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FRONTIER DESIGN: A PRODUCT USAGE CONTEXT METHOD

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ABSTRACT:
The need exists to develop foundational knowledge, methods, and tools to equip engineers in discovering, documenting, and acting upon contextual information important for successful product design. In response to this need, this paper addresses a gap in current design methodologies which inadequately support accounting for contextual information. Adequately 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. Based on a classification framework, literature search, and empirical study, a contextual needs assessment methodology is presented to assist the designer in discovering and documenting the "how," "where," and "who" factors of the product context. Experimental assessments and an application of the approach to an inventive product design provide both quantitative and qualitative measures of the usability, usefulness, and designer acceptance of the proposed contextual needs assessment method. Additionally, anonymous surveys report equal or greater perceived value of the new method for student design projects when compared with the benchmark of well-established methodologies such as black box and activity diagrams. These exciting results provide strong justification for the widespread dissemination of the methodology in education as well as in field practice.

KEY WORDS: Customer needs gathering, problem definition, product definition, contextual design, service learning

1. INTRODUCTION

The central hypothesis of this research 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 improved contextual understanding will lead to improved final designs. The primary contribution of this paper is the proposed contextual needs assessment method, which significantly extends the prior art of customer needs analysis by providing explicit support for discovering, documenting, and acting upon contextual information. Within this new methodology a half-dozen context identification approaches are proposed, by far the most significant of which is a generalized context questions template (Appendix A). Summary results are presented from extensive testing of the new method in a variety of design situations.

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[1]. 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 upon the context[2]. Since product designers rarely dictate the context surrounding products, it is necessary to understand and account for context in the design process.

In the following sections, the concept of context, as part of the design process, is defined and a method for systematically gathering contextual information, in conjunction with customer needs, is described. This method is based on our previous work (Green, 2005; Green, et al., 2006; Green, et al., 2004;

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

[2] Formally, Product Utility = f(product attributes, context factors) where f() is a model of user preferences.

Green, et al., 2005) and includes a foundation from the results of empirical product studies. We then present results from experimental assessment of the method. These assessments were performed at The University of Texas within the undergraduate and graduate design curricula. We also demonstrate the utility of the method on the inventive design of a novel classroom device for students in China. Both the assessment results and the design application provide clear evidence of the method's value.

2. A FRAMEWORK FOR CONTEXT

2.1 Definitions

The following definitions provide insight into the meaning of context:

> ***Context****: That which surrounds, and gives meaning to, something else.*[3]
>
> ***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.*[4]
>
> ***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*[5]
>
> ***Environment*** *(a): the circumstances, objects, or conditions by which one is surrounded*[5]

The first definition of context includes both surroundings and provision of meaning as elements of the definition. The second two definitions separate these two aspects of the definition, 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 paper is a blend of the four above:

> *Context* – the circumstances and setting in which an object occurs, and which influence its value.

In addition to the definition of context above, the definitions shown in Table 1 are also important in the discussions that follow.

2.2 Cases for Design Context: Mobility/Cooking 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). Table 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.

The importance of design context is evidenced both in successful products with attributes that match context, as well as in failed products which do not address critical context factors. Barnes, et al. (2002), present data from a World Bank review of numerous programs that introduced improved village cooking systems in a variety of countries. Out of 16 major reasons commonly causing the failure (or success) of a stove program, 8 of the reasons appear to be directly tied to how well context is understood and addressed (Table 15).

- *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.

Table1: Context Related Definitions

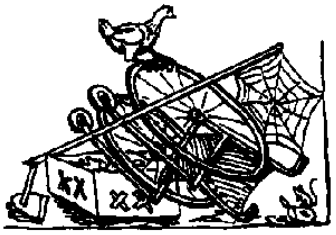


Figure 1: Wheelchairs Must Fit the Context to be Satisfactory (Werner, 1998)

[3] http://www.swif.uniba.it/lei/foldop/foldoc.cgi?context Free On Line Dictionary Of Philosophy 3.0

[4] The American Heritage® Dictionary of the English Language, 4th Ed. 2000, Houghton Mifflin.

[5] http://www.m-w.com/cgi-bin/dictionary

2.3 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 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 (2005). 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.

