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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 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

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[2] Definitions of key terms are collected in Appendix A for reference.

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*[2] 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)

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 [1]. 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 [2]). 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) [3]. 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.

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[3]. 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 [5]. 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 (e.g. [2,6,7,8,9]), 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 [2], "understanding the problem" [6,8], "clarification of task" [7], 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 first phase of the design process

[2] Changes in the market climate over time lead to changes in customer needs.

[3] 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.

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 [10]. 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 [8], and Otto and Wood [6] 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 [9]. 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 context [11], while Park states that consumer research often incorrectly assumes consumer consumption to be "independent of usage situations" [12].

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 [13] 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.

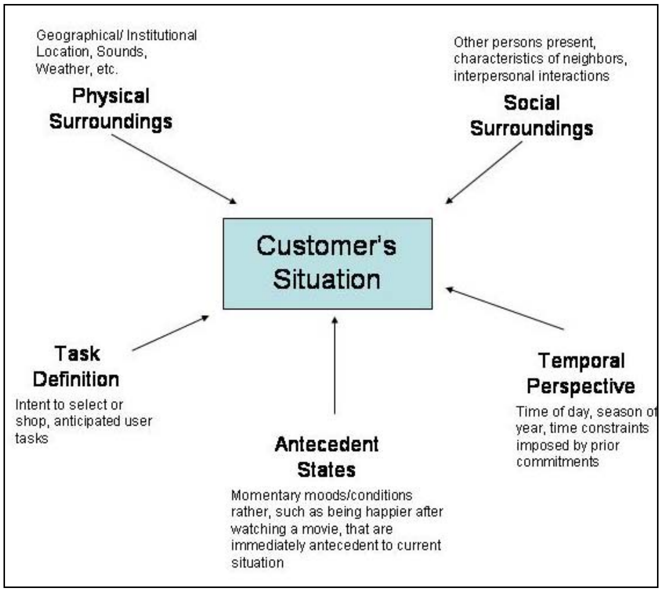


Figure 1: Situational Variables Affecting Customer Choice According to Belk [11]

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 [14]. 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 [15]. 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 [16]. 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." [17]. 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 [18] 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.

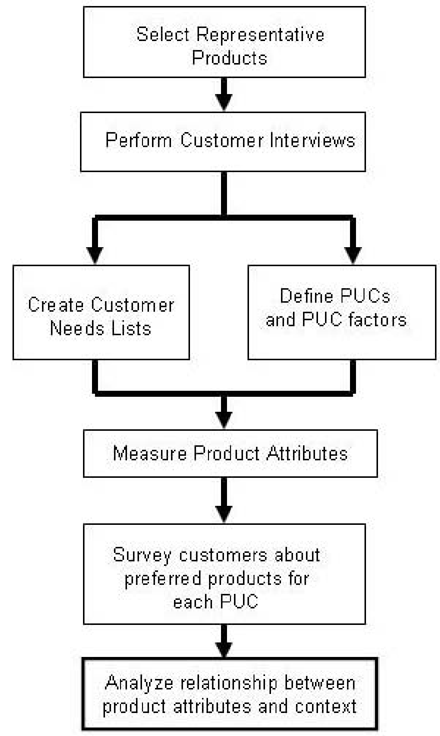


Figure 2: PUC Exploration Methodology

3.1 <u>Selecting Products for the Empirical Study</u>

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 [19,20])

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.[4] 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.

Products are found by researching local and online retailers[5]. 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.

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.

[4] 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.

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

					
1: Butane Gas	**2: Propane Gas**	**3: Liquid Fuel Pump**	**4: Kerosene**	**5: Candle Stick**	**6: Candle Lantern**
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	Cost: $1 for 3 hrs	Cost: $18 Fuel: $1 for 9 hrs
					
7: Paraffin Bottle	**8: Light Stick (Grn)**	**9: Krypton (4D Batt.)**	**10: Fluorescent (6D)**	**11: LED (4D Batt.)**	
Cost: $2 for 19 hrs	Cost: $2 for 12 hrs	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 [21])

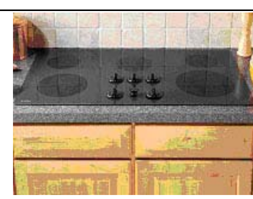
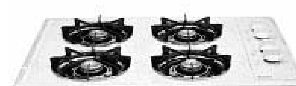
				
