2006-980: DESIGN FOR FRONTIER CONTEXTS: CLASSROOM ASSESSMENT OF A NEW DESIGN METHODOLOGY WITH HUMANITARIAN APPLICATIONS

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Design for Frontier Contexts: Classroom Assessment of a New Methodology with Humanitarian Applications

Abstract

Engineering educators are recognizing the value of exposing students to need-based engineering problems and pedagogies[1]. A parallel interest is the globalization the scope of engineering education. These important topics are both addressed by a service-learning approach to globally-based humanitarian projects[2-4]. The importance of integrating both globalization and social needs into the engineering curriculum is acknowledged by the ABET criteria. Human need is also a clear priority of the engineering profession, as indicated in the NSPE creed[i]. However, the majority of engineering students are not familiar with the contexts in which vast needs exist, such as among the physically disabled or the 4 billion people living on less than $2 a day (PPP)[5]. These conditions represent formidable *frontier design contexts*, environments and situations outside the experience and expertise of most engineering students.

Currently taught design methodologies advocate gathering customer needs, and many methods reference the importance of doing so within the context of use. However, sufficiently understanding design needs within the actual context of use of frontier contexts is notoriously problematic where data and contextual experience are not readily available. This is a challenge faced by organizations such as Engineers for a Sustainable World (ESW), Engineers without Borders (EWB), Engineering Ministries International (EMI), and other humanitarian and educational organizations engineering high human-impact solutions in these unfamiliar, frontier contexts. In response to this need, we have developed a basic but powerful *Design for Frontier Contexts* methodology[6] to improve discovery and application of contextual information vital to successful frontier design.

Grounded in empirical product-context studies[7,8], the Design for Frontier Contexts method supports gathering, documenting, and applying contextual design information. By improving needs assessment, the method is expected to increase the successful application of engineering to high human-need contexts such as poor areas of developing countries and assistive technologies for persons with disabilities. The new needs assessment method can also improve the design of everyday consumer products to provide greater benefit to humanity with lower consumption of resources. The method enhances the use of context-specific resources and knowledge within the frontier context and provides a common template for collaborative communication among geographically diverse groups.

Evaluation under controlled conditions suggests the new method is not only extremely effective, but also easy to use and well received by students. Classroom testing has shown very positive results, signifying broad applicability in education as well as field practice. We are currently integrating the method into the design curricula of our departments and conducting ongoing assessment for continued improvement.

Here we present the essence of the method, results of preliminary testing, and examples of student projects which could benefit from the method. Templates, lecture slides, and examples in electronic format are freely available from the corresponding author.

1 Introduction: Motivation and Background

1.1 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[9]. 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[10]). 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[11]. 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)[5]. Numerous opportunities exist for engineering designs to improve the quality of life on a global scale, many of which are in frontier design contexts. In addition to the large international development programs of many wealthy nations, smaller, non-governmental organizations such as Engineers for A Sustainable World (ESW), Engineers without Borders (EWB), and Engineering Ministries International (EMI), are also acting upon such opportunities.

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

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

Second, a framework of contextual understanding will improve the task of setting target values by equipping the designer to account for how contextual factors influence customer preferences for product attribute values. Current techniques prescribe capturing the "voice of the customer," but provide insufficient guidance on how to translate these data into quantifiable numbers. QFD is an excellent technique to *organize and document* this conversion; however, it is left to the designer to translate what the customer means by "light-weight," for example, into a quantity in kg. Or perhaps even more difficult than quantification is the problem of determining

what metrics appropriately measure the fulfillment of needs such as "easy to use" (possibly measured by "number of steps", and/or "minutes") or "good beverage taste" (possibly measured by "saturation and bitterness levels")[12]. The customer may clearly indicate the need for portability, but setting specifications accordingly for mass and volume depends heavily on the means and frequency with which the product will be transported.

Third, a framework of contextual understanding will better equip designers to leverage the known to design for the unknown through an improved understanding of how changes in usage context influence customer preferences. Forming design targets has traditionally relied heavily on benchmarking, but this activity can be difficult or impossible in frontier design contexts in which comparable designs are sparse. With an appropriate contextual understanding, product definition information from an accessible and information-rich environment may be intelligently brought to bear upon a frontier and information-scarce context. A product context framework and the concept of a *functional family* (a group of products which solve the same primary need) will provide the designer with tools to maximize domain cross-over of benchmarking information, intelligently selecting and adapting information from existing products that may exhibit some similarities, but do not occur in the target context. One example is the design of a $100 above-knee prosthetic by a US University for a charity hospital in Kenya[ii] [13]. The challenges of accessing and understanding Kenyan customers were partially addressed through local access to US amputees, and properly translating the knowledge gathered into the Kenyan context.

1.2 Cross-Cultural Design

Courage and Baxter[14] include a case study by Ann[15], "Cultural Differences Affecting User Research Methods in China" citing numerous cultural differences posing challenges to market research. Differences mentioned include: differing cultural concepts can cause difficulty in translating language without loss of actual concepts; a greater focus on relationships requires more attention to building trust and respecting privacy of the home than in western countries, and the intuitive/subjective mentality vs. the scientific/rational focus of the West can reduce effectiveness of objective and direct interview approaches. The discussion of these differences shows both the challenge and importance of understanding the cultural context.

Crawley et al.[16] present the "Design, Development and Marketing of Solar Lanterns" for the rural poor of African countries. They specifically address Kenya, which has a large population without hope of access to electricity in the near future; more than 90% of households use kerosene lighting, and 70% also use scarce cash supplies to buy batteries. Crawley et al. employ focus groups and general discussions to gather information about what customers want in a solar lantern. They note the importance of: (1) picking groups not dominated by a few dominant members, (2) holding surveys during the day for travel safety of participants, and (3) focusing on individuals with incomes similar to the target customers, who often had significantly different spending patterns than wealthier individuals. The authors note that product development is in general expensive and high-risk for companies in developing countries, and for the new products they design conventional customer needs gathering techniques are often incomplete and inaccurate in accounting for lifestyles and cultures.

