project was to proceed. Over the following summer, through the efforts of Dr. Bryn Jones, a Luke Society member and volunteer team leader, major funding for the project became available through the Luke Society, and Dordt College was asked if a team of seniors could be involved in the design and installation of an irrigation system.

Problem Approach. The senior student team became involved in the project in the Fall semester of 2000 and immediately began investigating possible solutions to the problem. Under the direction of Dr. Jones, who represented the client and arranged for logistical support, and the mentorship of a faculty member, the four students each took primary responsibility for one of the following aspects: Water Diversion, Holding Tank and Filtration, Transportation and Distribution (pipe layout), and Application. In January 2001, with Luke Society funding and in-country logistical support, they traveled to the site with a Dordt College agronomy professor and a volunteer licensed civil engineer, as well as several other Luke Society personnel. They spent 10 days in Honduras, with overnight lodging at the site in the school building in the village. They surveyed the site to determine the topography of the fields and the small streams that were chosen to be the water sources. On this first trip, they developed an initial irrigation piping layout and even helped to install small diversion dams (with bypasses) on the two streams.

The student team returned to the U.S. with significant topographical data and with enough mountain jungle experience to realize some of the challenges that would await them. The team began to design and plan for the installation of the irrigation mainline and laterals into some 25 acres of mountainside fields involving an 80-foot elevation drop from top to bottom. As analysis progressed and decisions were made about the layout of the project, needed piping and other equipment were communicated to the in-country personnel who purchased the PVC pipe and directed the villagers' work to clear brush and dig the necessary trenches for approximately 6,000 feet of buried mainline and laterals. Some of the necessary fittings and stainless steel filtering screens for the filtration tanks were brought in from the U.S. by the installation brigade.

In March 2001, Dr. Jones led a 10-day Luke Society volunteer brigade of 40 persons, including the team and its faculty mentor, to Honduras to install the system. Travel and lodging expenses for this trip were raised by the students and by each volunteer through requests to friends, family and home church communities.

Project outcomes. On March 20, 2001, after five days of intense effort from sun-up to sun-down by everyone involved, the dams and filtration boxes and valves were operated and checked, and the irrigation mainlines were flushed. The potential energy of water in the mainlines, coming down from the storage tanks upstream, “powers” this gravity-flow system, so no electricity or other power supplies are needed to irrigate the fields. One of the hand-moveable, pressure-regulated sprinkler lines was assembled in one of the fields for testing. Tolpan villagers and North American volunteers celebrated the success of the irrigation system that operated as planned in such a steep and challenging terrain. A small drip irrigation system to water a vegetable garden plot at the top of one of the hillside fields was also installed for demonstration purposes. After saying their goodbyes to the Tolpan people, and a day of sightseeing in the capital city of Tegucigalpa, the student team and the other volunteers flew home to the U.S. and Canada on "World Water Day," March 22, 2001.

Besides these desired engineering outcomes, a number of cross-cultural, socio-political, and international affairs lessons were learned by the team. One memorable aspect of the installation trip was the presence of seven armed members of the National Police and the Honduran army, who accompanied the large volunteer brigade the entire time that it was in the area of La Joya and San Juan. This escort was deemed necessary because of earlier incidents by a group of 'banditos' who had noticed increased activity of the in-country volunteers in the area during the preceding two months. Another more important lesson for the Dordt students involved is that the people they assisted and worked with are not poor due to any lack of industriousness! The Tolpan people worked very hard in advance of the brigade and alongside them to carry the pipe up the mountain and to help install the system. Though there was a language barrier for many of those involved, there was a great deal of communication of positive intent and respect as people from vastly different cultural backgrounds worked and relaxed together during the installation phase of the project.

Conclusions. One of the lessons learned by the department is that this project could not have been carried out without the extremely focused planning and diligent logistical support of the Luke Society leadership both in the US and in Honduras. Because of this support, it seems that similar projects of this magnitude would only be undertaken by the department every few years at best. Though it was (and continues to be) a successful project for the Tolpan people and for the design team, it appears obvious that future international humanitarian projects should be smaller in scope and involve fewer people in travel if the engineering department is going to provide the main logistical support.

Table 2 summarizes the data from this Dordt College project. This table includes important facts extracted from the Dordt College data. For example, Dordt College formed a working relationship with an external society (Project Selection, Funding, Mentoring & Teaching) to act as a student resource and handle important logistics.

Table 2: Model Summary - Design of a Crop Irrigation System in Honduras (Dordt)

Team Formation	Four self-selected students formed a team based on their interest in the project, with some instructor facilitation.
Project Selection	A faculty member had personal contact with the Luke Society, and Dordt was asked if seniors could participate in the project.
Funding	The Luke Society provided funding for the irrigation piping, fixtures, and tools. The student's first trip (surveying and initial irrigation layout plan) was funded by the Luke Society. For their second trip (system installation), the students raised their own travel and lodging funds from friends, family, and their churches.
Obstacles Identified	The (large) project required extensive planning and logistical support from the Luke Society. Travel to the site was critical to allow the team to perform work and have enough mountain jungle experience to design the installation.
Deliverables	Design plans and installation assistance for: water diversion, holding tank and filtration, mainline pipe layout, and an irrigation sprinkler system.
Mentoring & Teaching	A faculty mentor and a client both worked with the team, as well as Luke Society personnel.

Institution III: Engineering Design at Grove City College

Grove City College Background. Grove City College (GCC) is a four-year, independent college located in Grove City, PA with an enrollment of 2,200. Although the school is primarily a liberal arts college, it has ABET accredited electrical and mechanical engineering programs. Each program has its own department chairman. There are six electrical engineering faculty and eight mechanical engineering faculty. The electrical engineering majors can pursue a concentration in either "classical" electrical engineering or a concentration in computer engineering. The 15-25 electrical graduates each year are typically split equally between each concentration. The 25-35 mechanical engineering graduates likewise can pursue options including fluids, machine design and thermal.

Grove City College has a fine history of supporting science and technology. One of its founders, J. Howard Pew, also founded Sun Oil Company. Emphasis is placed not only on a quality technical education but also on the underlying characteristics of ethics, personal and community involvement and development, and community leadership. Many of its graduates have served as CEO's of technology based companies such as Motorola, Alcoa, U.S. Steel, and Tyco. One of its graduates, John Breem, recently was chosen as the new Tyco CEO to lead them to fiscal recovery.

The college has recognized the importance of providing its students an opportunity to study in developing countries or to participate in aiding their development. The college's academic structure recently has been reorganized with a greater emphasis placed on external studies. A new dean's position has been created, "Dean of International Studies, Graduate Advancement and Faculty Development." Faculty members also have been supported through faculty development funds to (1) travel to developing countries to investigate potential engineering projects, (2) attend conferences such as the Christian Engineering Educators Conference[16] (CEEC) in order to share like experiences, and (3) participate in the development of a possible new cooperative study center in Uganda, East Africa.

Senior Design. The electrical engineering students are required to take a three-hour course entitled "Introduction to Design" during the first semester of their senior year. They are taught the design process as well as soft science subjects such as ethics, professionalism, and communication skills. About half way through the course, they form groups of 3-5 students. At this time, the groups propose their design projects that they will develop during the remainder of the semester and during the second semester prior to graduation. They are required to complete lab work on their projects during the last third of a three-hour lab the first semester, and complete the project during a two-credit lab course the second semester. The college normally funds \$300-\$2000 for each senior project. The projects are student driven with faculty input in the form of recommendations and assistance with problem solving. Although GCC has both electrical and mechanical engineering departments, the students from both departments have not yet collaborated on projects.

Figure 3: Prototype of a Solar Power System for Remote Areas

Empirical Data Set III: Design of a Solar Power System for Remote Areas (Grove City)

Problem Statement. Throughout the world, situations arise in which conventional access to power grids is not available. Many people live in remote areas that do not have the infrastructure of power transmission systems or, if the system exists, it is unreliable. This scenario is common in Africa and areas of South America. The inaccessibility to electric power prevents people in remote locations from using everyday appliances, clean water, vital medical equipment and everything in between on that spectrum. One solution to this lack of available electrical power is solar energy. Solar systems that currently exist are usually rigidly mounted at a fixed location. If the system is needed at another location, it would be very difficult to move. If more or less capacity is needed, it would be difficult to change the capacity. It is likewise very difficult to monitor the reserve capacity of the system. The decision as to whether to draw from the charged batteries often is made without knowledge of the reserve capacity and, later, the system has no charge remaining when it is needed.

There thus exists a need to develop a scalable, modular solar power system that is easy to use, portable, and reliable. Products that partially meet this need currently exist on the market. However, there is no one system that is scalable and portable and has a reliable monitoring system built-in. In general, companies do not provide integrated systems that are easily reconfigured and include the solar cell, charge controller, battery, battery monitor, and inverter. Thus, consumers with little or no technical knowledge face a real challenge in solving this problem. The Scalable Portable Solar Power System project sought to provide a portable power system that eliminates this difficulty of setup and integration in current systems, while supplying reliable battery monitoring capabilities.

Project Selection. The need for a portable scalable solar power system originally was identified by a faculty member who had worked on missions related projects in Africa. He observed first hand the large number of solar power systems being installed in Uganda. Many were being donated by church groups and service organizations like the Rotary. A church diocese in Pittsburgh had recently installed their one thousandth solar system in Uganda. The faculty member observed the difficulties in using the solar systems and depending on them for critical electrical power. A second faculty member recognized the same need during a separate college funded trip to Africa to identify electrical engineering projects. The need also was confirmed by a medical doctor in Kenya who depended in part on reliable solar power for his medical work.

The general project idea was presented to all the upcoming seniors at the end of their junior year. The value of the project was strongly supported by both faculty members. The group of four students that tackled the problem included two students who had chosen the "classical" concentration and two students who had chosen the computer engineering concentration.

Design Approach. The students first identified the sub-components necessary to meet the objectives for the solar power system. They determined that they needed a solar panel, inverter, battery, charge controller, and system state monitor. The two "classical" students concentrated on the "power" aspects of the project and worked on the solar panel and battery specifications. The two computer engineering students concentrated on the system state monitor and the charge controller. The battery, inverter and solar panel were bought from commercial vendors according to the design team's specifications. The charge controller was modified from a circuit that they found in the literature. They made a printed circuit board of their final design. They researched the literature and found two promising theoretical approaches for the system state monitor. They settled on one of them and implemented its algorithm using an embedded controller. Part of this process required the students to develop a data acquisition system to measure operating parameters and to develop a database. The system sub-components were integrated, and the complete system was mounted on a dolly structure for portability. The total cost for the project was $1,700. The major purchases were $500 for the solar panel and $200 for the batteries.

The teaching staff checked the sizing to specifications of the major components before they were purchased and the initial use of the solar panel after it arrived. The staff also checked the modified design of the charge controller and guided the students in making the printed circuit board. Initially, the teaching staff guided the students in their search for a feasible system state monitor. After a promising approach was found in the literature, the students were instructed to verify the claims made in the paper, determine how to implement the concepts in their system, and then verify the operation of their system.

Project Results. The project required an understanding and application of circuit analysis and design, data gathering and analysis, embedded system programming, and system integration, construction and verification. The team designed, analyzed and implemented on a PCB a charge controller. The battery monitoring algorithm involved mathematical analysis techniques. The technique the team settled on is based on the techniques developed by Aylor, et al. [17] originally created for wheelchair users. The technique involves two measurements of the electrical condition of the battery. One is the open-circuit (or unloaded) voltage across the battery terminals and a coulometric measurement which tracks the current discharged from the battery. This technique was implemented using a Motorola 68HC11 to execute the required switching of the loads, the analog to digital conversions, the managing of the databases and the execution of the algorithms. The HC11 was also used to control the user display. The team had to determine reasonable specifications for the solar panel array and the inverter. Finally, they located manufacturers of scalable individual components, purchased the components, and installed them on a dolly structure.

The students were required to use a two channel data acquisition system for both the evaluation of the monitoring algorithm and the proof of performance of their integrated system. This step was an added benefit since they had just completed a senior lab in data acquisition, and they were able to use the system that they had designed in that lab.

In addition to the normal engineering required in a senior level project, the design team also had to consider the issues of ruggedness, adaptability to developing countries and sustainability. Although the students did not have the opportunity to travel to a developing country, the faculty member who had visited Africa gave them advice throughout the project.

Conclusions and Lessons Learned. The project was completed on time according to the design specifications at a reasonable cost of $1,700. This result was quite an accomplishment in itself. The students did not have the assistance of an electrical/electronic technician since the electrical department was just recently given approval to hire one. They would have profited from the help of a technician in the installation, testing and integration aspects. This project was the first time that some of the students had the chance to work with currents over 1 mA. It was also difficult to evaluate and integrate the large area solar panel (25.4 lbs., 4.3 feet long, 2.2 feet wide, and 1.6 inches thick). The students also had to rely on the help of the mechanical engineering technician for the construction of the dolly system. (The mechanical technician had the responsibility to assist the mechanical engineering students who were also trying completing their projects.)

The students additionally had to consider the ramifications of the fact that the system would potentially be used in a critical life-threatening situation in a hostile environment. Although the monitoring algorithm worked adequately, the students eventually concluded that more work needed to be done as well as more proof of performance testing should be completed before the system was shipped to a third world country and put into operation.