1: Firewood	**2: Charcoal**	**3: Butane Piezo-ignite**	**4: "White Gas" Liquid**	**5: Two-burner Propane**
				
6: Electric multi-cooker	**7: Microwave**	**8: El. Coil Cooktop**	**9: El. Smoothtop**	**10: Gas Cooktop**

Figure 4: Food Boiling Products Selected for Empirical Study (Pictures from [22])

Table 7: Select Attributes of Food Boiling Products

Product	Product Cost	Weight (lb)	Volume (gal)	Fuel Type	Fuel Cost	Burn time (if applicable)
1) Firewood	$0	3	6	Wood	$1.40 / 3 lb	~2 hr per 3 lbs.
2) Charcoal	$30	11	11	Charcoal	$7 / 20 lb bag	~1.5 hr per lb
3) Butane Piezo-ignition	$50	1.1	0.3	Butane	$2.90 / 220g can	~1.5 hr per can
4) "White Gas" Liquid	$70	2.5	0.5	Gasoline	$3.50 / gallon	~2.5 hr per 11 oz.
5) Two-Burner Propane	$50	13	4.5	Propane	$1.50 / 465g can	~2.5 hr per 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		

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[6].

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.

[6] Customer needs for mobile lighting products are reported in [10].

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[7]. 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 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.

[7] A 60W incandescent light bulb measures approximately 70 *Fc* by this testing method, and an "average" candle is ~1 *Fc*.

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

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			

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.

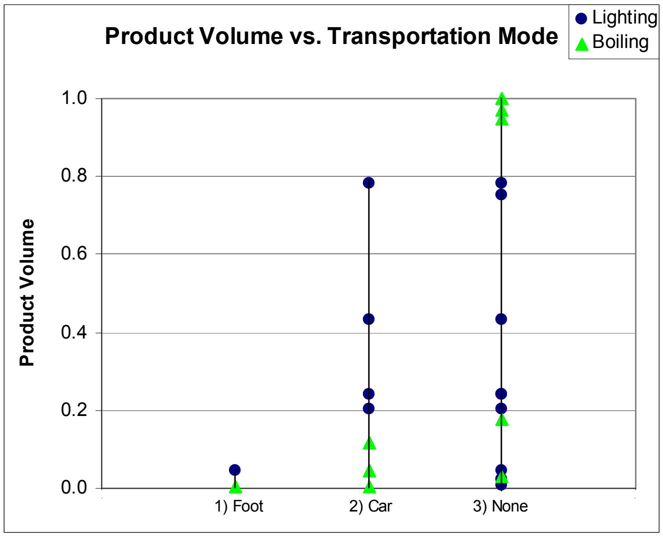


Figure 5: Product Volume vs. Transportation Mode

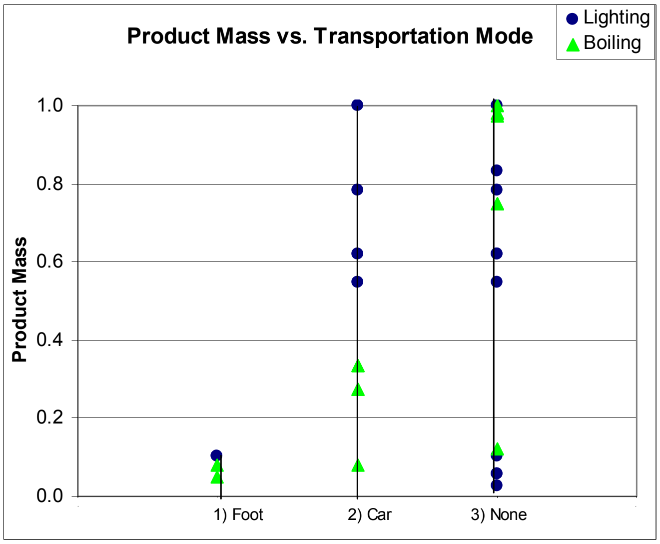


Figure 6: Product Mass vs. Transportation Mode

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.