Chen et al.[17] advise that when tapping global markets, multinational companies must be wary of segmentation errors on two extremes: attempting to standardize the product for significantly different markets, or excessive customization for essentially similar markets. A balance must be struck which properly accommodates real and important differences, without unnecessarily undercutting economies of scale through standardization. Examples of major differences faced when political and/or cultural boundaries are crossed include: language, ethnic,

religious, social structure, tradition, literacy, income patterns, geography and climate, infrastructure, product distribution, advertising, and legal climate.

Chen et al.[17] predict that "... multicultural factors are the most difficult issues for organizations to address … [and will be a] future direction in NPD [(New Product Development)]." They address the need for research in this area, commenting "… there are few successful or effective techniques available for the evaluation of multicultural factors in customer requirements." Chen et al. propose one system employing a laddering technique and radial basis function (RBF) neural network to help overcome multicultural barriers to customer needs gathering. A mobile phone design case study is included. The cultural factors addressed primarily deal with the customer context.

Other design researchers also explicitly address the consideration of "culture" in the design process. Culture may be defined as the customary beliefs, values, social forms, and material traits of a group of people that are learned from preceding generations (author's adaptation from[18]). Ellsworth et al.[19] report on the "effects of culture on refrigerator design." This paper does not define culture, but references the "needs and values" of customers which differ from place to place. The authors build a case for improved cultural understanding among design engineers, stating that products will be more successful worldwide as design engineers account for cultural needs. The authors propose the development of a Design for Culture (DfX) methodology, citing a lack of attention to the subject evidenced by a dearth of literature and suggesting that cultural considerations must include not only marketing but also design. They suggest studying the use of similar products across different cultures to begin development of such a method. Refrigerators were chosen for this study because they are in widespread use globally and the designs have stabilized with distinct differences in various countries. The paper itemizes a number of macro physical differences (such as volume, energy efficiency, and construction) in refrigerators used in the US, Europe, Japan, and Brazil, and comments on the apparent cultural reasons for these differences. The authors conclude by suggesting the following categories of cultural aspects to account for: aesthetic appeal, cultural habits (e.g. tendency to snack), traditions, available resources, and the physical environment.

Donaldson[20,21] proposes various items to improve product design for developing countries, and comments extensively on the particular barriers and problems associated with designing for this context. Some of Donaldson's findings may be generalize-able to other frontier design contexts.

Donaldson, et al.[22] describe Customer Value Chain Analysis (CVCA) as a tool to improve identification of needs and requirements in the product definition phase. One of the case studies is a micro-irrigation pump successfully designed and marketed in Kenya, implicitly illustrating the applicability of the CVCA tool to the complexities of projects in this economy and culture.

Donaldson and Sheppard[23] provide detailed observation and analysis of product design practice in Kenya, an example of a "less industrialized economy." They analyze design practice in the informal sector, the formal sector, and by donor-funded groups. They identify four types of product design: (1) imitated design, (2) imported design, (3) basic original design and (4) specialty design. Donaldson and Sheppard note that virtually all Kenyan products are designed outside the country or are imitations of imports. The local language has no complete equivalent for the verb "to design" and designers and producers typically view "design, sketching, pondering and brainstorming" as an extravagance. No formal design processes such as those defined in design literature were observed in the formal or informal sectors, and NGOs followed semi-formal processes. Economic and political instability along with business monopolies are possible contributors to the lack of attention to customer needs and the associated product

definition steps. These findings suggest the continued importance of donor-funded design until the local sectors begin designing products in response to customer needs, and likewise the need for design methodologies applicable in frontier design contexts.

1.3 The Importance of Contextual Information in Product Design

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[iii]. 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[iv]. Since product designers rarely dictate the context surrounding products, it is necessary to understand and account for context in the design process. The definition of *context* used throughout this paper is:

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

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

Table 1: Context Related Definitions

- *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.

Numerous authors reference the influence of context on product design, and many explicitly express its importance. Empirical studies of the influence of product design context[v] on customer preferences are reported in previous work[7,8]. These studies include: exploration of customer needs and attributes of functional product families, customer product choice surveys, and an exploration of how individual factors of a target usage context influence customer preferences for product attributes.

Clarkson, et al.[24] report a large-scale study of the UK health system to recommend a design approach to improve patient safety. They report that improving patient safety requires an improved understanding of the context of the health care system. "Without a sound understanding – from a design perspective – of the healthcare services as a complex system of

interacting organizations, professions, care *environments, procedures and tasks* … there can be no certainty that discrete design solutions will contribute to patient safety" (emphasis added).

Sutinen, et al.[25] report results of an empirical study of an IT-based requirements management tool. They map the requirements management process, identify tools and information needed by various participants, and recommend a process for introducing new requirements management tools into the product development process. Among other findings they observe that, "the requirements specifications used in the cases studied could have been enriched by adding requirement *context information ... and scenarios* in order to provide a better understanding of why the requirement is stated" (italics added).

Maier and Fadel[26] discuss the consideration of context in choosing design methods. They suggest that the concept of function is well suited to capture design aspects characterized by input/output relationships, whereas the concept of affordance is well suited to describe the more complex relationships involved when the interrelationships among the *context of the artifact, designer,* and *user* are taken into account. In other words, the role of contextual information is an important factor in the selection of appropriate design methods.

Norman's classic work[27] 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.