Recently, an expert with shipping experience from a developing country evaluated the project and was pleased with it. He concluded that the system was indeed portable and scalable. In his opinion, the unit could be easily dismantled, shipped and then reconstructed. It could be easily moved once in the working environment. System components that met the student's specifications could also be readily purchased in the developing country.

Table 3 summarizes the data from this Grove City College project. This table includes important facts extracted from the Grove City College data. For example, faculty members had a personal interest due to their travels to Africa (Project Selection).

Table 3: Model Summary - Design of a Solar Power System for Remote Areas (Grove City)

Team Formation	A self-selected team of four students composed of two "classical" EE's and two from the computer engineering concentration.
Project Selection	The need was identified independently by two faculty members traveling to Uganda (one on a school funded trip to identify design projects). The need was confirmed by a medical doctor in Kenya. The project was presented to the class and one team volunteered to take it.
Funding	The college provided $1,700 which was primarily spent on prototype components.
Obstacles Identified	The team had to account for ruggedness, adaptability and sustainability appropriate for a developing country. Students were not able to travel to Africa.
Deliverables	Design specifications and a working system.
Mentoring & Teaching	The project was student-driven. Staff checked student work at critical points, and provided guidance searching for a system state monitor. Mechanical technician support and outside expert review was also provided.

Institution IV: Design as an Extra-Curricular Activity at Messiah College

Messiah College's mission is "to educate men and women toward maturity in intellect, character, and Christian faith in preparation for lives of service, leadership, and reconciliation". Messiah has a student body of 3,000 students, 160 of which are enrolled in the engineering program taught by eight faculty. Messiah employs summer work experiences and internships to provide valuable real world experience for their students in all disciplines. In addition, for many years the Engineering Department has been utilizing extra-curricular projects, both locally and globally, to help educate engineering students. Several local urban projects in Harrisburg, PA have included community gardens, building straw-walled sheds, and roof-top gardening techniques.

Many of the Engineering Department's global extra-curricular projects have been facilitated through Dokimoi Ergatai[18] (Greek for "Approved Workers"), basically a student run organization, which collaborates with faculty, staff, and the local community to initiate, nurture, and oversee the development of appropriate technologies for implementation in needy areas abroad. Some of the projects have included:

- Photovoltaic(solar) electric power systems for a medical dispensary in Burkina Faso and a hospital in Zambia
- Solar-powered drinking water pumps supplied to a school for persons with physical disabilities
- Human powered pumps to irrigate a micro-enterprise farm run by persons with disabilities

- Hand-powered tricycles which provide mobility and freedom to polio victims

Other projects with global interest have been sponsored by the Collaboratory for Experiential Learning program, a "hands-on" learning laboratory. Some of these projects include work on water purification and on landmine detection, removal, and detonation.

Figure 4: Prototype of a Three Filter Ultra-violet Water Purification System

Empirical Data Set IV: Design of a Water Purification System in Guatemala (Messiah)

Water for the World[19] is an interdisciplinary extra-curricular project started in January 2002, inspired by one man's concern to provide pure drinking water to the world. A simple two-fold mission was developed:

- Create an awareness in people that there is a need for clean drinking water (education)
- Create devices to provide clean drinking water to people groups at an affordable cost and who can be easily trained to maintain the devices (sustainable purification)

Presently there are 14 students, first year to senior year, from four of the five schools within Messiah College who are now committed to take part in this on-going project.

Four teams have been established. An engineering team has built a small, three filter, ultra-violet light prototype purification system which can be powered by AC or DC electricity. A natural sciences team tests and documents the purity of the water being filtered. A business team has developed a marketing strategy for the device which was developed. A communications-education team has developed (and maintains) a website for the project [19] and has developed a brochure in both an English and Spanish edition and educational materials. Faculty advisors from each department/school were solicited and have been involved with the teams.

The teams meet bi-weekly together in a large meeting and as needed during the week to fulfill the objectives of each team. The man who inspired the project and an alumni advisor who is an environmental chemist come to most of the meetings, giving valuable input to the teams.

In addition the mechanics and chemistry of water purification techniques, teams have also learned team dynamics including: time management, project management, communications skills, division of labor, conflict resolution and the use of logbooks.

In August 2003, a scouting team of students and advisors visited a Kekchi Educational Center in San Juan Chamelco, Guatemala to investigate water needs of the school, find local suppliers of water purification materials and equipment, and field-test the prototype system mentioned above. All three objectives were met. Based on the scouting team's recommendation, the center has installed a system which saves the school $1,600-$1,700 per year in purchasing bottled water and firewood to boil water. Another system is being planned for a seminary in Guatemala City.

Through this and other similar extra-curricular projects, engineering students have begun to fulfill the mission of Messiah College, "to educate men and women toward maturity in intellect, character, and Christian faith in preparation for lives of service, leadership, and reconciliation."

Table 4 summarizes the data from this Messiah College project. This table includes important facts extracted from the Messiah College data. For example, projects need not be associated with credit-based courses, but through established service organizations (Team Formation).

Table 4: Model Summary - Design of a Water Purification System in Guatemala (Messiah)

Team Formation	Students voluntarily participate in a student-run service organization. 14 students ranging from freshmen to seniors, from four different schools within Messiah, formed into teams: engineering, natural science, business, and communications/education.
Project Selection	The Guatemala site was suggested by the Mennonite Central Committee. It was selected by students based on the inspiration of a local philanthropist.
Funding	A local philanthropist purchased the equipment. Students raised their own travel funds.
Obstacles Identified	The cost of overseas travel for field-testing. The language barrier required a translator.
Deliverables	A prototype purification system with demonstrated effectiveness, a marketing strategy, and publicity through brochures and a website.
Mentoring & Teaching	Faculty advisors from each of the departments provided mentoring. The man who inspired the project and an alumni environmental chemist served as consultants.

INSIGHTS: Designing, Selecting, and Executing International Humanitarian Design Projects

Using the extracted data from the previous sections, insights may be derived through similarities, contrasts and distinguishing project features of the summary models of Tables 1-4. This section highlights these insights with the goal of elucidating approaches for successfully executing international humanitarian (IH) design projects in an engineering curriculum.

Team formation. The impact team formation has on success and learning during design projects is well documented [20,21]. It is notable that in all four of the exemplary projects presented, teams were composed primarily of self-selected students who chose the project because of their interest. It is well documented that self-selected project teams can have mixed results in success. In the case of these IH projects, the inherent need associated with humanitarian efforts appears to overcome (or at least temper) typical self-selected team problems.

As demonstrated by the four institutions, IH projects also foster interdisciplinary work. Structuring teams in an interdisciplinary fashion is not an afterthought, as in many efforts in academia. Instead, the projects implicitly call for interdisciplinary skills. These skills are a prerequisite to success.

Project selection is a challenge for successfully executing IH projects. Geographic, cultural and language barriers can all complicate the process of identifying and scoping a project (reference 10 discusses IH project selection in-depth). Perhaps because of these challenges, all four projects studied involved an outside person or organization already actively working to address a social need: EMI and WFMIC were working to assist injured mothers in Nigeria, the Luke Society was assisting the Tolpan people in Honduras, church groups and service organizations like the Rotary were installing solar system in Uganda, and MCC Missions was serving the Ketchi people in Guatemala.

An additional challenge is to choose meaningful projects that excite student's interest as well as provide a quality educational experience. In each example given, the faculty were actively involved in the project selection and specification. In several cases, the international involvement of faculty members led to identification of the projects and their inherent commitment to teams which chose the projects. In most cases, the faculty traveled to the developing country to see first hand the needs and obstacles.

Funding. Due to the importance of international travel and/or prototype delivery, IH projects may incur higher costs than normal course fee structures can support. In three of the projects the students traveled internationally to visit the site, and the Grove City team, which did not travel, relied heavily on the observations and experiences of a faculty member who had visited the site. In the case of the women's hospital design team and the water supply system design team, students worked to raise additional funds to cover travel and other project expenses. For the Water for the World project, the students and faculty raised their own funds for traveling, approximately $750 each. The equipment for the Kekchi educational center was purchased by the philanthropist who inspired the project.

While greater funds may be needed (in some cases), the likelihood to secure the appropriate funds also appears to increase significantly, compared with typical academic design projects. The willingness of philanthropists, foundations, certain government agencies, churches, and community groups to support IH projects is greater due to the inherent needs and potential payoffs.

A further consideration of the funding data also indicates that a wide range of project costs are possible. Low cost projects with existing technologies are possible, as shown by the Grove City College project. This project, while modest in terms of financial demands, presented significant technical changes to the students, drawing and extending their engineering knowledge.

Overcoming Obstacles Characteristic of IH Design Projects. Overseas travel was both desirable and a special challenge in the case of every project. One of the most difficult cases was the Calvin team which chose to visit Nigeria despite a US State Department Travel advisory. An email to the students read, "Although Calvin would prefer that you not go to Nigeria at this time, we of course wish you success in your project and safe and healthy travel." In this case, EMI provided some of the logistical support that the college normally would have supplied. Logistics must be well planned and scheduled to overcome these obstacles. External groups may be willing to assist with these logistics, as in the case of EMI with Calvin or the Luke Society with Dordt. Such partnerships are invaluable, and can be informally developed on an as-needed basis.

IH projects present potential problems with language barriers. In the case of the Messiah team trip to Guatemala, for example, a student majoring in Spanish was invaluable in translating discussions with local health officials and school personnel as well as written documentation during and after the trip. Most Ketchi people could communicate in Spanish, even though it was not the language most familiar to them.

Deliverables for the four IH design projects were similar to more traditional domestic projects: design specifications and prototypes. The unusual deliverables for these projects were the international on-site assistance; a survey of Nigerian terrain, and the installation assistance of 6,000 feet of irrigation piping in Honduras. The engineering outcomes included:

- Design specifications, drawings, and cost estimates were provided for a women's hospital in Nigeria.
- Design specifications, installation plans, and installation assistance were provided for 6,000 feet of irrigation piping in Honduras.
- A scalable solar power system suitable for shipment to Africa was designed and constructed.
- A water purification system was tested and recommended for installation in a Guatemalan school, saving $1600-$1700 per year.

Such outcomes represent tremendous results on the part of undergraduate engineering students. Such deliverables should instill a pride in the students, provide a word-of-mouth source of advertisement and publicity for future projects, and create an outreach avenue to an institution's local or extended community. These secondary outcomes are a critical aspect of an engineering student's education and an institution's mission.

Mentoring and Teaching Considerations. All four cases presented involved close faculty mentoring of student teams, and, in several cases, teams were assisted by subject-area experts. A summary of learning outcomes specific to IH design projects includes:

- Increased awareness of social (in this case Christian) responsibility
- Cross-cultural, socio-political, and international affairs lessons were learned by the teams (e.g. necessity of security, strong work ethic of poor farmers, camaraderie built across linguistic and cultural differences).

- Exposure to the issues of ruggedness, adaptability and sustainability for developing countries.
- Increased maturity in intellect, character, and Christian faith in preparation for lives of service, leadership, and reconciliation.

General Insights. A number of insights are apparent from these exemplary projects that cross the categories described by the IH project framework:

- Many of the customer needs and requirements of the projects extended the students' perspective and skill set beyond any coursework or typical industrial project. Needs related to power consideration, environment, ergonomics, and culture are unique, or the parameter ranges required are beyond those encountered when considering industrialized countries. These needs appear to naturally engage the students. They also call upon the students to independently investigate literature and other sources to extend their knowledge. Such research provides a foundation for life-long learning and education beyond the baccalaureate degree.
- In terms of creating a teaching model, external and invested personnel are essential to IH projects. The expertise provided by external sources must be balanced by the students' genuine interest and commitment to the project. The combination of motivated students and committed external personal appears to be a consistent factor of project success.
- IH projects may be solved through the adaptation of low to medium technologies. As demonstrated by all the exemplary projects (existing building and complex layouts, water purification technologies, water supply materials, and solar technologies), existing technologies are synthesized, in novel and creative ways, to solve real human needs. Technical expertise must be brought to bear by the student teams, but resources are readily available due to the technologies employed.

Implementing IH Design Projects. The four projects reviewed here illustrate how international humanitarian design projects can be implemented in an engineering curriculum. Six key elements for project success are highlighted and compared across projects. The above insights give additional guidance regarding how each key element may be successfully negotiated when implementing an IH project. Table 5 presents a summary of insights for each key element in the form of actionable guidelines. These guidelines, along with the data analysis above, provide a model for implementing such projects. Although the examples given are all in the context of faith-based institutions, the model developed is more generally applicable (provided differences among institutions are accounted for.) Table 6 suggests possible sources of IH design projects.

Faculty who wish to implement domestic service-oriented design projects are referred to references 1 and 9.

Table 5: Model Guidelines

Team Formation	• Students should be self-motivated to tackle an IH project. • Self-selected teams may be appropriate, if united by their motivation. • IH projects may call for teams with interdisciplinary skills.
Project Selection	• Partner with individuals knowledgeable about the problem context. • Ideally, partner with individuals already involved with the problem. • Carefully scope projects for feasibility in consideration of the obstacles involved.
Funding	• Prepare for higher costs than traditional domestic projects. • Consider philanthropic churches, community groups, and individuals. • Students and their communities may be willing to help fund an IH project.
Obstacles Identified	• Plan in advance for international travel which is often critical and difficult. • Partner with knowledgeable individuals for help with travel logistics. • Insure students have an adequate awareness of special design constraints. Travel, contact with individuals, and supplemental lectures and research can help.
Deliverables	• Encourage or require delivery of a working design or actionable recommendations to provide motivation, satisfaction, and community rapport. • Avoid assuming that high-technology is required. Creative adaptation and synthesis of low to medium technologies may be appropriate.
Mentoring & Teaching	• Seek mentors with problem-related expertise, particularly if faculty lack it.