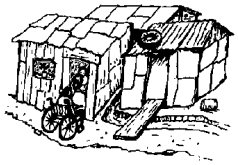
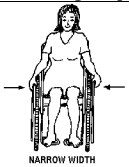
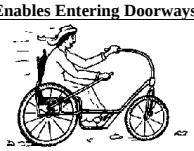
Design Need Context	Context-Appropriate Product
 Meals Cooked Low to the Ground	 Enables Reaching the Pot
 Steep, Hilly Terrain	 Enables Traversing Steep Terrain
 Narrow Doorways	 Enables Entering Doorways
 Rocky Terrain	 Enables Traversing Rocky Terrain

Table 2: Different Mobility Products for Different Contexts (Werner, 1998)

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 influences on customer needs and preferences will improve the success of the product definition phase in defining products that satisfy and delight customers.

2.4 The Design Context Framework

In view of the need for improved contextual understanding, a *product design context* framework is desirable for handling contextual information. 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 3): (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, as derived from product empirical studies, are reported in (Green, et al., 2004; 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 these methods with the addition of activity diagram techniques (Otto and Wood, 2001) do not provide adequate support for accurately discovering, documenting, and applying usage context information.

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 • . . .

Table 3: Product Design Context Categories

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 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. 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 4 shows examples of differences in usage context which dramatically impact customer expectations of product attributes. Table 5 illustrates how usage factors such as storage mode or transportation mode impact customer preferences for attributes such as volume and mass.

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 4: Examples of PUC Differences

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

Table 5: Sample Usage Context Factors and Attribute Preferences Impacted

3. LITERATURE REVIEW

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.

Numerous authors reference the influence of context on product design, and many explicitly express its importance. 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).

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.

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.

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."

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 market differences, without unnecessarily foregoing the economies of scale realizable through standardization.

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.

A chapter on international market research (Worcester and Downham, 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.

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.

4. CONTEXTUAL NEEDS ASSESSMENT METHOD

4.1 Types of Design Needs, Contextual Needs Assessment

Successful design requires an adequate understanding of the context of the design need, and attaining this understanding is much more difficult for some design needs than others. Table 6 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. The greater the difficulty of the needs

assessment task, the greater the need (and benefits expected) for the methodology proposed here.

	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?

Table 6: Assessing the Difficulty of Adequate Contextual Needs Assessment

One additional indicator[6] of needs assessment difficulty which is not directly referenced above is the accessibility of existing products that already address a similar 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 7. 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[7] way with the customers who will use the product.

The map in Table 7 shows four quadrants, along with the position of four product development scenarios to which the proposed contextual needs assessment method is applied for validation and refinement. The "PersonaWarmth" design example is a personal warming device for university students in China. Although interviews are 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 design of enabling devices for high school students with physical and mental disabilities. Although the design teams are able to experience the usage environment and interview experts (teachers), communication with the students who will use the devices is often extremely limited due to their impaired communication abilities. The "controlled interviews" 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 testing the proposed methodology 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 are generally able to interview actual users of the products in the intended context. The contextual needs assessment method presented in this section addresses design problems falling in all four quadrants; however, the method is most critical for the leftmost quadrants and particularly the upper-left quadrant.

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

Table 7: Frontier Contexts 2D Map

4.2 Contextual Needs Assessment

The generalized procedure for contextual needs assessment is shown in Figure 2 and detailed in the following sections. The method accommodates the inclusion of 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 2: Contextual Needs Assessment Method

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 in the following section. Step (2) is more straightforward to accomplish, and involves 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). In cases without accessibility to a comparable physical product, these techniques may be modified to interview customers with their imagined products. If suitable customers are inaccessible, secondary sources of customer information must be used with caution. 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

[6] Other difficulty factors are possible as well, such as design need complexity and variability with time.

[7] Examples of barriers include geography, language/cultural differences, and communication disability.

of these five steps, and Appendix A contains supporting templates.

4.2.1 Identify Relevant Contextual Factors

It is useful to begin contextual needs assessment by forming a list of context 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 significant judgment is required to predict the relevance of contextual factors. The key is to identify factors that have a *probable importance to appropriately satisfying the design need*. For a mobile pencil sharpener, for example, the usage altitude does not meet the criteria of probable importance, the safety expectations of the user may be important, and the type and characteristics of pencils used are clearly important.

Contextual factors should also be listed with an *appropriate level of detail*. The fact that the 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. Predicting the appropriate level of detail also requires significant judgment.

Table 8 itemizes techniques for identification of important and appropriately detailed contextual factors. The techniques are roughly ordered from the least to most resource intensive. The following sections discuss each of these context factor identification techniques in more detail.