1.4 A Case for Design Context: Mobility Enabling Products

Healthwrights and the Hesperian Foundation have worked for years to improve the quality of life for persons with disabilities in developing countries. As part of this effort they have published extensive self-help guides for community workers and those they serve with prolific illustrations to transcend language and literacy barriers[28,29]. One of the books in this series[29] 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.

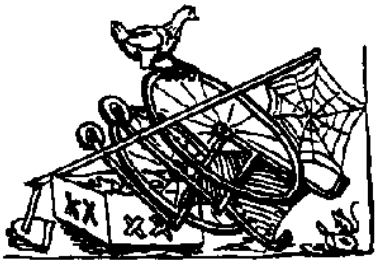
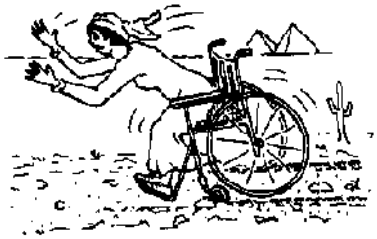


Figure 1: Wheelchairs Must Fit the Context to be Satisfactory[29vi]

Table 2: Different Mobility Products for Different Contexts[29][vi]

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

1.5 A 2nd Case for Design Context: Improved Village Cooking Systems

The importance of design context is evidenced both in successful products with attributes that match context, as well as in failed products which did not address critical context factors. Table 3 is based on data from a World Bank review of numerous programs to introduce improved village cooking systems in countries around the world[30]. Out of 16 major reasons commonly causing the failure (or success) of a stove program, 8 of the reasons[vii] appear to be directly tied to how well context is understood and addressed. The importance of accounting for context is evident from the report text, as shown in the following quote[30 p. 28]:

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

Table 3: Historical Reasons for Failure of Improved Village Cooking Systems Data from[30]

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

1.6 Conclusions and Implications for Product Design

Empirical studies of two product families[7,8] have shown that: (1) different context scenarios exist within the same functional family and even the same products, (2) the customers surveyed prefer different products for different context scenarios, and (3) clear relationships exist between context factors and attributes of the preferred products. These findings, along with the previous sections, give strong evidence that product attribute preferences depend, in part, upon factors of the intended usage context scenario. These results affirm the importance of accounting for contextual factors in product design processes intended to realize products delivering customer satisfaction.

2 The Contextual Needs Assessment Methodology

2.1 Product Design Context Framework

In response to the need for improved contextual understanding, a *product design context* framework for handling contextual information is presented as a foundation for contextual needs assessment. 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 4): (1) *usage context factors* cover the application and environment in which the product will be used such as task frequency, weather and infrastructure; (2) *customer context factors* include consumer values, practices, and demographics such as wealth and education level; and (3) *market context factors* include aspects of competing products. More details of the context framework are reported prior work[7,8]. 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[12] is a well known method to explore the market context, and customer context is partially explored through currently prescribed needs

assessment methods. However, even with activity diagram techniques[12], designers are essentially on their own when it comes to accurately discovering and applying important usage context information.

Table 4: Product Design Context Categories

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

2.2 Contextual Needs Assessment Method

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

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

Figure 2: Contextual Needs Assessment Methodology

Table 5: Context Factor Identification Techniques

- Use context factor checklists, such as the template provided (Appendix 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

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

3 Case 1: Undergraduate Reverse Engineering of Consumer Products

3.1 Design Team Background

The UT Austin Department of Mechanical Engineering undergraduate curriculum includes a senior design methods course followed by a semester of capstone design. Students in the design methods course apply design methodologies in a semester-long project involving the reverse engineering and re-design of a consumer product. The text used for the course[12] conceptually presents the design process in three phases: (1) task clarification (understanding the re-design need), (2) concept generation, and (3) concept implementation (detailed design and prototyping). In the first phase students use a number of tools to understand the re-design need such as: a mission statement, a checklist of technical questions, and articulated-use or like/dislike customer needs interviews[12,31]. Additionally, students perform a number of reverse-engineering steps such as prediction, product teardown, and functional modeling to identify re-design avenues. The students choose one or two high-priority, re-design avenues based on the understanding gained of the re-design need. The accuracy and completeness of customer needs understanding directly influences the correct selection and implementation of a re-design avenue that will maximize value added to the customer. This design methods course was chosen as a case study in part because students are already learning design methods and are therefore open to learning and implementing a newly developed method. Additionally, since the students are near the end of their undergraduate degree they are a good representation of the intended users of the proposed methodology.

3.2 Classroom Delivery of the Methodology

For this study the task clarification lectures given in past semesters are augmented with some additional steps intended to enhance understanding of the re-design need context. Students are provided the five-step method shown in Figure 3 and a supporting tool in the form of an MS-Excel template (Figure 4) in which each Excel worksheet tab corresponds to one step of the method. The method would ideally be presented step-by-step in an interactive lecture format in which each step is illustrated "live." After each step is partially demonstrated, a complete version would be reviewed in a prepared example using the template (Appendix A) and distributed via a courseware website. However, classroom realities limited the time available, so in this case the methodology was reviewed in a single lecture with an emphasis on conceptual

understanding of the methodology and detailed exploration left for homework. (Although the study results are very positive, there is also evidence of the need for increased teaching time to improve understanding of the method).