Table 6: Potential Sources of IH Design Projects

- Personal contact with individuals and organizations working in developing countries
- The Basic Utility Vehicle design initiative www.drivebuv.org
- Development by Design www.thinkcycle.org/tc-topics/
- Engineering Ministries International www.emiusa.org
- Design that Matters http://www.designthatmatters.org/

Conclusions and Future Work

The international humanitarian projects presented here were carefully selected for their exemplary success. This selection, and subsequent data analysis, has lead to an identification of how key elements were addressed in each project, highlighting notable similarities and differences among projects. These key elements provide a basis, at least in part, for including international humanitarian design projects in any engineering curriculum. With the inherent motivation from the reported projects, it is hoped that engineering faculty will internalize these key elements and guidelines, and initiate similar efforts at their home institutions. By so doing, faculty will encourage engineering students to embark on a learning journey harmonizing their technical studies with humanitarian pursuits, and thus engaging the intellectual, physical and spiritual aspects of their personhood.

While the model's assessments, as reported here, provide useful insights into successfully selecting and executing IH projects, future study of additional and perhaps less successful projects will underscore and expand these insights. Future work for this research may include monitoring future IH projects using the key elements identified here as a template for project documentation. Further study may also uncover additional key elements important to project success.

References

[1] Tsang, E., Projects That Matter: Concepts and Models for Service-Learning in Engineering, American Association for Higher Education, 2001. Preview: www.aage.org/service/series_new.htm

[2] Emanuel, Joseph, "The Community-Based Capstone Design Experience: More Than Meets The Eye," *Proceedings of the ASEE Annual Conference*, Session 3657, Nashville, TN, June 2003.

[3] Rabiee, Max and Kreppel, Maria, "University/ Community Partnership Though Senior Design Projects," *Proceedings of the ASEE Annual Conference*, Session 2625, Nashville, TN, June 2003.

[4] Goldberg, Jeff; Aronson, Meredith; Reyes, Marie, "Giving Back: Engaging Young Women Engineers In Community Based Design," *Proceedings of the ASEE Annual Conference*, Session 1392, Nashville, TN, June 2003.

[5] Doerry, Eck, "The Global Engineering College: Exploring A New Model For Engineering Education In A Global Economy," *Proceedings of the ASEE Annual Conference*, Session 2360, Nashville, TN, June 2003.

[6] Malkin, Robert, "Engineering World Health: A Novel Approach To Teaching A Global Viewpoint," *Proceedings of the ASEE Annual Conference*, Session 2793, Nashville, TN, June 2003.

[7] Sterkenburg, Ronald, "The Continuing Globalization Efforts Of The Purdue Aviation Technology Department - The China Experience," *Proceedings of the ASEE Annual Conference*, Session 2260, Nashville, TN, June 2003.

[8] Jewell, Thomas, "Gaining Global Perspective Through Terms Abroad," *Proceedings of the ASEE Annual Conference*, Session 2793, Nashville, TN, June 2003.

[9] Green, M.G., Dutson, A., Wood, K.L., Stone, R.B., McAdams, D.A., "Integrating Service-Oriented Design Projects in the Engineering Curriculum," *Proceedings of the ASEE Annual Conference*, Session 3660, Montreal, Quebec, June 2002.

[10] Duda, Frank T., "Experiences with Identifying Senior Level Engineering Design Projects to Meet Developing Country Needs," *Proceedings of the 4th Christian Engineering Education Conference (CEEC)*, June 19-21, 2002, Montreal, Canada, pp 18-22.

[11] VanderLeest, Steven H. and Nielsen, Edward G., "Global Engineering and the Liberal Arts," *Proceedings of the 1998 American Society for Engineering Education (ASEE) Conference*, Seattle, WA, 1998.

[12] Green, M.G., Wood, K.L., VanderLeest, S.H., Duda, F.T., Erikson, C., Van Gaalen, N., "Service-Learning Approaches to International Humanitarian Design Projects: Assessment of Spiritual Impact," *Proceedings of the 2004 Christian Engineering Education Conference*, Salt Lake City, UT, June 2004*, in preparation.*

[13] Engineering Ministries International, www.emiusa.org

[14] Worldwide Fund for Mothers Injured in Childbirth (WFMIC), http://www.wfmic.org/

[15] Luke Society, http://www.lukesociety.org/

[16] Christian Engineering Education Conference, Homepage, http://engr.calvin.edu/ces/ceec/

[17] Aylor, J.H, Thieme, A., and Johnson, B. W., "A Battery State-of-Charge Indicator for Electric Wheelchairs," IEEE Transactions on Industrial Electronics, 1992, 39(5): p. 298-409.

[18] Dokimoi Ergatai "Approved Workers", Agape Center for Service and Learning, Messiah College, http://www.messiah.edu/agape/nat_internat/dokimoi/

[19] Water for the World, Messiah College, http://www.messiah.edu/acdept/depthome/engineer/Projects/water_purification_project/home.html

[20] Jensen, D.L., and Wood, K.L., 2000, "Incorporating Learning Styles to Enhance Mechanical Engineering Curricula by Restructuring Courses, Increasing Hands-on Activities, & Improving Team Dynamics," Proceedings of the 2000 ASME International Mechanical Engineering Congress and Expo., November 5-10, Orlando, Florida.

[21] Jensen, D., Wood, K.L., And Wood, J., "Enhancing Mechanical Engineering Curriculum Through the Use of Hands-on Activities, Interactive Multimedia and Tools to Improve Team Dynamics," *International Journal of Engineering Education*, 2003.

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Publication 5: Effects of Product Usage Context on Consumer Product Preferences

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ABSTRACT

We present a framework for understanding product usage context and its impact upon customer needs and product preferences. We conduct customer interviews with two sets of representative products from the functional families of "mobile lighting" and "food boiling" products. Customer interviews lead to identification and characterization of distinct product usage contexts. Interactive surveys measuring customer product choice support the hypothesis that customer product preferences differ for each usage context identified. Further analysis shows that attributes of these chosen products are related to factors of the usage context (e.g. mass is related to transportation mode). These results demonstrate that valuable insight for product design is available through an

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[2] Definitions of key terms are collected in Appendix A for reference.

understanding of usage context, and future work will refine and test methods to formally bring contextual information to bear on product design. These capabilities will be especially important for contexts in which needs assessment has traditionally been difficult, such as with latent needs and frontier design environments.

Keywords: Product definition, customer needs, product usage context, specifications, empirical study.

1 INTRO TO PRODUCT USAGE CONTEXT (PUC)

Product usage context[2] (PUC) refers here to all factors characterizing the application and environment in which a product is used that may significantly impact customer preferences for product attributes. For the usage context of long-distance backpacking, for example, the remote outdoor environment is an important *usage factor*[2], which leads customers to choose products with different attributes than they might for a domestic use. We use *product attribute(s)*[2] throughout to refer to important characteristics such as volume, mass, operating cost, and convenience (characteristics often included in product specifications or a customer requirements list). Table 1 shows examples of PUC differences which dramatically impact customer expectations of product attributes.

Table 2 illustrates how usage factors such as storage mode or transportation mode impact customer preferences for attributes such as volume and mass.

Table 1: Examples of PUC Differences

Need (Product)	PUC #1	PUC #2	Differences
Cook food (Stove)	Backpacking	Domestic kitchen	Size constraints, Energy supply
Loosen/tighten nuts (Wrench)	Space station	Garage	Ruggedness of use, Mass constraint
Store ink writing (Paper)	Office	Clean room	Allowable particle emissions
Harvest crop (Scythe/Tractor)	Rural village	Commercial farm	Maintenance, Prevailing wages

Table 2: Sample Usage Context Factors and Impacted Preferences for Food Boiling Products

Usage Factor	Usage Context (PUC)		Attribute Preferences Impacted
	Backpacking	Average Kitchen	
Storage Mode	backpack	room	Volume, mass
Transportation	foot	none	Volume, mass
Ventilation	outdoor	limited	Gas emission
Energy Supply	user provided	electricity	Energy accepted
Usage Duty	light	heavy	Operating cost

As shown in Table 3, PUC may be thought of as one part of the larger definition of *product design context*, which also accounts for customer context and market context. We categorize (1) *customer context factors* to include consumer beliefs, values, practices, and demographics (e.g. wealth and age); (2) *market context factors*[3] to include aspects of competing products; and (3) *usage context factors* to cover the application and situation in which the product will be used, such as weather and infrastructure (e.g. the state of roads, maintenance systems, energy supply, and supply chains). Of these three major categories of contextual factors influencing a customer-driven product design process, usage context often receives the least attention. This research reports the results of an empirical product study showing how usage context factors influence customer product preferences.

Table 3: Product Design Context Categories

Category	Example Factors
Customer Context	• Disposable income available • Safety expectations • Convenience expectations
Market Context	• Features of available products • Performance and quality of available products • Cost of available products
Usage Context (PUC)	• Application task • Infrastructure (e.g. energy supply) • Harshness of environment • Usage duty (frequency and duration)

[3] Changes in the market climate over time lead to changes in customer needs.

1.1 Key Definitions

Product

- Functional family – a group of substitute product performing the same primary function such as "cook food by boiling" or "broadcast light with mobility"
- Product attribute – an observable characteristic of a product such as cost, performance, or safety
- Product attribute metric (product metric) – a quantifiable measure of a product attribute, such as mass in kg (portability) or a subjective rating scale for safety

Customer (User)

- Customer attribute preferences (customer preferences) – the levels of attributes a customer desires in a product. For example, "low mass."
- Customer product preferences – the aggregation of customer attribute preferences as manifested in product choice.
- Customer product choice – the product(s) a customer selects from a given choice set for use in a specific context.
- Customer perceptions – customer evaluation of how well a product satisfies individual customer needs, often ranging from "very unsatisfactory" to "very satisfactory."

Context

- Usage (context) factor – a characteristic of a product's usage that influences customer attribute preferences. Example: outdoor usage influences preference for weather resistant attributes.
- Product usage context (PUC, usage context) – the usage factors characterizing the application and environment in which a product will be used that may significantly impact customer attribute preferences.
- Product design context – the collection of factors influencing customer attribute preferences including: product usage context, customer context, and market context

NEED FOR UNDERSTANDING CONTEXT FACTORS. Engineers are often called on to design for frontier design environments outside their experience and expertise. This occurs by default because engineers are a subset of society; they design products to be used by children, remote villagers, the illiterate, and other groups typically not represented among design engineers. Additionally, the importance multi-national companies place on positioning products in a global marketplace requires design for customers in other countries, cultures, and economies. Although most design engineering is performed in developed countries, 86% of the world lives in a developing country (Mahajan and Banga, 2005). A special case of global design occurs when engineers in affluent societies create life-improving designs for use in high human-need environments, such as the Freeplay Radio initially targeted at rural African customers. (A case study of the Freeplay Radio design is included in (Cagan and Vogel, 2002). One of the top business books of 2004, "*The Fortune at the Bottom of the Pyramid*" makes the case that "the world's poor [are] potential customers …" and that everyone will benefit when recognizing the market potential among the 4 billion people living on less than $2 a day (PPP) (Prahalad, 2004). Numerous opportunities continue to exist for engineering designs to improve the quality of life on a global scale ([4], for example).

We anticipate numerous benefits from discovering how PUC factors influence customer preferences. We expect that an improved theoretical understanding of the fundamental contextual causes influencing customer needs and preferences will improve the success of the product definition phase to define products which satisfy and delight customers.

First, an improved understanding of PUC will facilitate and organize the customer needs gathering process. This understanding will improve the quality and quantity of information gathered within resource constraints, and illuminate latent customer needs which might be missed otherwise. Designers will be able to select and interview customers more effectively and better understand and classify the information received in interviews.

[4] "Basic Utility Vehicle – Institute for Affordable Transportation," Homepage, Accessed May 2005. www.drivebuv.org

Second, a PUC framework will improve the task of setting target values by clarifying for the designer how contextual factors influence customer preferences for product attribute values. Current techniques prescribe capturing the "voice of the customer," but provide insufficient guidance on how to translate these data into quantifiable numbers[5]. The primary technique for forming design targets is benchmarking, but this can be difficult or impossible in frontier design situations in which comparable designs are sparse. A PUC framework and the concept of a *functional family* (a group of products which solve the same primary need) will provide the designer with tools to maximize domain cross-over of benchmarking information, intelligently selecting and adapting information from existing products that may exhibit some similarities, but do not occur in the target context.

Third, a PUC framework will better equip designers to leverage the known to design for the unknown through an improved understanding of how changes in usage context influence customer preferences. Product definition information from an accessible or information-rich environment may then be intelligently brought to bear upon a frontier and information-scarce environment. An example is the design of a $100 above-knee prosthetic by a US University for a charity hospital in Kenya [[6]]. The challenges of accessing and understanding Kenyan customers may be partially addressed through local access to US amputees, provided the needs gathered are properly translated into the Kenyan context.