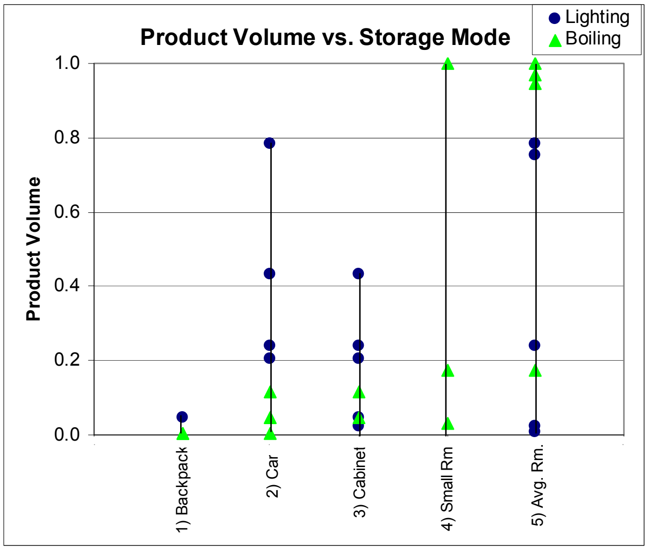


Figure 7: Product Volume vs. Storage Mode

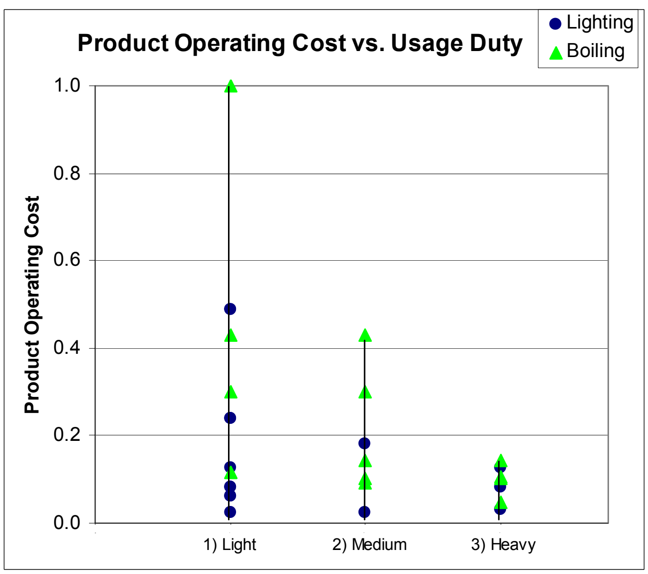


Figure 8: Product Operating Cost vs. Usage Duty

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.

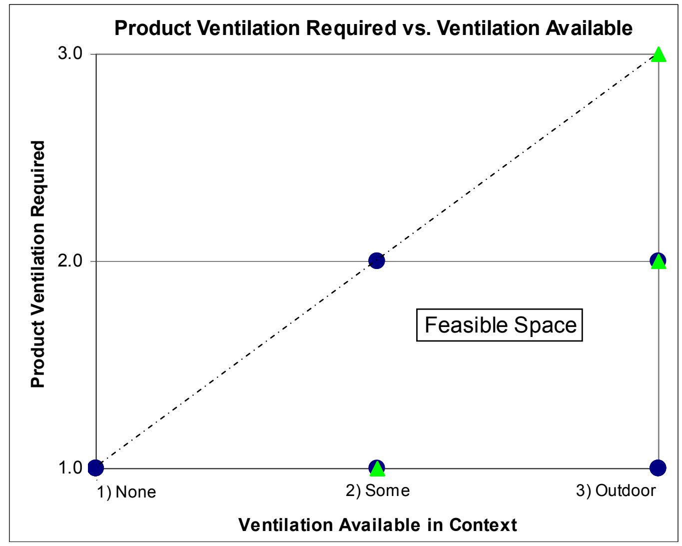


Figure 9: Product Ventilation Need vs. Available

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 ($/L)	*usage duty*	disposable income
Weather resistance	*location - outdoor/indoor*	
Ventilation required	*ventilation available*	
Boil Time ± 30 (s)		convenience expectation
Product Cost ($)		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 [23]

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 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.

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The late John W. Jensen, friend and classmate of the first author, died in an avalanche on March 6th, 2005. He was an avid outdoorsman, and provided critical advice on lighting product selection and customer needs. John has gone on to a better place, and he will be missed.

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APPENDIX A: 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

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.