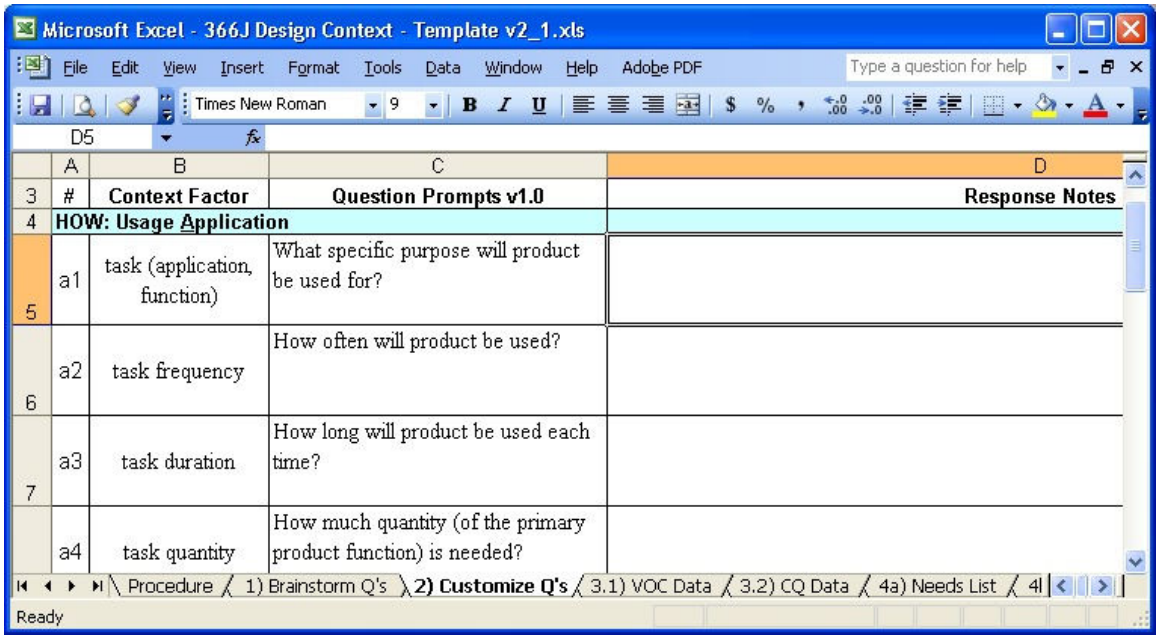
Procedure for Gathering Customer Needs & Product Context

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

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

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

Figure 3: Contextual Needs Assessment Methodology



	A	B	C	D
3	#	Context Factor	Question Prompts v1.0	Response Notes
4	HOW: Usage Application			
5	a1	task (application, function)	What specific purpose will product be used for?	
6	a2	task frequency	How often will product be used?	
7	a3	task duration	How long will product be used each time?	
	a4	task quantity	How much quantity (of the primary product function) is needed?	

Figure 4: MS-Excel Template Supporting Contextual Needs Assessment

3.3 Methodology Results – Customized Context Questions

Fourteen out of 20 design teams voluntarily submitted their contextual needs assessment data for the study. The contextual needs assessment data submitted by the teams was analyzed in detail to assess patterns and insights into how the teams customized the context questions template. A major purpose of this assessment was to glean insight to improve the generalized template for future use. Virtually all of the customized questions the teams wrote took one of the four forms listed in Table 6. Modifications which departed from form #1, although helpful

for the team's specific project, were often not appropriate for a template intended to be generalizable across products and types of design other than reverse engineering and re-design. Dozens of modifications and additions to the general template are derived from careful analysis of the data, and these are incorporated into the updated context questions template provided in Appendix A. More detail is provided in Green, et al. (2005), including details of each change made to the template as a result of this case study.

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

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

Table 6: Four Forms of Context Elicitation Questions

1. *Question Form: What is _____ (context factor)?*
   Example: What is the cost & availability of possible energy sources?
   This question is the most basic and direct type of elicitation prompt, and is the form of almost all of the elicitation questions in the generalized template.

2. *Question Form: How satisfactory is the current product for (context factor)?*
   Example: Are you satisfied with how long the current product's batteries last?
   This question bears similarity to a like/dislike interview technique and in the same way it is most effective when the current product (or solution) is similar to the future product such as is the case with reverse engineering.

3. *Question Form: How will (or does) the future (or current) product interact with the context?*
   Example: What energy sources would you use to power the product?
   This question bears similarity to an articulated use interview, and requires a clear mutual understanding the solution being discussed between the customer and interviewer.

4. *Question Form: What product attributes are needed in light of (context factor)?*
   Example: How long should the batteries last for jogging?
   Although accurate answers to this question are very valuable, they are often difficult to obtain from customers. Sometimes it is necessary, however, as in the case of customer expectations such as costs.

3.4 Survey Results – Designer Perceptions of the Method

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

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). 80% of the students agreed they were personally very involved in using the contextual needs assessment method.

3.4.1 Perceived Value of Methodology and Re-Use Likelihood

Figure 5 compares the perceived value of the contextual needs assessment methodology with other "benchmark" methodologies shown in Figure 6. It is not possible to benchmark perceptions against traditional needs assessment methods since students do not have either a clear understanding of or experience base with alternative methods. For this reason other aspects of design methodology familiar to the students are used as a comparison. The figures combined show that the new methodology has an equal or higher perceived value than benchmark methods used in the comparison. Both figures distinguish between perceived value for the respondent's actual class design project and the perceived value for a foreign product. The data shows, virtually without exception, that students believe design methodology has even more value for products in a foreign context than for those in a familiar context. The graphs additionally show a level of re-use likelihood averaging midway between neutral and likely.