Multiple texts have put forward formal product design methods (Cagan and Vogel, 2002; Otto and Wood, 2001; Pahl and Beitz, 1996; Ullman, 2002; Ulrich and Eppinger, 2004), exhibiting some variations among definitions. The beginning stages of the product design process may be collectively referred to as the "front-end" of the design process (Cagan and Vogel, 2002), "understanding the problem" (Otto and Wood, 2001; Ullman, 2002), "clarification of task" (Pahl and Beitz, 1996), or the "product definition" phase. This beginning phase is characterized by extensive information gathering, and is foundational to creating successful designs. By product definition here we refer to the

[5] QFD is an excellent technique for this conversion, however it is left to the designer to translate what the customer means by "light-weight," for example, into a quantity in kg.

first phase of the design process including: background research (often including competitive benchmarking), gathering customer needs, and formulating product requirements/engineering specifications. The product definition step is critical for the success of any new product, and particularly problematic for frontier design environments. An opportunity exists to increase the success of products designed for these markets through formalizing methods of discovering, documenting, and addressing the product design context during the design process. This research focuses on developing an understanding of the product usage context, leaving exploration of customer context and market context for future work.

Product usage context (PUC) has been studied previously through exploration of customer needs and attributes of a functional family of mobile lighting products (Green, et al., 2004). This research expands the previous study to include: additional literature review, the addition of "food boiling" products, customer product choice surveys, and an exploration of how individual factors of a target usage context influence customer preferences for product attributes.

2 USAGE CONTEXT RELATED LITERATURE

Most design methodology texts address the importance of understanding customer needs during the product definition phase. Ullman (2002), and Otto and Wood (2001) provide sections about addressing customer needs. Ulrich and Eppinger provide a section on addressing customer needs stating that designers should experience a product's "use environment" when studying customer needs (Ulrich and Eppinger, 2004). The methodologies discussed in these texts, however, may be inadequate for engineers designing for unfamiliar environments. Because of time, money, and physical limitations, designers may not be able to adequately experience or understand the use environment of a product.

The effect of usage context effects on product design and consumer preference is addressed somewhat in marketing and consumer research literature. Belk, for example, suggests that consumer research needs to explicitly account for situational variables and

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[6] "L.E.G.S. Homepage," Accessed May 2005. www.letu.edu/legs

context (Belk, 1975), while Park states that consumer research often incorrectly assumes consumer consumption to be "independent of usage situations" (Park, 1993).

Belk defines a usage situation as "all those factors particular to a time and place of observation that do not follow from a knowledge of personal (intra-individual) and stimulus (choice alternative) attributes and which have a demonstrable and systematic effect on current behavior." He groups situational characteristics into five groups, shown in Figure 1, two of which are of primary interest to engineering design: physical surroundings and task definition. Belk's definition of a usage context is similar to ours in that it incorporates application (task) and environmental characteristics. The remaining three elements represent possible sources of variation which were not controlled in the empirical study, and likewise are difficult or impossible to accommodate during a product design process.

Belk points out that the main problem in accounting for usage context is the lack of a comprehensive taxonomy of "situational characteristics" and combinations of these characteristics ("Situational characteristics" is similar to our term *usage context factors,* with combinations termed *PUCs*). Here we do not seek a comprehensive taxonomy, but rather empirical examples.

Galvao (Galvao and Sato, 2004) provides a framework to isolate information from the context-of-use defined by users. The paper defines three knowledge sets: structure-functional, procedural and contextual. "Structure and function" pertain to the product's behavior and attributes, "procedures" refers to the tasks users engage in during product interaction, and "context-of-use" refers to the wide range of influences by which product performance can potentially be affected.

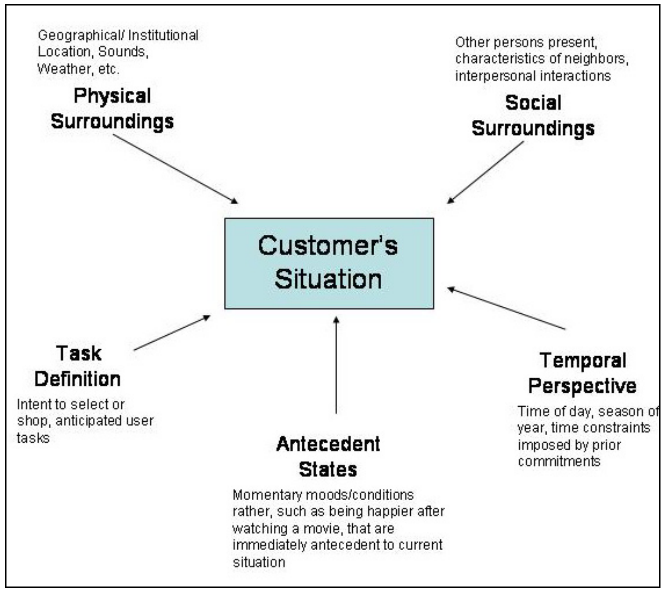

Figure 1: Situational Variables Affecting Customer Choice (Belk, 1975)

In research concerning market segmentation, Dickson claims that besides the popular use during the 1970s of person-based characteristics to segment markets, markets can also be segmented by usage situation, since demand often results from person-environment interaction (Dickson, 1982). He presents a general framework for person-situation analysis and says it is probably most useful for product development, among other activities.

Warlop and Ratneshwar, based on studies of consumer choice for desserts and candies, speculate that usage context may remind customers of “known solutions” when they choose between products and may impose constraints on possible product choices (Warlop and Ratneshwar, 1993). They state that their research (ca. 1993) is part of an emerging stream of research studying the role of context and goals in consumers’ learning and decision making. Similarly, accounting for usage context might remind designers of “known solutions” and allow them to better select successful concepts for unfamiliar environments.

The Substitution in Use (SIU) Approach developed by Stefflre involves having customers generate a set of usage contexts and list substitute products they would use in those contexts (Stefflre, 1971). The underlying idea behind SIU is that "usage contexts act as environmental constraints that help define consumers' ends or goals, and thus limit the nature of the means (products) that can achieve those goals." (Ratneshwar and Shocker, 1991). In engineering design, usage context also creates constraints that limit engineering means to achieve certain functional goals.

From the literature, we observe that the influence of usage context on customer choice and preferences has received some attention in the past. There is a need for the formal application of contextual information in the design of engineered products. Specifically, the development of methods and tools to discover, document, and apply contextual information in the product design process holds much promise for improved satisfaction of customer needs.

3 RESEARCH APPROACH

We conduct an empirical product study to investigate the effect of usage context on customer product preferences. For example, how does the way the product will be stored (storage usage factor) affect customer choice among products of various volumes and masses? Is this effect similar from one functional family of products to another? We believe customer product preferences are strongly influenced by factors of the intended usage context, and thus we hypothesize that:

(a) Customers will prefer different products for different usage contexts, and (b) Products preferred for a specific usage context will exhibit attributes related to that context.

For example, our hypothesis suggests that for mobile lighting products, for usage contexts such as "power outage" and "heavy domestic use" with a usage context factor of "storage=cabinet," the products customers prefer will have similar "volume" attributes. It is expected that attributes will show correlations with driving usage factors, whereas attributes driven by customer factors (such as disposable income) will vary independently of usage factors.

To test this hypothesis, we partially reverse engineer (Otto and Wood, 1998) two families of successful, market-mature products to determine customer needs and product attributes. Our methodology is shown in Figure 2. First, two functional families are selected to allow cross-functional comparisons: eleven products that broadcast light with portability, and ten products that cook food through boiling. Second, customer interviews yield customer needs lists and usage contexts. Third, the products are measured across key attributes determined from the customer needs list. Fourth, interactive surveys show which products customers prefer for each usage context identified. Finally, the data are analyzed to investigate the relationship between product attributes and factors of the contexts for which they are preferred.

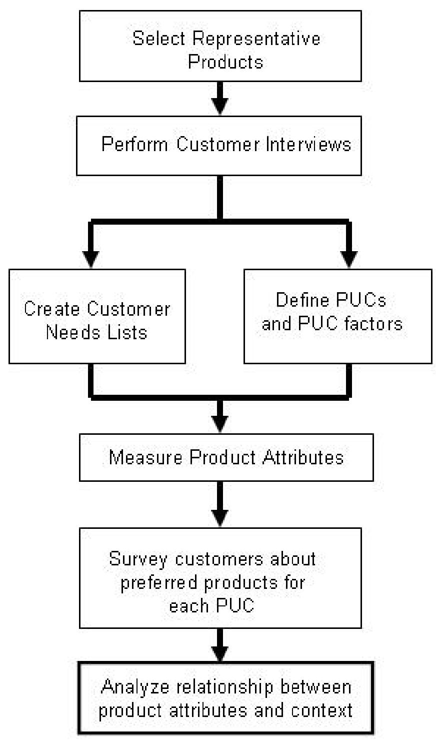

Figure 2: PUC Exploration Methodology

3.1 Selecting Products for the Empirical Study

To determine correlations between usage context factors and product attributes, two functional families of products are partially reverse engineered. Functional families are defined here to consist of products addressing the same primary functional need.

Choosing appropriate products is critical at this stage. Therefore, product families chosen for our study must fulfill several criteria: (1) address a need that most consumers are familiar with; (2) be technologically mature and stable (high on the S-curve) so that customer desires for product features are relatively stable; (3) contain products addressing a ubiquitous need spanning multiple PUCs so that differences can be compared; and (4) contain products of reasonable size, availability, and cost for an empirical study.

The most obvious products fulfilling these criteria are those addressing basic needs. The two domains of lighting and cooking are selected because each encompasses a variety of products satisfying the above criteria.

The domain of lighting is broad, because human need for lighting spans many applications and environments. Since thousands of distinct products fulfill this need, we define it more specifically to be the need for *"mobile lighting that allows broad visibility of other objects."* The term *mobile lighting products* is used hereafter to refer to products fulfilling this need. Mobile lighting products exclude permanently installed lighting products, self illumination and signaling products, and flashlights (which focus light rather than broadcast light broadly within a space). This definition leaves a manageable domain of lantern-type products for our study.

The cooking domain is also broad, as cooking encompasses many different cooking styles (see Table 4). Boiling is chosen as the required cooking style for several reasons. First, boiling cooks food evenly, which removes the need to account for this hard-to-measure metric. Second, products used for boiling food are varied, ranging from large kitchen cooktops to portable camping stoves. Boiling products are therefore a good representation of all cooking products. Lastly, boiling is a ubiquitous cooking method used throughout the world. We therefore specifically limit ourselves to studying products meeting the need of "*cook food through boiling*." The term *food boiling products* is used hereafter to refer to products meeting this need.

Table 4: Cooking Styles Classification (after [7,[8]])

Cooking Style	Primary Heat Transfer Mode	Description
1. Grilling/ Broiling	Infrared Radiation	Using direct, dry, radiated heat in an open environment to cook food.
2. Roasting/ Baking	Infrared Radiation	Using dry, radiated heat in a closed environment to cook food.
3. Sautéing	Conduction	Cooking food in a hot pan with some amount of fat.
4. Smoking	Infrared Radiation	Using radiated heat with smoke or other flavoring particles to give food a smoky flavor.
5. Frying	Convection	Immersing food in oil and heating.
6. Steaming	Convection	A wet heat method that uses water vapor to cook food, but does not soak food in water.
7. Boiling	Convection	Submersing food in boiling water.

Products neither commonly used to boil food nor intended by manufacturers for that purpose are excluded from our study.[9] These include electric kettles and conventional ovens. Selected boiling products must also convert energy into heat, since cooking involves heat generation and transfer. Therefore pots and other cookware are not treated as food boiling products but rather are considered accessories. We assume similar cookware (in terms of material and geometry) is used for boiling food on all products, and neglect a specific cookware's effect on the functional capabilities of any single boiling product.

[7] Bittman, M., 1998, *How to Cook Everything: Simple Recipes for Great Food,* Wiley.

[8] McGee, H., 1997, *On Food and Cooking,* Scribner.

9 Both solar lanterns and induction stoves are candidates for future study, but the relative rarity and expense compared to the other similar products makes these a less favorable choice for this phase of the research.

Products are found by researching local and online retailers[10]. Because our functional families include hundreds of similar products, groupings are devised for each functional family and representatives from each grouping are selected for testing.

Table 5: Classification of Mobile Lighting Products

Energy Import	Product Categories
Batteries (Chemical)	*Lantern (battery)*
Fossil Fuel	*Lantern (fuel)* Torch *Candle*
Renewable	Lantern (solar)
Chemical (non-battery)	*Lightstick* Lightning bugs Flares (for area lighting)

For mobile lighting products, we find the most effective groupings to be those based on energy domains. Table 5 shows the groupings for lanterns and highlights the representative products chosen from each group. For boiling products, we find the most effective groupings to be those used by industry. Table 6 shows the groupings for cooking products and highlights the representative products chosen from each group. Each chosen product fulfills the intended primary need and is representative of its group, but lacks unnecessary frills and features that might be considered luxuries (e.g., reputable but not professional-chef branded cooktops). This decision is made to compare product costs based on function and basic features rather than on brand names and luxury features.