- 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

Table 8: Context Factor Identification Techniques

Use context factor checklists, such as the template provided (App. A): 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 be applied to identify contextual factors for the purpose of contextual needs assessment. Table 9 shows a partial checklist for the purpose of identifying contextual factors common to consumer products (the full version, developed as part of this research, is in Appendix A). The checklist includes generalized elicitation questions designed for use in step 2 of the contextual needs assessment methodology (Figure 2). The contextual checklist in Appendix A is drawn from multiple sources: results of an empirical product study (Green, et al., 2004; Green, et al., 2005), design literature references to contextual factors (many indirect), a set of customer interviews conducted to elicit contextual factors, and results from application of the checklist in UT graduate and undergraduate classes (Green, et al., 2006).

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 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 10. 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.

#	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?
	. . .	

Table 9: Partial Context Factor Checklist

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

Table 10: Translation of Customer Needs into

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 for a mobile pencil sharpener is shown in Figure 3, Table 11, Table 12, and Table 13.

Figure 3: Battery Pencil Sharpener Product

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

Table 11: Battery Pencil Sharpener Black Box

	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 12: Translation of Black Box Flows into Context Factors – Input 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

Table 13: Translation of Black Box Flows into Context Factors – Output Flows

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 (Otto and Wood, 2001). 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 in Figure 4 and Table 14. 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 user's 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."

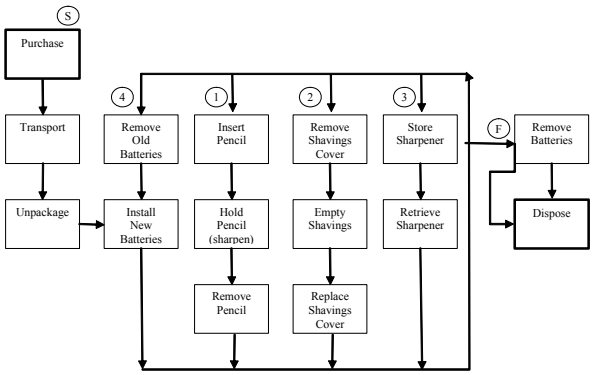


Figure 4: Battery Pencil Sharpener Activity Diagram

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.

Table 14: Translation of Activity Diagram into Context Factors

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[8] (2005) 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 15 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.

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?

Table 15: Historical Reasons for Failure of Improved Village Cooking Systems

4.2.2 Generate List of Contextual Questions to Be Answered

The next step of Contextual Assessment 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 16 shows an example of converting context factors into elicitation questions for use in an interview (based on an earlier version of the template in Appendix A and sampled in Table 9).

4.2.3 Gather Customer Needs and Factor Values

The third step of the contextual needs assessment method consists of traditional customer needs gathering followed by context factor value gathering. A variety of well-established customer needs gathering techniques such as those discussed in the literature review may be used. 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.

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

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?
. . .	

Table 16: Conversion of Context Factors into Elicitation Questions

Gathering context factor values (often qualitative) is simply a matter of obtaining answers to the context elicitation questions generated in step 2 (Figure 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 17 presents an example of recording values for context factors (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.

4.2.4 Aggregate Customer Needs into Weighted List

The 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).

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		
. . .					

Table 17: Recording Context Factor Values from Interviews

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 (Green, et al., 2004; Green, et al., 2005) 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 18 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.

5. METHOD APPLICATION AND ASSESSMENT

5.1 Application: PersonaWarmth Product

An inventive design case study illustrates the application of the contextual needs assessment methodology. The case study illustrates key insights derived from the application of the methodology to design for a frontier design need.

Need and Customer Definition - Mission Statement: The product need is defined as a: "portable, personal hand warming

device for university students in China." For the purposes of this case study, the scope is limited to the primary market (university students in China), 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.

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.

Table 18: Combining Factor Values into Context Scenario (Pencil Sharpener Example)

Existing products analogous to the design need are researched, and many 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.

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 Section 4 is customized for this case study. The first two steps (Figure 2) are to "Identify relevant contextual factors" and "… list contextual questions …" Brainstorming categories employed are 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, "Gather customer needs and factor values," is implemented according to the adapted procedure shown in Table 19. The data collected are the basis of step four, "Aggregate customer needs into weighted list" (Table 20) and step five, "Aggregate factor values into context scenario(s)" (Table 21 through Table 24). The context scenario for this case study is very broad, and as the design process progresses it becomes clear that the target scenario should be reduced in scope to a primary market of university students in southern China, where classrooms are not heated.

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
6. Ask any remaining unanswered questions from customized context questions template.

Table 19: Adapted Interview Procedure

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 20: PersonaWarmth Customer Needs List

#	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 21: PersonaWarmth Context Scenario – "How" Factors

Concept Generation: Following functional modeling and other process steps, concept variants are generated based on the product design context provided by Tables 20-24. 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. Figure 5 shows a partial set of the PersonaWarmth Concepts.