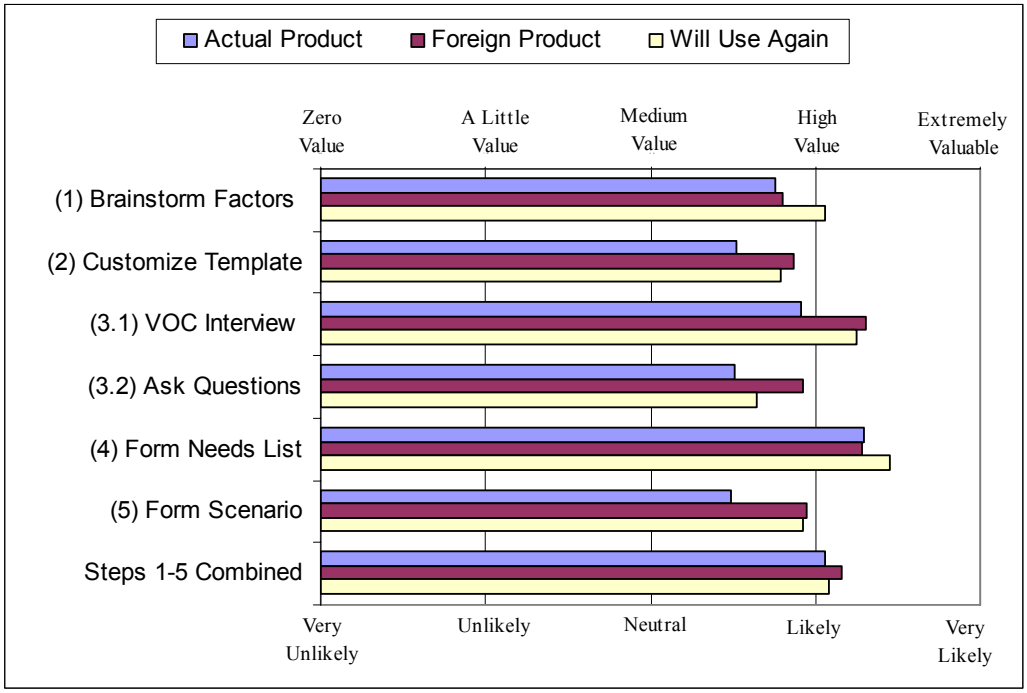


Figure 5: Experimental Methodology – Perceptions and Re-Usage Likelihood

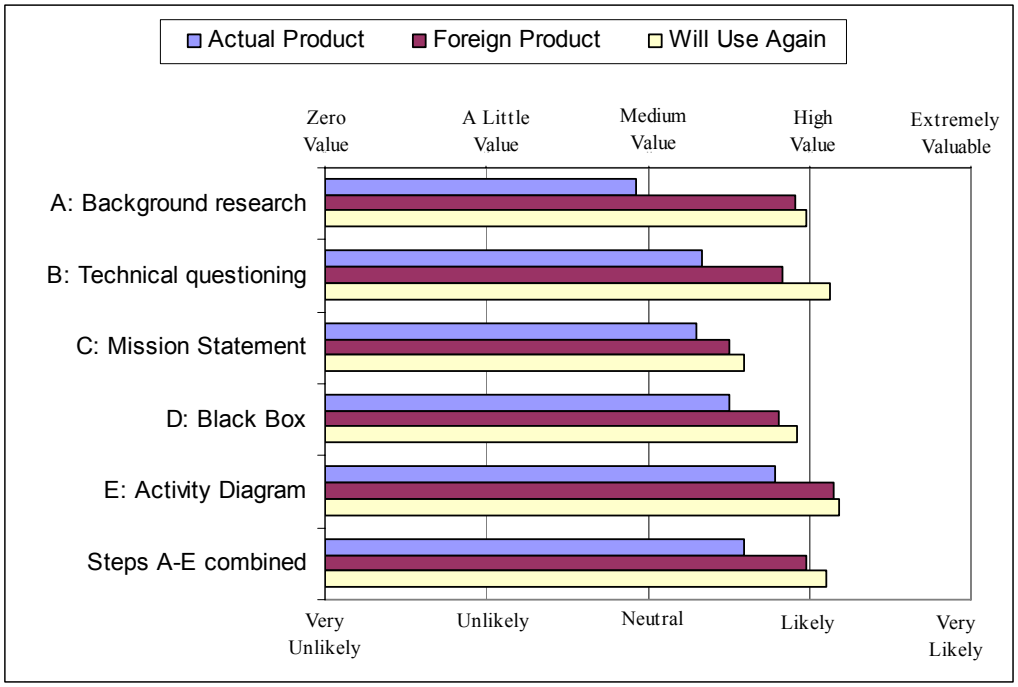


Figure 6: Benchmark Methodologies – Perceptions and Re-Usage Likelihood

3.4.2 Perceived Usability and Usefulness of Methodology

Table 7 presents survey data rating the perceived usability of the contextual needs assessment method. The data shows a high level of agreement with all statements related to usability, and neutral agreement on whether the method needs improvement. Table 8 similarly shows a high level of agreement for the perceived usefulness of the method.

Table 7: Perceived Usability of Experimental Method

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

Table 8: Perceived Usefulness of Experimental Method

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

3.4.3 Participant Free Response Comments Regarding Methodology

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

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

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

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

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

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

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

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

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

3.5 Conclusions

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

4 Case 2: Graduate Original Design of Assistive Devices

4.1 Design Team Background

The second case study was conducted within the graduate Product Design and Prototyping class at UT Austin, which culminates with students delivering fully functional prototypes to local "customers" with physical disabilities. Table 9 summarizes this course[3]. The basis of the course is product design, development, and prototyping. Product design projects are the focus of the student efforts, with emphasis on functional, working designs as opposed to the common ink-paper concepts. Students must produce a working, tested, and robust design by the end of a semester, delivering the result to the customer. This focus provides graduate students from mechanical engineering, social work, and special education with a unique opportunity to work with hardware, in contrast to the theoretical focus of most graduate-level courses. Thus, the intent of the course is to produce functional designs based on real product/humanitarian needs. The course includes other innovative pedagogies such as experiential learning with hands-on in-class activities, instruction in drawing for design, and experiential walls as a medium for team presentations.