[10] Including: amazon.com, epinions.com, Oshman's, Wal-Mart, Academy, and REI

Table 6: Classification of Food Boiling Products

Product Category	Representative Products
Kitchen Cooktops (or Rangetops)	*Electric Coil* *Electric Smoothtop* *Natural Gas* Electric Induction
Barbeque	*Charcoal* *Firewood*
Small Home Appliances	*Multi-Cookers* Electric Woks Electric Skillets
Microwaves	Microwave
Camping Stoves	*Propane* *Butane* *Liquid Fuel* Wood

The eleven mobile lighting products and ten food boiling products selected are shown in Figure 3 and Figure 4, respectively. Brief product descriptions are contained in Appendix B. Table 7 gives select attributes of products in the food boiling product family.

			
1: Butane Gas	**2: Propane Gas**	**3: Liquid Fuel Pump**	**4: Kerosene**
Cost: $35 Fuel: $4.50 for 3 hrs	Cost: $23 Fuel: $1.50 for 8 hrs	Cost: $38 Fuel: $0.35 for 8 hrs	Cost: $5 Fuel: $0.25 for 10 hrs

			
5: Candle Stick	**6: Candle Lantern**	**7: Paraffin Bottle**	**8: Light Stick (Grn)**
Cost: $1 for 3 hrs	Cost: $18 Fuel: $1 for 9 hrs	Cost: $2 for 19 hrs	Cost: $2 for 12 hrs

			
9: Krypton (4D Batt.)	**10: Fluorescent (6D)**	**11: LED (4D Batt.)**	
Cost: $11 Fuel: $5 for 14 hrs	Cost: $18 Fuel: $8 for 10 hrs	Cost: $40 Fuel: $5 for 40 hrs	

Figure 3: Mobile Lighting Products Selected for Empirical Study (Pictures from [11])

[11] www.coleman.com, www.outinstyle.com, www.rei.com, www.jd-therapy.co.uk, www.candleshop.com, www.ortec-products.de

Figure 4: Food Boiling Products Selected for Empirical Study (Pictures from [12])

Table 7: Select Attributes of Food Boiling Products

Product	Cost	Wt. (lb)	Vol. (gal)	Fuel Type	Fuel Cost	Burn time
1) Firewood	$0	3	6	Wood	$1.40 / 3 lb	~2 hr/ 3 lbs.
2) Charcoal	$30	11	11	Charcoal	$7 / 20 lb bag	~1.5 hr/ lb
3) Butane Piezo-ignition	$50	1.1	0.3	Butane	$2.90 / 220g can	~1.5 hr/ can
4) “White Gas” Liquid	$70	2.5	0.5	Gasoline	$3.50 / gallon	~2.5 hr/ 11 oz.
5) Two-Burner Propane	$50	13	4.5	Propane	$1.50 / 465g can	~2.5 hr/ can
6) Electric Multi-Cooker	$35	5	2.9	Electricity		
7) Microwave	$100	30	17	Electricity		
8) Electric Coil Cooktop	$300	40	98	Electricity		
9) Electric Smoothtop	$460	40	95	Electricity		
10) Gas Cooktop	$370	40	93	Natural Gas		

[12] hem.passagen.se/rfrgu/campfire.jpg, www.amazon.com, www.sears.com

3.2 Gathering Customer Needs

Correlations between usage context factors and customer preferences are studied through gathering customer needs, product attribute measurements, and customer product choice surveys. Gathering and understanding customer needs is achieved through three means: researchers experience the products through setup and usage, researchers interview potential customers one-on-one after letting them set up and use the products, and researchers review customer comments from online retailers.

In a one-on-one interview, each potential customer is asked to examine, set up, and use each product, and then comment on prompts including, "What do you like?", "What do you dislike?", and "In what situations could you envision yourself using this product?" Because of time and budget limitations, interviewed customers include both experienced and inexperienced users of each product, rather than solely experienced users. This increases dependence upon experienced users to articulate needs unfamiliar to other users, and in the researchers' opinion this dependence did not significantly degrade the aggregate needs list. Interviews are recorded in the "voice of the customer."

Customer comments from online sites such as amazon.com and epinions.com are also reviewed. These comments, along with the interview comments, are then translated into weighted needs. Needs are inferred and weighted based on a combination of how frequently a need is mentioned, how forcefully it is articulated, and the researchers' assessment of a product and its intended usage based on accumulated customer comments. Table 8 shows the customer needs list for boiling products. Customer needs for mobile lighting products are reported in (Green, et al., 2004).

Usage contexts are inferred from interviews based on questions to each customer explicitly addressing usage context. Each customer is asked to describe the environments and situations in which they would use each product. PUCs are also inferred from online customer reviews, as reviewers often explicitly mention situations where the reviewed product could be used. General usage contexts are identified and defined from these data by the researchers.

The customer needs list for food boiling products is shown in Table 8 along with the product usage contexts (PUCs) identified. Customer needs are rated on a scale of 1 to

5, with 5 indicating very high importance. Certain basic needs, such as boiling quickly and low product cost, are equally important across all PUCs. Many other needs, however, vary considerably in importance across PUCs. For example, customers wanting a food boiling product to use while backpacking mentioned compactness as very important, while customers wanting a food boiling product to use in the home kitchen show little concern for compactness.

Assigning meaningful weightings to customer needs across differing PUCs is complicated by the fact that customer perceptions of a given product are sensitive to context factors. What constitutes a “compact” product differs according to context factors such as how it will be transported, if at all. This difficulty further supports the need to properly identify relevant usage contexts before and during customer needs gathering. We assign weightings in Table 8 based on our best judgment of the collected data in order to illustrate the variation of the needs across contexts. The significance of customer preference differences by PUC is shown in more depth in results sections 4.1 and 4.2 through an exploration of the relationship of product attributes with associated context factors.

Table 8: Customer Needs for Boiling Products

Category	Customer Need	All PUCs	PUCs: 1:Backpacking	2: Camping Near Car	3: Picnic/Tailgate	4: Average Home	5: Tiny Kitchen	Attribute Metric
Cooks well	Boils quickly	**5**						s (±30)
	Maintains simmer	**4**						[Y/N]
Portable	*Compact*	→	5	4	3	2	5	m^3
	Lightweight	→	5	4	3	1	3	kg
Low cost	Low product cost	**4**						$
	Low fuel op. cost	→	3	3	3	5	5	$/L-water
Easy to use	Easy to start	**4**						[1-5]
	Easy to clean	**3**						[1-5]
	Large capacity	→	2	3	4	4	3	L
	Intuitive Controls	**5**						[1-5]
Safe	*Low fire hazard*	→	3	3	4	5	5	[1-5]
	Low burn hazard	**4**						[1-5]
	Stable to cook on	**5**						[Y/N]
Reliable	*Tolerates weather*	→	5	5	2	1	1	[1-3]
	Durable	**5**						

3.3 Measuring Product Attributes

To study the impact of usage context factors on customer preferences for product attributes, key attributes of each product are measured. *Product attribute metrics* (shown in Table 8) are defined based on the compiled customer needs lists using a house of quality style approach.

Measurements for both mobile lighting and food boiling products are obtained from a combination of manufacturer data, direct measurements, and third-party reviews. Equipment and fuel costs are taken as the average retail price from five or more retail sources.

The ranges of scales selected to quantify product attributes are chosen to approximate the resolution believed to exist in *customer perceptions*. For example, customers would be unlikely to sort products into more than three distinct groups when categorizing them by perceived burn hazard. Here we use primarily physical quantities to differentiate products, however measuring customer perceptions in future work will add a more meaningful way to distinguish products.

Mobile Lighting Product Measurement. For mobile lighting products (Figure 3), operating cost is determined by dividing the average fuel cost (determined by searching through retail and web sources) by the fuel consumption rate (determined by manufacturer specifications and experimental tests). Safety is given a rating of 1-5 based on glass, fuel, and burn hazard to user, with 5 being safest. Brightness is measured in foot-candles, *Fc,* using a light meter placed one foot from the light source[13]. Multiple measurements are taken over different days. For mass, each product is weighed using an electronic scale while fully fueled. Approximate volume is calculated from height and diameter. For products with open and closed positions, volume is taken as the compact transport volume in closed position, since this quantity best represents the compactness of the product. Run time is calculated based on three or more 20 minute burn tests, with the mass decrease of fuel used to calculate run time. If manufacturer's claims are available, these claims are compared with the measured values, and the lower value is accepted as run time.

Food Boiling Product Measurement. For food boiling products (Figure 4 and Table 7), boil time is measured using a store-bought boiling indicator. The boiling indicator is a grooved piece of metal that vibrates to indicate boiling intensity. When the boiling indicator vibrates more than four times a second, water is considered boiling, within an uncertainty of 30 seconds. Mass is measured with the product fully fueled (where applicable), and volume is taken as the smallest transport volume, including fuel bottle if applicable. Fuel cost per liter of water boiled is calculated as average fuel cost divided by calculated or third-party verified run time per unit of fuel multiplied by boil time per liter of water. Time to start is measured from start of set-up to when steady heat is provided for cooking. "Maintains simmer" is rated yes or no depending on whether a product's heat control is fine enough to maintain a low rate of boiling without boiling over. Cooking capacity is defined as the number of standard 2-4 quart pots a product can

[13] A 60W incandescent light bulb measures approximately 70 *Fc* by this testing method, and an "average" candle is ~1 *Fc*.

hold and heat simultaneously. Fire safety is rated on a scale of 1-3 based on containment and control of output fire. Burn safety is rated on a scale of 1-3 based on heat protective measures, such as warning lights and insulation. Outdoor operating ability is rated 1-3 based on a product's tested ability to work in light wind and light precipitation. Stability is measured yes or no based on cookware inclination to tip and injure the user.

3.4 Usage Contexts and Factors Identified

During customer interviews we ask customers the open-ended question, "In what situations would you consider using this product?" For the mobile lighting products, customer responses to this question may be grouped into the general usage contexts of: backpacking, camping near a car, intermittent electrical outage, heavy domestic use (no electricity), and domestic mood lighting. For the food boiling products, customer responses may be grouped into the usage contexts of: backpacking, camping near a car, picnic, average home, and small housing. We break these contexts down into factors in order to characterize the essence of each and allow for side-by-side comparison.

As shown in Table 9, the usage factors used to characterize the contexts include: storage mode, transportation, ventilation, weather, energy availability, usage frequency, and usage duty. (Identification of these factors flowed from customer statements; however, considerable judgment is still involved and future development of a common factors list will considerably reduce the likelihood of overlooking a significant factor). A specific example of each general usage context category is defined for both the lighting and boiling product families, and shown in Table 9 and coded according to the accompanying usage factor value key. The values shown are not the only context configuration possible within the general category (particularly with usage frequency and duty), but serve the purposes of this study by giving customers a clear instance of each PUC.

Table 9: Usage Contexts and Usage Factor Values Chosen for Survey

	Lighting Contexts					Boiling Contexts					
Usage Factors	**1:Backpacking**	**2: Camping Near Car**	**3: Occasional Elec. Outage**	**4: Heavy Domestic Use**	**5: Dom. Décor. & Mood**	**1:Backpacking**	**2: Camping Near Car**	**3: Picnic/Tailgate**	**4: Average Home**	**5: Tiny Kitchen (RV/Apt./Dorm)**	**Usage Factor Value Key**
Storage Mode	1	2	3	5	5	1	2	3	5	4	1=backpack, 2=car, 3=cabinet, 4=small space, 5=room
Transportation	1	2	3	3	3	1	2	2	3	3	1=foot, 2=car, 3=none
Ventilation	3	3	1	2	1	3	3	3	2	2	1=none, 2=some, 3=outdoor
Weather	3	3	1	1	1	3	3	2	1	1	1=indoor, 2=calm, 3=outdoor
Energy Avail.	1	1	1	1	2	1	1	1	2	2	1=no electricity, 2=electricity
Usage freq	1	1	1	3	2	1	1	1	3	3	1=infrequent, 2=moderate, 3=heavy
Usage Duty	1	1	1	3	2	1	1	2	3	2	1=light, 2=medium, 3=heavy

3.5 Surveying Customer Product Preferences

After identifying usage contexts based on customer comments and establishing a specific instance of each (Table 9), interactive surveys are used to determine which products customers prefer for each usage context. The interview begins with the customer using each product in one family (either lighting or boiling) and receiving data an experienced user would know about the product. For mobile lighting products this information includes: product cost, fuel type, run time, and cost per fueling (similar to what is shown in Figure 3). For food boiling products, interviewees are provided with: product cost, weight, volume, fuel type, and burn time (Table 7). The goal of having the customer experience the products and review the provided data is to educate them to a "quasi-user" level of product familiarity because so few people have adequate experience with every product in the family. Operating cost is not given directly in terms such as $/L-boiled since this information is not available to customers, but rather it is often available in terms of the cost of a purchase unit of fuel and total burn time. In order to facilitate survey logistics, customers are shown videos of full product usage from set-up through boiling for the gas cooktop and other cumbersome products.

After the interviewee becomes familiar with each product, they fill out a survey indicating which products they prefer for use in each PUC. A specific instance of each general PUC category is defined by giving a value for each context factor (Table 10). As shown in Table 11, customers then rank the strength of their preference (usage likelihood) for each product on a scale of 1-5, and then rank all products in the family in order of preference from 1-10 (with ties allowed). This process is repeated for each context.