WHERE: Usage Environment		
e1	What type of surroundings will warmer be used in?	Outside, dorm, classroom. Classroom – 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 part
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 22: PersonaWarmth Context Scenario – "Where" Factors

WHO: Customer Characteristics	
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.
How familiar is the average user with active heating elements?	Students familiar with electric kettles.
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.
Does the user have any physical conditions that may make it difficult to perform this task?	
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).
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.
About how much is the buyer willing to pay to purchase this warmer?	$2-4
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 (?)
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.
How much additional material/equipment to activate?	Minimize. Match or lighter OK. Many men have lighters. Make use of other common products?
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.
How long does the user expect warmer to last?	Last through one cold season.

Table 24: PersonaWarmth Context Scenario – "Who" Factors

Concept Selection, Modeling and Prototyping: Using a Pugh selection process, the concepts of Figure 5 are ranked and then refined to satisfy the product design context. Heat transfer modeling of the system with different materials is also performed. The result of this process is the development of a "Hot Writer" concept, a tablet shell that is filled with hot water[9]. This concept (based on the Datum in Figure 5, with appropriate refinements) enables students to receive hand warmth simultaneously while taking notes. 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 in the Chinese university context, which increase the chances of new product success.

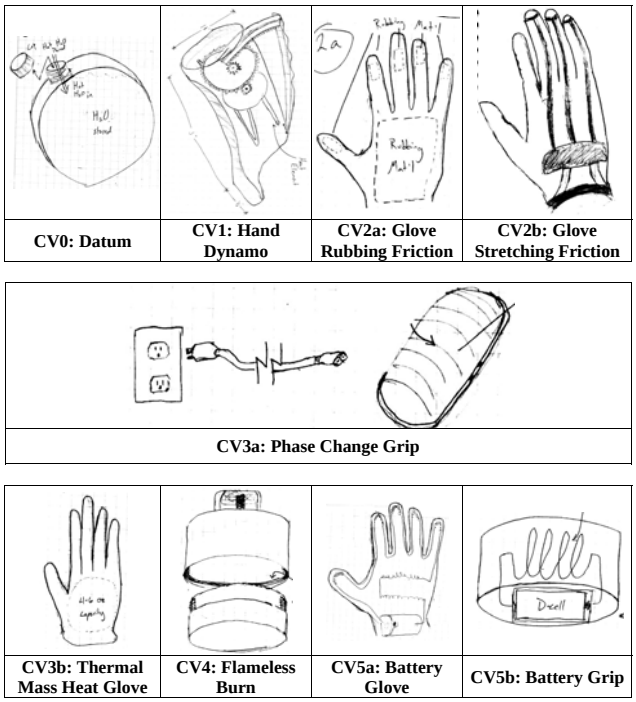


Figure 5: PersonaWarmth Concepts

A prototype is developed from the concept (Figure 6). Experimentation shows the prototype provides significant hand warming and is convenient to carry. The prototype is tested (Figure 6) in the vegetable compartment of a refrigerator to simulate a classroom with ~50°F ambient conditions and no wind. A thermocouple is held on the surface of the prototype with a small piece of insulation and a rubber band. Figure 7 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°F and 90°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.

[9] Contextual interviews revealed that limited amounts of water hot enough to steep tea are often readily available in the target usage context.

Figure 6: PersonaWarmth Prototype

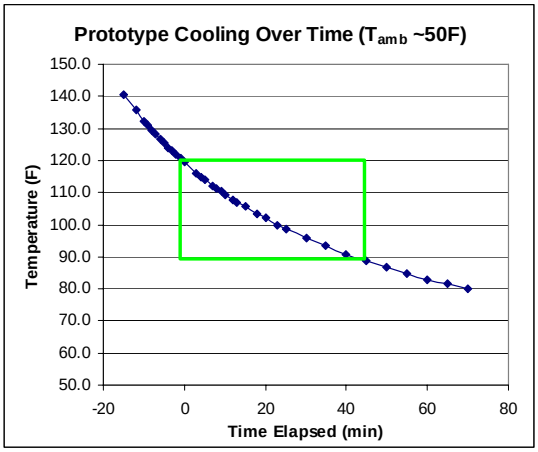


Figure 7: Prototype Surface Cooling Curve in a ~50°F Test Environment

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 un-encumbering 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 achieving the successful PersonaWarmth design shown. Finally, a better understanding of customer expectations for cost, maintenance, and ease-of-use guided design decision making.