Table 9: Graduate Product Design and Prototyping Class (UT Austin)

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

Projects are selected which require the novel synthesis of low to medium technology (not high technology), and involve $100-$300 of funding. Projects are solicited from facilities that include persons with disabilities: the Austin State School and two local school districts. Interdisciplinary design teams of 4-5 graduate students from engineering, social work, and special education are formed using team selection algorithms[32] based on MBTI, Six Hats, and technical/hands-on skills. The teams work with supervisors, teachers, and the students (customers) at the schools to refine project ideas into electromechanical design problems related to the customers' occupations and learning environments. These projects present a unique challenge to the design teams in that most of the problems admit solutions that provide assistive technologies for the tasks currently performed by the customers. Table 10 shows examples of projects completed since the course's inception.

Table 10: Examples of Past Design Projects in the Graduate Product Design Class.

- Assistive bowling device (Figure 7)
- Key turner usable with limited strength and range of motion (Figure 8)
- Switch activated ball thrower (Figure 9)
- Visual phone interface for deaf persons
- Device to wrap baking potatoes in foil using only one hand
- Letter labeler to assist persons with disabilities on a job site
- Sand-bagging system to assist persons with disabilities on a job site
- Electro-mechanical can crushing system
- Sensory-stimulation system for persons with disabilities
- Décor chip sorter to assist persons with disabilities on a job site
- Accessible shelving system for persons with disabilities

After initial project choices and visits to their customer locations in Austin, the students systematically follow the product development process[12] taught in the class. Design teams produce a proof-of-concept, an alpha prototype, and a beta prototype at key milestones. Students are required to deliver a package at the end of the semester to the customer that includes: a working device or system that satisfies the customer needs, a brief report documenting the project results and chronological decisions, a Bill-of-Materials, an illustrated manufacturing plan, and a brief user's manual. Each team also submits a 3-page article and a 5-minute videotape to the annual Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) international student design competition[33]. Since 1994, twelve teams from UT Austin have been selected to present their designs at the annual RESNA conference.

For illustration, Figure 7 through Figure 9 show three RESNA winners that have been used in Austin schools. The assistive bowling project focused on the design of a bowling device that would allow people, especially children, with disabilities to bowl with more autonomy and normalization than current wheelchair bowling ramps offer. The innovative design enhanced accessibility for children with many types of disabilities and greatly increased the performance

of the bowling ball ramp. The adaptive key handler (Figure 8) allows a wheel-chair user with severely limited strength and range of motion to use key-operated elevators and doors. The device was designed to be compact, portable and lightweight for use by an 11-year-old student with rheumatoid arthritis. His use of a wheelchair requires riding the elevator to attend classes. The switch activated ball thrower (Figure 9) is a portable device enabling students with limited mobility, strength, and coordination to participate in ball throwing activities integrated with their peers. A RESNA paper reporting the design, prototyping and testing of the switch activated ball thrower is available[34].

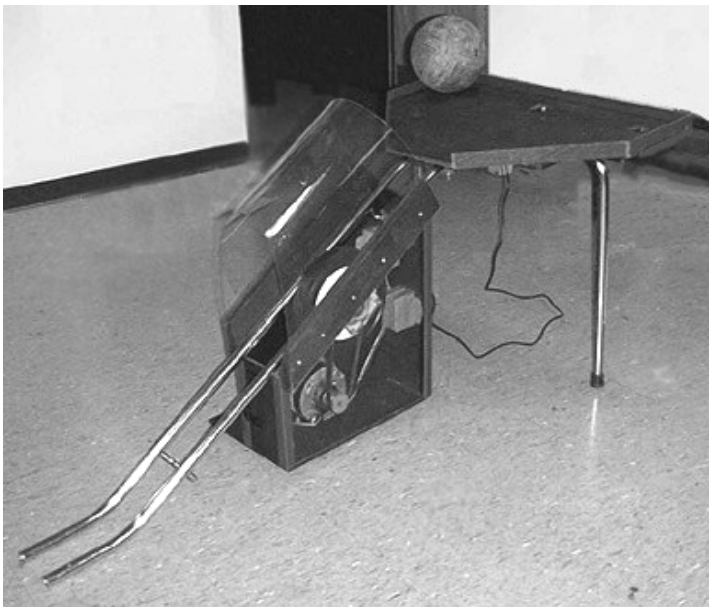


Figure 7: Assistive Bowling Device[35].

Figure 8: Assistive Key Handler[36].

Figure 9: Switch Activated Ball Thrower [34].

4.2 Classroom Delivery of the Methodology

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

4.3 Methodology Results – Customized Context Questions

The class is divided into three teams of 5 to 6 students each, and all three teams submitted their contextual needs assessment data for the study. Table 11 itemizes the design needs addressed by each team.

Similar to the reverse engineering undergraduate teams, virtually all the customized template questions in the Case 2 study took one of the four forms listed in Table 6. Again modifications which departed from form #1, although helpful for the specific project, were often not appropriate for a template intended to be generalizable across products and types of design other than reverse engineering and re-design. Dozens of modifications and additions to the general template are derived from careful analysis of the data, and these are incorporated into the updated context questions template provided in Appendix A. More detail is provided in Green, et al. (2005), including details of each change made to the template as a result of this case study.

Table 11: Summary of Graduate Teams for Case Study 2

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

4.4 Survey Results – Designer Perceptions of the Method

An online survey was deployed to measure designer perceptions of the contextual needs assessment method, essentially identical to the one discussed in Section 3.4 . The survey collected data on: participant background, perceived value of the methodology and re-use likelihood, and perceptions of the usability and usefulness of the methodology. Similar to Case 1, survey results for Case 2 were extremely positive in all aspects.

4.4.1 Study Participant Background

The response rate was 16 students, 94% of the class of 17. The survey participants self-reported demographics indicate 75% are male and 25% female with an average age of 23.3 (ranging from 21-26). A number of the respondents are first semester graduate students, and did not report an average GPA. A significant number of students recently came to the US to attend graduate school, but virtually all are fluent in English. Table 12 indicates most respondents and their teams were very involved in using the contextual needs assessment method. Table 13 shows participants have a high level of previous design experience and virtually all believe in the importance of design in both education and engineering practice.