Table 10: Survey Excerpt for "Backpacking" Context

Imagine that you need to bring water to a boil to cook food, and you are contemplating purchasing one of the products shown previously in the grid of products. Please carefully read the usage context described in the box below, and then on the rest of the page tell us how suitable you think each product is for this usage context:
Backpacking - *an outdoor adventure in which individuals carry all personal supplies in a backpack for several days or more.* Characterized by: 1. Significant travel by foot (>1 mile at a time) 2. Outdoors (well ventilated, subject to weather conditions) 3. No electricity (wood is available) 4. Lightly used (infrequent use, trips 3-14 days) 5. Users are skilled and exercise caution

Table 11: Customer Product Preference Survey

<u>Circle a number beside each product below:</u> *For the situation described above, I would:* (1) Definitely not consider using this product (2) Probably not consider use this product (3) (Undecided) (4) Probably consider using this product (5) Definitely consider using product			**Usage Likelihood (1-5)**	**Ranking (1-10)**
1) Firewood	1 2 3 4 5			
2) Charcoal	1 2 3 4 5			
3) Butane Piezo-ignition	1 2 3 4 5			
4) "White Gas" Liquid	1 2 3 4 5			
5) Two-burner Propane	1 2 3 4 5			
6) Electric multi-cooker	1 2 3 4 5			
7) Microwave	1 2 3 4 5			
8) Electric Coil Cooktop	1 2 3 4 5			
9) Electric Smoothtop	1 2 3 4 5			
10) Gas Cooktop	1 2 3 4 5			

4 RESULTS

4.1 Results: Customer Product Preferences

The survey data support part (a) of the hypothesis, indicating different product preferences for different usage contexts as shown in Table 12 and Table 13. The data include eleven surveys for the food boiling products, and fifteen for the mobile lighting products. The strength of each preference reported here is an aggregate measure of the average usage likelihood score (1-5) and the number of interviewees ranking the product in their top two choices for the usage context of interest.

Thresholds are selected to distinguish products favored by most respondents from those favored by only a few. For the usage likelihood data, an average score of 4.0 or greater is classified as a strong preference, and a score from 3.0-3.99 is classified as a weak preference. For the ranking data, products ranked first or second by 6 or more interviewees (more than 50%) are classified as a strong preference, and 3-5 top two rankings are interpreted as weakly preferred. This analysis gives similar results for usage likelihood and ranking data, indicating internal consistency and supporting survey validity.

For a number of minor differences between results from the usage likelihood and ranking data, tie-breaking is judged by the researchers to obtain the aggregate results shown here. Tie-breaking influences the rating of "strong preference" for only one boiling product, but for eight lighting products. This is consistent with the observation that the lighting functional family is more tightly defined than the boiling family, and thus exhibits less variety in product attributes. It is therefore more difficult to distinguish preferences for the lantern products under study. However, in every case if either data set indicated a strong preference for one product, the other indicated at least a weak preference for that product.

Table 12: Customer Boiling Product Preferences

Products / PUC	**1: Backpacking**	**2: Camping Near Car**	**3: Picnic/Tailgate**	**4: Average Home**	**5: Tiny Kitchen**
Firewood (1)	•	•	•		
Charcoal (2)		■	■		
Butane (3)	■	•			
White gas (4)	■	■			
Propane (5)		■	■		
Multi-cooker (6)				•	■
Microwave (7)				■	■
Electric coil (8)				■	■
Elect. Smoothtop (9)				■	•
Gas cooktop (10)				■	•
■ = strong preference; • = weak preference					

Table 13: Customer Lighting Product Preferences

Products / PUC	1: Backpacking	2: Camping Near Car	3: Occ. Elect. Outage	4: Heavy Domestic	5: Mood
Butane/Prop.(1)	•	•			
Propane (2)		■		■	
Liquid Fuel (3)		•		■	
Kerosene (4)					
Candle Stick (5)			•		■
Candle Lantern (6)	■		■	•	•
Paraffin Bottle (7)			■		■
Light Stick (8)					
Krypton Batt.(9)	•	■	■	•	
Fluorescent Batt.(10)		■	■	•	
LED (11)	•	■	■	■	
■ = strong preference; • = weak preference					

The preference survey results in Table 12 and Table 13 show that the customers surveyed have distinct product preferences for each usage context. For each context there is not unanimous agreement on one or two products, but rather a range of products is preferred. Additionally, most products show suitability for more than one context.

Some products are not strongly preferred for any context, as is seen in the boiling products with firewood (1), and in the lighting family with: butane/propane (1), kerosene (4), and the light stick (8). This lack of a strong preference for these products suggests they may have been incorrectly classified as part of the functional family for this study. For example, firewood may be sold in this country for the function of heating or aesthetics, and not cooking food by boiling. Similarly, the basic kerosene lantern used here may be preferred for nostalgia and the light stick for recreation or signaling rather than the function of "mobile lighting for visibility of other objects."

The lack of strong preference for the butane/propane piezo-ignition is more difficult to explain, since it currently exists on the market as a mobile lighting product.

This suggests that either the population surveyed does not statistically represent all customers, or that even though the average preference is weak, there are enough customers who prefer the lantern to create a profitable market segment. These above occurrences are exceptions in the data, however, and the overall results are both internally and logically consistent.

4.2 Results: Product Attributes vs. Context Factors

The results of the empirical study partially support part (b) of the hypothesis, showing that in certain cases product attributes are related to usage context factor values. Figure 5 shows product volume plotted against the dominant transportation mode of the usage contexts. (Note that if a product is strongly preferred for multiple contexts with differing transportation mode factor values, the product appears on the graph more than once). The graph does not show a pattern of clustering attributes, as might be expected, but rather a pattern of increasing maxima. The largest boiling product chosen for contexts with foot transportation has less than 10% the volume of the largest product approved for transportation by car, and less than 1% the volume of the largest product approved for contexts that do not require transportation. A similar pattern is seen for lighting products, however no difference is observed between the maxima for car transportation and "no transportation." This is not surprising since the mobile lighting functional family is defined to include only portable products. In contrast, the food boiling functional family includes both portable and non-portable products, which naturally encompass a broader range of mass and volume. The same insights derived from Figure 5 also apply to Figure 6, product mass plotted against transportation mode.

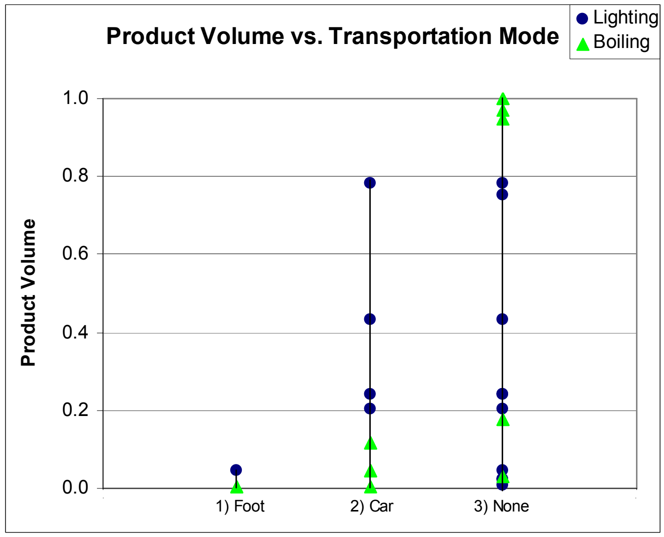

Figure 5: Product Volume vs. Transportation Mode

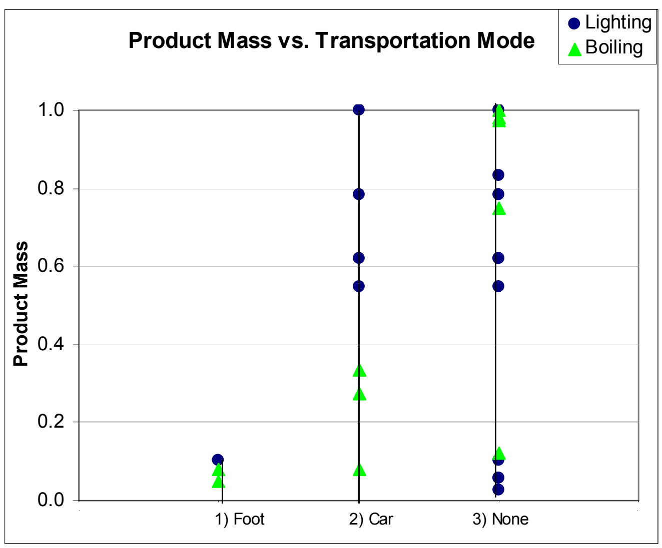

Figure 6: Product Mass vs. Transportation Mode

In contrast to the above graphs, for mobile lighting products Figure 7 does not show a clear relationship between product volume and storage mode. Boiling products are distinct between room storage (4 & 5) and smaller storage modes represented as 1-3.

Figure 8 shows maximum operating cost decreasing as usage duty increases for both lighting and boiling products. This is consistent with intuition that as usage context involves greater usage amounts, customers have a stronger preference for lower operating costs.

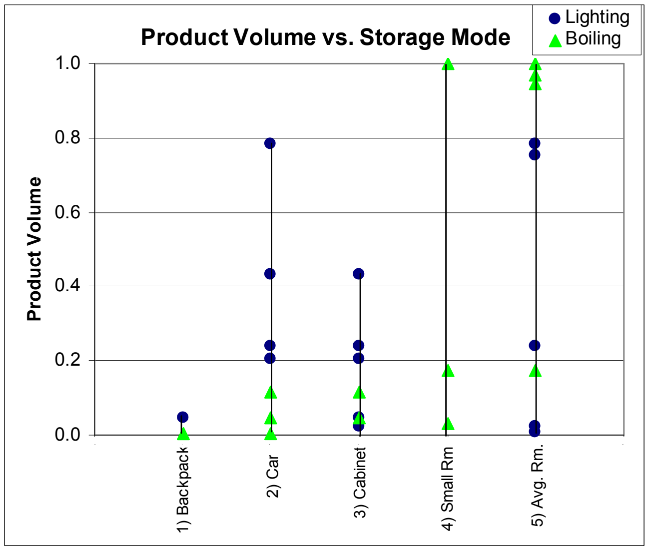

Figure 7: Product Volume vs. Storage Mode

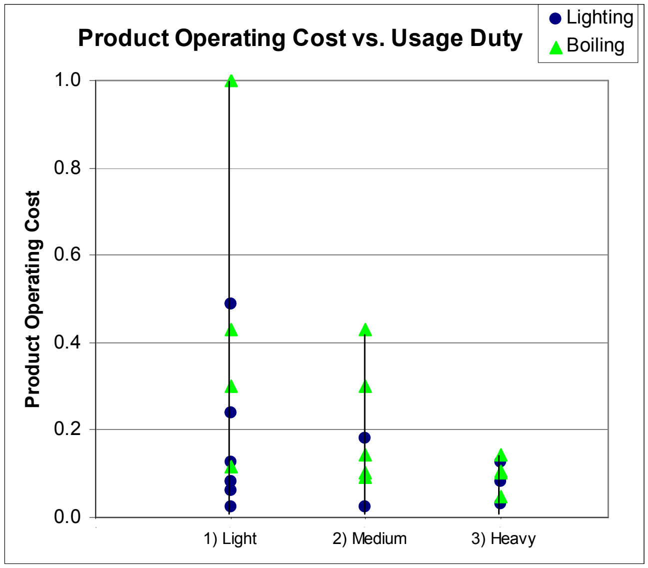

Figure 8: Product Operating Cost vs. Usage Duty

Figure 9 plots the ventilation required by products on the vertical axis against the ventilation available in various contexts. The X and Y scales are defined with a one-to-one correspondence, such that a product requiring a ventilation level of "2" is only safe in a context with an available ventilation rating of 2 or higher. Therefore, the lower right half of the graph is the "feasible space" in which available ventilation meets or exceeds product requirements. The graph shows that, for the scale intervals defined, the feasible space is fully populated. This serves as a check, since customer preference survey data does not violate the feasible space. It also shows that products do not necessarily exploit all available ventilation, as may be seen with a battery lantern (requiring no ventilation) preferred for camping near a car. Similar graphs may be shown for energy availability and weather conditions.

In all of the data showing patterns, preferred products exhibited a range of attributes for each context factor value, up to a maximum value.

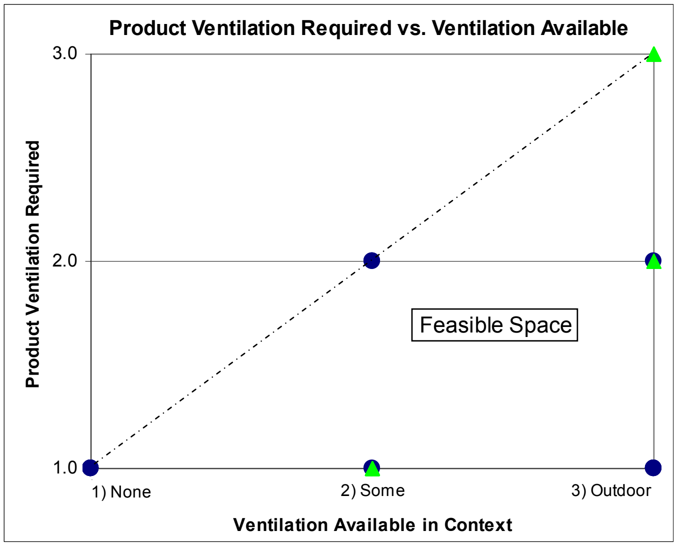

Figure 9: Product Ventilation Need vs. Available

Table 14 presents predictions of context factors driving customer preference for product attributes. Highlighted factors are those shown in this study to have strong relationships with maximum attribute values. (Note that storage is crossed out, since Figure 7 does not support the impact of storage mode upon product volume). The remaining product attributes are thought to be at least partially driven by customer factors, which are beyond the scope of this study. Note that market factors are expected to have some influence on preferences for all product attributes, in the sense that customers desire Pareto optimality in their product choice. The influence of market factors is controlled in this study by limiting customer choice to the set of products presented. Testing the hypotheses contained in Table 14 is a topic for future work.