5.2 Assessment Study: UT Design Methods Course

In addition to the product application of Section 5.1, the contextual needs method was also assessed through: a UT undergraduate design methods course, a UT graduate course in which students design and deliver products for persons with disabilities, and a volunteer human study for the design of a cooking device for African villages. Space limitations prevent the reporting of all findings here (refer to Green, 2005 for details); however, Tables 25-26 show the results for the UT undergraduate design methods course.

In this undergraduate design course, teams of 4-6 senior-level mechanical engineering students reverse engineer and redesign consumer products, learning and applying various design methods throughout the semester. As part of their customer needs methods, the students implemented the newly developed contextual needs assessment method. The students were also provided with an Excel tool embodying the steps presented in Section 4 (summarized in Figure 2).

Fourteen out of 20 design teams from the course voluntarily submitted their contextual needs assessment data for the study. Students from these teams were then asked to complete an anonymous web-based questionnaire. 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 25 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 26 similarly shows a high level of agreement for the perceived usefulness of the method.

	Strongly disagree	Disagree	Neutral / Undecided	Agree	Strongly agree
I understand how to gather information using the above method.	0%	2%	2%	**81%**	16%
I like using the above method.	0%	14%	28%	**49%**	9%
The above method does not need improvement.	0%	24%	**49%**	22%	5%
The above method is not difficult to understand and use.	4%	12%	18%	**58%**	9%

Table 25: Perceived Usability of Experimental Method

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

Table 26: Perceived Usefulness of Experimental Method

Overall, this study demonstrates that within an undergraduate reverse engineering setting, the contextual needs assessment methodology can be realistically deployed and well received, and results in significant improvement in needs assessment. Data analysis identifies eight new context factors and eighteen question revisions to improve the generalized template (included in Appendix A). Survey results show students rated the contextual needs assessment methodology to have "medium-high" value for their products and "high" value for a product foreign to them. These rating are comparable to the perceived value ratings given for well-established 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 some student misunderstandings indicating the need for more thorough teaching.

6. CONCLUSION

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, a contextual needs assessment methodology and supporting techniques are developed, and two 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.

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APPENDIX A - CONTEXTUAL NEEDS ASSESSMENT QUESTIONS TEMPLATE[10]

HOW: Usage Application		
#	Context Factor	Suggested Questions v3.0[10]
a0	task application	What specific purpose(s) will product be used for? How will the product be used?
a1	task function	What major function(s) should the product provide?
a2	task quality	What quality of the primary function is needed?
a3	task process	What is the current usage process? How will product change the current usage process?
a4	task frequency	How often will product be used?
a5	task duration	How long will product be used each time?
a6	task quantity	How much quantity of the product's output is needed?
a7	task rate	At what rate should the product perform?
a8	task ruggedness	How roughly will product be handled/treated?
a9	transportation type & amount	How often, how far, and in what way will product be transported?
a10	operator position	What physical position will the user be in (standing, sitting, hands occupied)?
a11	cleaning	How and where might the product be cleaned?

Table A-1: Questions Template – "How: Usage Application" Factors

[10] To receive or share updated and customized templates, please contact the corresponding author (MatthewGreen@letu.edu).

WHERE: Usage Environment		
#	Context Factor	Suggested Questions v3.0
e0	surroundings	Where and in what type of surroundings will product be used? What in the surroundings might influence what the product must be like?
e1	surroundings (sound)	How noisy are product surroundings? How much noise from the product is acceptable?
e2	weather/ climate	What weather/climate will product be exposed to?
e3	environment ruggedness	What objects and substances will product interact with? 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 and where will product be stored? How much space is available for storing product?
e6	aesthetics of surroundings	What do the product surroundings look like? How should the product interact w/ the surrounding aesthetics?
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)?

Table A-2: Questions Template – "Where: Usage Environment" Factors

WHO: Customer Characteristics		
#	Context Factor	Suggested Questions v3.0
c0	user	Who will use the product? (Choose? Buy?) What user characteristics affect what the product must be like?
c1	user skills & education	How skilled/experienced is the user with the 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?
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 product safety concerns does the user have? What safety features is the user expecting? What dangers must be avoided? What is the most dangerous product familiar to the user? Must this one be less dangerous?
c10	durability expectations	How long does the user expect the product to last?
c11	purchase context	Where and how might the product be purchased? How would the buying decision be made (research, referral, impulse)?

Table A-3: Questions Template – "Who: Customer Characteristics" Factors