Table 12: Involvement Using Experimental Method

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

Table 13: Previous Design Experience and Design Attitudes

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

4.4.2 Perceived Value of Methodology and Re-Use Likelihood

Figure 10 compares the perceived value of the contextual needs assessment methodology with other "benchmark" methodologies shown in Figure 11. It is not possible to benchmark perceptions against traditional needs assessment methods since students do not have either a clear understanding of or experience base with alternative methods. For this reason other aspects of design methodology familiar to the students are used as a comparison. The figures combined show that the new methodology has an equal or higher perceived value than benchmark methods used in the comparison. Both figures distinguish between perceived value for the respondent's actual class design project and the perceived value for a foreign product. The data shows virtually without exception that students believe design methodology has even more value for products in a foreign context than for those in a familiar context. The graphs additionally show a level of re-use likelihood averaging midway between neutral and likely.

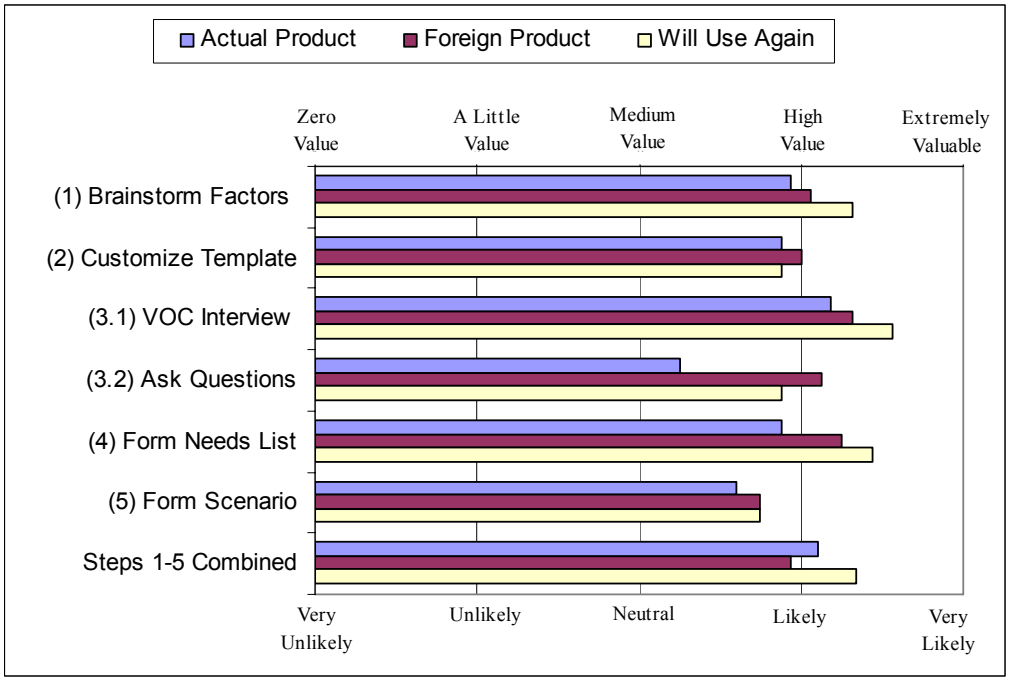


Figure 10: Experimental Methodology – Perceptions and Re-Usage Likelihood

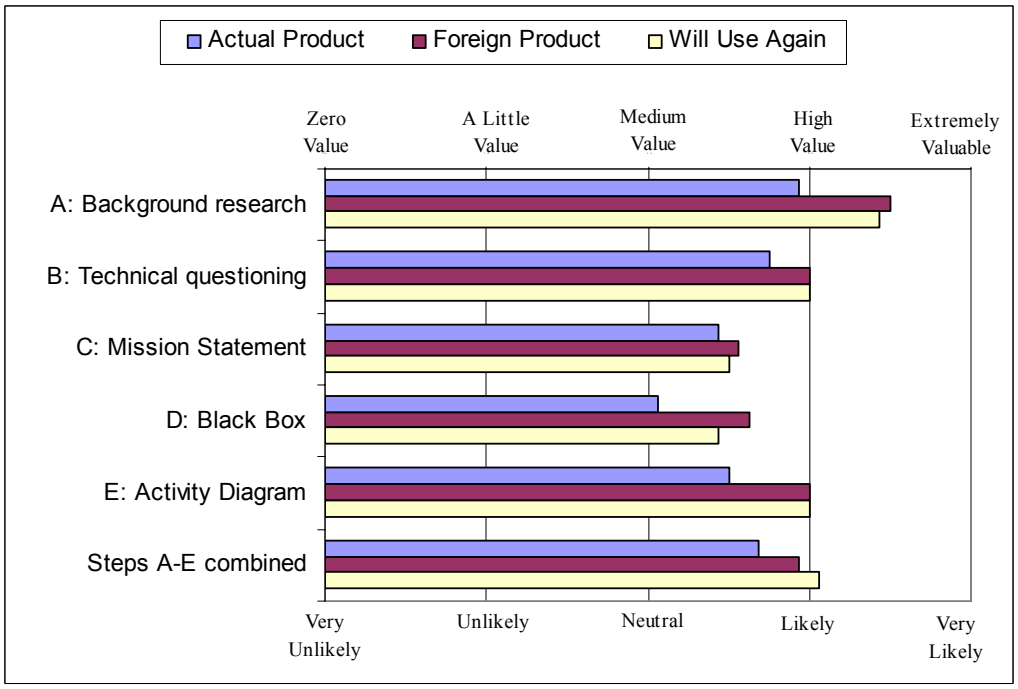


Figure 11: Benchmark Methodologies – Perceptions and Re-Usage Likelihood

4.4.3 Perceived Usability and Usefulness of Methodology

Table 14 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 15 similarly shows a high level of agreement for the perceived usefulness of the method.