Table 14: Context Factors Hypothesized to Drive Customer Attribute Preferences

Lighting Metrics	Usage Context factors	Customer factors
Mass w/ fuel (g)	*transportation*	
Volume (cm^3)	*transportation*, ~~storage~~	
Fuel Op. Cost ($/hr)	*usage duty*	disposable income
Weather resistance	*location - outdoor/indoor*	
Ventilation required	*ventilation available*	
Brightness (fc)	application - lighting task	functional expectations
Run Time (hr)	application	convenience expectation
Equip. Cost ($)		disposable income
User Time (s/hr)		convenience expectation
Hazard [1-5]		skill, safety expectation

Boiling Metrics	Usage Context factors	Customer factors
Mass (Kg)	*transportation*	
Volume (L)	*transportation*, ~~storage~~	
Fuel Op. Cost ($/L)	*usage duty*	disposable income
Weather resistance	*location - outdoor/indoor*	
Ventilation required	*ventilation available*	
Boil Time $\pm$ 30 (s)		convenience expectation
Product Cost ($)		disposable income
Time to Start (s)		convenience expectation
Maintains Simmer		convenience expectation
Cooking Capacity	application - meal size	convenience expectation
Fire Safety	surrounding flammability	skill & caution
Burn Safety to User		skill, safety expectation
Stable	surface available	skill, safety expectation

5 FRONTIER DESIGN: PORTABLE DENTAL CHAIR

One long-range application of this work is to increase the ability of engineers to design for frontier design contexts. As an example of this type of work, the Indigenous People's Technology & Education Center has developed "a robust, fully articulating dental chair and battery-operated hand piece, all in a package you can comfortably carry on your back" shown in Figure 10. This product is an example of frontier design, and the promotional material for the dental chair suggests some of the usage factor values which resulted in product attributes radically different from existing dental chairs.

Figure 10: Dental Chair for Remote Environments [14]

Some select features referenced in promotional statements are as follows: compact, 23 pounds, LED headlamp, solar panel, and setup time less than two minutes. The attention drawn to these features indicates the chair is targeted for customers who prioritize attributes of: compactness, lightweight-ness, high efficiency or long run time, and fast setup (convenient mobility).

Currently projects such as the portable dental chair are dependent upon the rare individual who possesses both the technical training and the in-depth insight into frontier regions required to realize such designs. Continued research into product design context is expected to greatly enhance the frequency and success of such projects.

6 Conclusions and Future Work

Customer needs analysis in product design has undergone a metamorphosis over the last three decades. Increasingly global markets and high international trade led to the infusion of the "voice of the customer" into product developers' consciousness. This concept was soon followed with quality function deployment techniques to understand the customer needs and competitors' products as quantified metrics, as opposed to qualitative statements. Yet, even with these historical and groundbreaking contributions, the process of capturing customer preferences remains ill-defined and elusive. This paper

[14] "I-TEC Portable Dental System," Accessed May 2005. www.itecusa.org/pds.htm

presents foundational data and a new construct for addressing this area, especially for product domains that include substantial latent needs and frontier design environments.

At the most basic level, we hypothesize a triad construct for understanding customer preferences: customer context factors, market context factors, and usage context factors. The first two types of context factors, customer and market, have been studied by a number of researchers across a variety of disciplines and product domains. The level of success and understanding from these studies, while varied, has been significant. The third type of context factor, usage, however, is not well defined or understood. While usage context is being recognized as an important area of research, supporting definitions, empirical data, and techniques are inadequate to support the design of an engineered product.

To support our work in specifying customer preferences with context factors, we focus on usage context, completing a parallel empirical study in two fundamental product domains: mobile lighting products and food boiling products. A systematic research methodology is developed and followed for completing the empirical study, with the goals of determining if usage contexts exist, if customers prefer different products for different contexts, and if usage contexts may be differentiated by product attributes.

The results of this methodology are exciting and illuminating. The research methodology provides not only a vehicle for testing our hypotheses, but a foundational contribution as a basic technique for identifying usage context for any product domain. Usage context becomes not merely an unknown quantity or an elusive qualitative description, but, through the methodology, a defined set of contexts each with a clear set of characteristic factors. For the specific product domains studied, we show supportable quantitative data from customer surveys and product performance tests that usage contexts are measurable and realistic. Mobile lighting products may be grouped into the usage contexts of backpacking, camping near an automobile, occasional electric outage, heavy domestic use, and domestic décor and mood setting. Food boiling products, on the other hand, include the usage contexts of backpacking, camping near an automobile, picnicking or tailgating, average home use, and tiny kitchen use.

Through the findings in this empirical study, a foundation is established for defining usage contexts, for hypothesizing the factors that vary to understand and describe different usage contexts, and for translating customer preferences to measurable product attributes. This foundation provides designers with the necessary tools to attack latent needs and frontier design environments. Significant guess work and supposition is removed in understanding the customer more fully. By so doing, we increase the likelihood for successful products and for realizing the true desires of the customer.

The significant results of this study encourage continued work. In this study we use primarily physical quantities to differentiate products, however measuring customer perceptions of product attributes in future work will add a more meaningful way to distinguish products. Additionally, measuring customer preferences for virtual products will allow exploration of a much richer product set, allowing increasingly detailed assessment of how customer preferences change with changing context factors.

References

I-TEC Portable Dental System; http://www.itecusa.org/pds.htm; May, 2005.

Belk, R. W., 1975, "Situational variables and consumer behavior," *Journal of Consumer Research,* Vol. 2, No. 3, pp. 157-164.

Cagan, J. and C. M. Vogel, 2002, *Creating Breakthrough Products: Innovation from product planning to program approval*, Prentice Hall.

Dickson, P. R., 1982, "Person-Situation: Segmentation's Missing Link," *Journal of Marketing*, pp. Vol. 46 Issue 4.

Galvao, A. B. and K. Sato, 2004, "Human-centered system architecture: A framework for interpreting and applying user needs," Salt Lake City, UT, United States. American Society of Mechanical Engineers, New York, NY 10016-5990, United States**,** pp. 487.

Green, M. G., R. P. K. Palani and K. L. Wood, 2004, "Product usage context: Improving customer needs gathering and design target setting," Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY**,** pp. 393.

Mahajan, V. and K. Banga, 2005, *The 86 Percent Solution: How to Succeed in the Biggest Market Opportunity of the Next 50 Years*, Wharton School Publishing.

Otto, K. N. and K. L. Wood, 1998, "Product evolution: A reverse engineering and redesign methodology," *Research in Engineering Design - Theory, Applications, and Concurrent Engineering,* Vol. 10, No. 4, pp. 226.

Otto, K. N. and K. L. Wood, 2001, *Product design: techniques in reverse engineering and new product development*, Prentice Hall, Upper Saddle River, NJ.

Pahl, G. and W. Beitz, 1996, *Engineering Design – A Systematic Approach,* 2nd Ed., Springer, New York.
Park, C. W., 1993, "Context Effects on Consumer Choice, Brand Awareness and Decision Making," *Advances in Consumer Research,* Vol. 20, No. 1, pp. 395-396.
Prahalad, C. K., 2004, *The Fortune at the Bottom of the Pyramid: Eradicating Poverty Through Profits*, Wharton School Publishing.
Ratneshwar, S. and A. D. Shocker, 1991, "Substitution in use and the role of usage context in product category structures," *Journal of Marketing Research,* Vol. 28, No. 3, pp. 281-295.
Stefflre, V., 1971, *New Products and New Enterprises: A report of an Experiment in Applied Social Science*, University of Ca., Irvine, Irvine.
Ullman, D. G., 2002, *The mechanical design process,* 3rd Ed., McGraw-Hill, Boston, Mass.
Ulrich, K. and S. Eppinger, 2004, *Product Design and Development,* 3rd Ed., McGraw-Hill, New York.
Warlop, L. and S. Ratneshwar, 1993, "The Role of Usage Context in Consumer Choice: A Problem Solving Perspective," *Advances in Consumer Research,* Vol. 20, No. 1, pp. 377-382.

Appendix B: Product descriptions

The eleven mobile lighting products selected for study are shown in Figure 3, and have the following characteristics: (1) The butane/propane gas lantern is a compact, lightweight lantern that uses pressurized butane gas mixture. A bright, yellow flame is given off through a frosted white glass cover. It comes with a piezoelectric lighter (all other fuel lighting products are match lit). Brightness is continuously adjustable. (2) The propane gas lantern is a screw-on bottle that releases gas into the mantles, where it burns with a bright, yellow-white flame. The user lights the flame with a match. Brightness has limited adjustability. (3) The liquid fuel pump-up uses liquid fuel poured into the base and is pressurized using the built-in hand pump. The fuel vaporizes inside an ash bulb (mantle) where it burns with a bright, yellow-white flame. Brightness has limited adjustability. (4) The kerosene lantern is hollow and lightweight. An adjustable wick draws kerosene up from the base for a controlled burn. (5) The candle is a long burning, low-drip candle. (6) In the candle lantern a spring advances the candle into a glass shielded burn chamber for better all-weather performance. The shield nestles inside the base to decrease the candle stowage volume. (7) The paraffin bottle is a recycled bottle with a wick through a hole in the lid and is filled with 99% pure paraffin for clean burning. (8) The light stick (green) is a chemical light stick that emits a soft green light when user snaps it. The light gradually wears down. (9) The battery—krypton bulb lantern is rugged and almost water-proof; a krypton bulb casts a soft, pleasant glow through the frosted white cover. (10) In the battery--florescent lantern two bright 4 Watt fluorescent tubes are independently controlled for two brightness settings. (11) The battery—LED lantern uses 12 LED's powered by four D batteries. Brightness is continuously adjustable.

The ten food boiling products selected for study are shown in Figure 4, and have the following characteristics: (1) Firewood is a campfire of birch, mahogany, or other suitable wood inside a small hole lined with rocks or in some other suitable container and used to cook food. (2) The charcoal product is a small, no-frills aluminum charcoal grill. Charcoal is brand-name (Kingsford) from Wal-Mart. (3) The butane gas piezo-ignition product is a palm-sized, foldable stove that comes with a piezoelectric lighter and uses a screw-on canister of butane fuel mixture. (4) The White gas liquid stove is a foldable stove that attaches to fuel bottles of various sizes. Manual pumping pressurizes the liquid gasoline-like fuel. (5) The two-burner propane product is a foldable briefcase-sized stove that can use either a screw-on propane canister or a large propane tank. (6) The electric multi-cooker is an electric appliance with heating elements incorporated into the bottom of a pot. A temperature knob and thermostat control heat output. (7) The microwave is a commercial mid-sized, over-the-counter microwave with mid-level heat output (900-1300W). (8) The electric coil cooktop is a kitchen cooktop that uses electric coil burners. (9) The electric smoothtop is a kitchen cooktop that uses coil burners situated under a glass surface for easy surface cleaning. (10) The gas cooktop is a kitchen cooktop that uses piped-in natural gas.

Bibliography

1986, "Chapter 23: International Market Research," *Consumer Market Research Handbook* (R. Worcester and J. Downham, Eds.).

Appropriate Technology Library; http://villageearth.org/pages/AT_Library/index.htm; December, 2005.

Basic Utility Vehicle – Institute for Affordable Transportation Homepage; http://www.drivebuv.org; May, 2005.

Engineering Ministries International Homepage; http://www.emiusa.org/; November, 2005.

Engineers for a Sustainable World Homepage; http://www.esustainableworld.org/; November, 2005.

Engineers without Borders Homepage; http://www.ewb-usa.org/; November, 2005.

I-TEC Portable Dental System; http://www.itecusa.org/pds.htm; May, 2005.

Inclusive Design Homepage; http://www.eng.cam.ac.uk/inclusivedesign/; October, 2005.

L.E.G.S. Homepage; http://www.letu.edu/legs; May, 2005.

Rehabilitation Engineering and Assistive Technology Society of North America Homepage; http://www.resna.org; May, 2005.

Ann, E., 2003, "Cultural Differences Affecting User Research Methods in China," *National Educational Conference, Industiral Design Society of North America (IDSA)*, New York.

Barnes, D. F., K. Openshaw, K. R. Smith and R. v. d. Plas, 2002, *What Makes People Cook with Improved Biomass Stoves? a Comparative International Review of Stove Programs*, World Bank technical paper; no. 242. Energy series, World Bank.

Bartlett, J. P., 2002, "Learning Engineering Pedagogy from the Master Teacher," *Proceedings of the 2002 Christian Engineering Education Conference*, Montreal, Que. Available: http://engr.calvin.edu/ces/ceec/2002/mainProceedings.doc.

Bayus, B. L., 2006, "Understanding Customer Needs," *Blackwell Handbook of Technology and Innovation Management* (S. Shane, Ed.), Blackwell Publishers, Cambridge, MA, *forthcoming*.

Belk, R. W., 1975, "Situational Variables and Consumer Behavior," *Journal of Consumer Research,* Vol. 2, No. 3, pp. 157-164.

Bettman, J., M. Luce and J. Payne, 1998, "Constructive Consumer Choice Processes," *Journal of Consumer Research,* Vol. 25, No. 3, pp. 187-217.

Beyer, H. and K. Holtzblatt, 1998, *Contextual Design: Defining Customer-Centered Systems*, Morgan Kaufman Publishers, San Francisco.

Bittman, M., 1998, *How to Cook Everything: Simple Recipes for Great Food*, Wiley.

Bittner, K. and I. Spence, 2003, *Use Case Modeling*, Addison-Wesley, Boston.

Bødker, S., 2000, "Scenarios in User-centered Design - Setting the Stage for Reflection and Action," *Interacting with Computers,* Vol. 13, pp. 61-75.

Cagan, J. and C. M. Vogel, 2002, *Creating Breakthrough Products: Innovation from Product Planning to Program Approval*, Prentice Hall, NJ.
Chakrabarti, A., S. Morgenstern and H. Knaab, 2004, "Identification and Application of Requirements and Their Impact on the Design Process: A Protocol Study," *Research in Engineering Design,* Vol. 15, No. 1, pp. 22.
Chen, C.-H., L. P. Khoo and W. Yan, 2003, "Evaluation of Multicultural Factors from Elicited Customer Requirements for New Product Development," *Research in Engineering Design,* Vol. 14, No. 3, pp. 119.
Clarkson, P. J., J. Ward, P. Buckle, D. Stubbs and R. Coleman, 2004, "Designing for Patient Safety: A Review of the Effectiveness of Design in the UK Health Service," *ASME Design Theory and Methodology Conference*, Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY.
Conley, C. V., 2005, "Contextual Research for New Product Development," *The PDMA Handbook of New Product Development* (K. B. Kahn, Ed.), Wiley, Vol. Hoboken, New Jersey.
Courage, C. and K. Baxter, 2005, *Understanding Your Users: A Practical Guide to User Requirments Methods, Tools, and Techniques*, Morgan Kaufmann, San Francisco, CA.
Cox, D., S. Koshti, B. Jackson, A. Malish, M. Numan and D. Shipley, 1999, "Design of an Assistive Bowling Device," *Proceedings of the Rehabilitation Engineering Society of North America Annual Conference*.
Crawley, K., R. Holland and S. Gitonga, 2001, "Design, Development, and Marketing of Solar Lanterns," *Development by Design: 1st International Conference on Open Collaborative Design of Sustainable Innovation*, Boston, MA.
Dai, Z. and M. J. Scott, 2004, "Product Platform Design Through Sensitivity Analysis and Cluster Analysis," *ASME Design Theory and Methodology Conference*, Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY.
Dickson, P. R., 1982, "Person-Situation: Segmentation's Missing Link," *Journal of Marketing*, pp. Vol. 46 Issue 4.
Donaldson, K., 2002, "Recommendations for Improved Development by Design," *Development by Design: 2nd International Conference on Open Collaborative Design of Sustainable Innovation*, Bangalore, India.
Donaldson, K. and S. Sheppard, 2001, "Modification of a Methodological Design Tool for the Developing Country Scenario: A Case Study in Product Definition," *ICED01 13th International Conference for Engineering Design*, Glasgow, Scotland. Professional Engineering Publishing, pp. 505-512.
Donaldson, K. M., K. Ishii and S. D. Sheppard, 2004, "Customer Value Chain Analysis," *ASME Design Engineering Technical Conference*, Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY.
Donaldson, K. M. and S. D. Sheppard, 2004, "Approaches to Product Design in Kenya: Is Design Practice Universal?" *ASME Design Engineering Technical Conference*, Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY.
Eggert, R. J., 2005, *Engineering Design*, Prentice Hall, Upper Saddle River.
Ellsworth, K., S. Magleby and R. Todd, 2002, "A Study of the Effects of Culture on Refrigerator Design: Towards Design for Culture," *ASME Design Theory and*

Methodology Conference., Montreal, Que., Canada. American Society of Mechanical Engineers, New York, NY. Paper No: DETC 2002/EDC-34383.
Franke, H.-J., 1975, “Methodische Schritte beim Klären konstruktiver Aufgabenstellungen,” *Konstruction,* Vol. 27, pp. 395-402.
Galvao, A. B. and K. Sato, 2004, "Human-centered System Architecture: A Framework for Interpreting and Applying User Needs," *ASME Design Engineering Technical Conferences*, Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY.
Gershenson, J. A., 1995, "Incorporation of Life Cycle Requirements Into the Product Definition Process," *PhD Dissertation,* Mechanical Engineering, University of Idaho,
Gershenson, J. K. and L. A. Stauffer, 1999, “Taxonomy for Design Requirements from Corporate Customers,” *Research in Engineering Design - Theory, Applications, and Concurrent Engineering,* Vol. 11, No. 2, pp. 103.
Green, M. G., C. Anderson, C. Nguyen and S. Samad, 2000, "Switch Activated Ball Thrower," *Proceedings of the Rehabilitation Engineering Society of North America Annual Conference*, Orlando, FL.
Green, M. G., A. Dutson, K. L. Wood, R. B. Stone and D. A. McAdams, 2002, "Integrating Service-Oriented Design Projects in the Engineering Curriculum," *ASEE Annual Conference*, Montreal, Quebec. American Society for Engineering Education.
Green, M. G., J. S. Linsey, C. C. Seepersad and K. L. Wood, 2006, "Design for Frontier Environments: A Novel Methodology and Results of Classroom Integration," *ASEE Annual Conference*. American Society for Engineering Education, *in preparation.*
Green, M. G., R. P. K. Palani and K. L. Wood, 2004a, "Product Usage Context: Improving Customer Needs Gathering and Design Target Setting," *ASME Design Engineering Technical Conferences*, Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY.
Green, M. G., J. Tan, J. S. Linsey, C. C. Seepersad and K. L. Wood, 2005, "Effects of Product Usage Context on Consumer Product Preferences," *ASME Design Theory and Methodology Conference*, Long Beach, CA. American Society of Mechanical Engineers, New York, NY.
Green, M. G., K. L. Wood, S. H. VanderLeest, F. T. Duda, C. Erikson and N. Van Gaalen, 2004b, "Service-Learning Approaches to International Humanitarian Design Projects: A Model Based on Experiences of Faith-Based Institutions," *ASEE Annual Conference*, Salt Lake City, UT. American Society for Engineering Education.
Hauge, P. L., 1993, "Enhancing the Elicitation of Customer Requirements," *MS Thesis,* Mechanical Engineering, University of Idaho,
Hauge, P. L. and L. A. Stauffer, 1993, "ELK: a Method for Eliciting Knowledge From Customers," *ASME Design Engineering Technical Conferences*. American Society of Mechanical Engineers, New York, NY.
Hölttä-Otto, K., 2005, "Modular Product Platform Design," *PhD Dissertation,* Helsinki University of Technology, Helsinki.

Hubka, V. and W. E. Eder, 1988, *Theory of Technical Systems*, Springer, Berlin.
Hull, E., K. Jackson and J. Dick, 2002, *Requirements Engineering: A Structured Project Information Approach*, Springer-Verlag London, Great Britain.
Jensen, D. L. and K. L. Wood, 2000, "Incorporating Learning Styles to Enhance Mechanical Engineering Curricula by Restructuring Courses, Increasing Hands-on Activities, and Improving Team Dynamics," *Proceedings of the 2000 ASME International Mechanical Engineering Congress and Expo.*, Orlando, Florida.
Khudhair, A., M. Farid, N. Ozkan and J. Chen, 2002, "Thermal Performance and Mechanical Testing of Gypsum Wallboard with Latent Heat Storage," *International Conference and 4th Experts Meeting on Thermal Energy Storage Technologies*, Indore, India.
Kurakawa, K., 2004, "A Scenario-driven Conceptual Design Information Model and its Formation," *Research in Engineering Design,* Vol. 15, No. 2, pp. 122.
Kurakawa, K. and H. Tanaka, 2004, "Effects of a Scenario-based Design Information Model on Design Activities," *ASME Design Theory and Methodology Conference*, Salt Lake City, UT, United States. American Society of Mechanical Engineers, New York, NY.
LaFleur, R. S., 1992, "Principal Engineering Design Questions," *Research in Engineering Design - Theory, Applications, and Concurrent Engineering,* Vol. 4, No. 2, pp. 89-100.
Mahajan, V. and K. Banga, 2005, *The 86 Percent Solution: How to Succeed in the Biggest Market Opportunity of the Next 50 Years*, Wharton School Publishing.
Maier, J. R. A. and G. M. Fadel, 2002, "Comparing Function and Affordance as Bases for Design," *ASME Design Theory and Methodology Conference*, Montreal, Que., Canada. American Society of Mechanical Engineers, New York, NY.
McGee, H., 1997, *On Food and Cooking*, Scribner.
Merriam-Webster; Merriam-Webster On-Line Dictionary; http://www.m-w.com; January 29, 2002.
Norman, D., 2002, *The Design of Everyday Things*, Basic Books, New York.
Otto, K. N. and K. L. Wood, 1998, "Product Evolution: A Reverse Engineering and Redesign Methodology," *Research in Engineering Design - Theory, Applications, and Concurrent Engineering,* Vol. 10, No. 4, pp. 226.
Otto, K. N. and K. L. Wood, 2001, *Product Design: Techniques in Reverse Engineering and New Product Development*, Prentice Hall, Upper Saddle River, NJ.
Pahl, G. and W. Beitz, 1996, *Engineering Design – A Systematic Approach,* 2nd Ed., Springer, New York.
Park, C. W., 1993, "Context Effects on Consumer Choice, Brand Awareness and Decision Making," *Advances in Consumer Research,* Vol. 20, No. 1, pp. 395-396.
Prahalad, C. K., 2004, *The Fortune at the Bottom of the Pyramid: Eradicating Poverty Through Profits*, Wharton School Publishing.
Ratneshwar, S. and A. D. Shocker, 1991, "Substitution in Use and the Role of Usage Context in Product Category Structures," *Journal of Marketing Research,* Vol. 28, No. 3, pp. 281-295.

Rounds, K. S. and J. S. Cooper, 2002, “Development of Product Design Requirements Using Taxonomies of Environmental Issues,” *Research in Engineering Design - Theory, Applications, and Concurrent Engineering,* Vol. 13, No. 2, pp. 94.

Shimek, M., M. Van Wie, S. Kothawade, R. Subrahmanyam and M. Escobar, 2001, "An Assistive Technology Key Turning Device For Independent Entryway Access," *Proceedings of the Rehabilitation Engineering Society of North America Annual Conference*, Reno, NV.

Squires, S. and B. Byrne, Eds., 2002, *Doing the Work: Customer Research in the Product Development and Design Industy*, Creating Breakthrough Ideas: The Collaboration of Anthropologists and Designers in the Product Development Industry, Bergin and Garvey, Westport, Conn.

Stefflre, V., 1971, *New Products and New Enterprises: A report of an Experiment in Applied Social Science*, University of Ca., Irvine, Irvine.

Sutinen, K., G. Gustafsson and J. Malmqvist, 2004, "Computer Support for Requirements Management in an International Product Development Project," *ASME Design Engineering Technical Conference*, Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY.

Takai, S. and K. Ishii, 2004, "Testing Subjective Bias in the Analysis of the Customer Needs," *ASME Design Theory and Methodology Conference*, Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY.

Ullman, D. G., 2002, *The mechanical design process,* 3rd Ed., McGraw-Hill, Boston, Mass.

Ulrich, K. and S. Eppinger, 2004, *Product Design and Development,* 3rd Ed., McGraw-Hill, New York.

Urban, G. and J. Hauser, 1993, *Design and Marketing of New Products,* 2nd Ed., Prentice-Hall, Upper Saddle River.

Urban, G. and J. Hauser, 2004, “Listening In to Find and Explore New Combinations of Customer Needs,” *Journal of Marketing,* Vol. 68, pp. 72-87.

Van Der Vegte, W., Y. Kitamura, Y. Koji and R. Mizoguchi, 2004, "Coping with Unintended Behavior of Users and Products: Ontological Modelling of Product Functionality and Use," *ASME Design Engineering Technical Conference*, Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY.

Warlop, L. and S. Ratneshwar, 1993, “The Role of Usage Context in Consumer Choice: A Problem Solving Perspective,” *Advances in Consumer Research,* Vol. 20, No. 1, pp. 377-382.

Werner, D., 1987, *Disabled Village Children: A Guide for Community Health Workers, Rehabilitation Workers, and Families*, Healthwrights, Palo Alto, CA. Available: http://www.healthwrights.org/books/disabledvch.htm.

Werner, D., 1998, "Introduction 2 - Disabled Persons as Leaders in the Problem-Solving Process," *Nothing About Us Without Us: Developing Innovative Technologies For, By and With Disabled Persons*, Healthwrights, Palo Alto, CA. Available: http://www.healthwrights.org/books/nothingabout.htm.

Young, R. R., 2004, *Requirements Engineering*, Artech House, Norwood, MA.

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