Table 14: Perceived Usability of Experimental Method

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

Table 15: Perceived Usefulness of Experimental Method

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

4.4.4 Participant Free Response Comments Regarding Methodology

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

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

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

- This method is extremely effective. If I had only used the like/dislike method my team would have very little information about the customer needs of our product. The

like/dislike method is very difficult to use when designing a very innovative and different product.

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

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

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

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

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

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

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

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

- More clearly define some of the template questions …

- I think the method should involve the manufacturing part of the design process too.

- [Provide] more generic context questions … to capture an even wider sphere of customer/design needs. [Provide further guidance] in generation of specific questions for peculiar design needs from the [template]. *Increasing the breadth of the template is one result of these case studies, and continues as future work.*

- Most times when the customer is asked to give quantitative values … the values are very [far from practical]. It is always better to perform such interviews … using an existing product or compare the expected values with some analogous product … *This is an important avenue for future work, and can be addressed in large part by the development of semantic inquiry scales as proposed.*

5 Conclusions and Call to Action

The case studies in this paper provide strong quantitative and qualitative support for the usability, usefulness, and designer acceptance of the proposed contextual needs assessment method. The case studies further provide valuable illustrations of methodology application and

numerous findings to continue improving the usefulness and generality of the method. Table 16 itemizes the outcomes of the two case studies discussed here. Case 1 demonstrates that within an undergraduate reverse engineering setting, the contextual needs assessment methodology can be realistically deployed and well received, and result in significant improvement in needs assessment. Data analysis identifies eight new context factors and eighteen question revisions to improve the generalized template. Survey results show students rated the contextual needs assessment methodology of medium-high value for their product and high value for a foreign product, comparable to the perceived value of benchmark methodologies such as a black box and activity diagram. The majority of students rate the proposed methodology as usable and useful. Free response comments are favorable towards the method, but reveal misunderstandings indicating the need for more thorough teaching. Case 2 demonstrates very similar results to Case 1 for graduate teams performing original design in a frontier context. Data analysis identifies four new context factors and eleven question revisions to improve the generalized template[x]. These case study results provide strong justification for continued improvement and applications of the methodology leading towards widespread dissemination in education as well as in field practice.

Table 16: Case Study Outcomes Summary

Case Study	Outcomes
Case 1: UT Reverse Engineering	• Assessment of designer perceptions of usefulness, usability, and re-use likelihood → validation of method in undergraduate reverse engineering application • Analysis of template customization → template revisions to increase usefulness and generality
Case 2: UT Assistive Technology	• Assessment of designer perceptions of usefulness, usability, and re-use likelihood → validation of method in graduate original frontier design application • Analysis of template customization → template revisions to increase usefulness and generality

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

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

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References and Endnotes

1. Tsang, E., 2001, *Projects That Matter: Concepts and Models for Service-Learning in Engineering*, American Association for Higher Education.
2. Duda, F. T., 2002, "Experiences with Identifying Senior Level Engineering Design Projects to Meet Developing Country Needs," *Proceedings of the 4th Christian Engineering Education Conference (CEEC)*, Montreal, Canada.
3. Green, M. G., A. Dutson, K. L. Wood, R. B. Stone and D. A. McAdams, 2002, "Integrating Service-Oriented Design Projects in the Engineering Curriculum," *ASEE Annual Conference*, Montreal, Quebec. American Society for Engineering Education.
4. VanderLeest, S. H. and E. G. Nielsen, 1998, "Global Engineering and the Liberal Arts," *ASEE Annual Conference*, Seattle, WA. American Society for Engineering Education.
5. Prahalad, C. K., 2004, *The Fortune at the Bottom of the Pyramid: Eradicating Poverty Through Profits*, Wharton School Publishing.
6. Green, M. G., 2005, "Enabling Design in Frontier Contexts: A Contextual Needs Assessment Method with Humanitarian Applications," *PhD Dissertation,* Mechanical Engineering, University of Texas, Austin.
7. Green, M. G., R. P. K. Palani and K. L. Wood, 2004, "Product Usage Context: Improving Customer Needs Gathering and Design Target Setting," *ASME Design Engineering Technical Conferences*, Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY.
8. Green, M. G., J. Tan, J. S. Linsey, C. C. Seepersad and K. L. Wood, 2005, "Effects of Product Usage Context on Consumer Product Preferences," *ASME Design Theory and Methodology Conference*, Long Beach, CA. American Society of Mechanical Engineers, New York, NY.
9. Mahajan, V. and K. Banga, 2005, *The 86 Percent Solution: How to Succeed in the Biggest Market Opportunity of the Next 50 Years*, Wharton School Publishing.
10. Cagan, J. and C. M. Vogel, 2002, *Creating Breakthrough Products: Innovation from Product Planning to Program Approval*, Prentice Hall, NJ.
11. I-TEC Portable Dental System, http://www.itecusa.org/pds.htm, May, 2005.
12. Otto, K. N. and K. L. Wood, 2001, *Product Design: Techniques in Reverse Engineering and New Product Development*, Prentice Hall, Upper Saddle River, NJ.
13. L.E.G.S. Homepage, http://www.letu.edu/legs, May, 2005.
14. Courage, C. and K. Baxter, 2005, *Understanding Your Users: A Practical Guide to User Requirements Methods, Tools, and Techniques*, Morgan Kaufmann, San Francisco, CA.
15. Ann, E., 2003, "Cultural Differences Affecting User Research Methods in China," *National Educational Conference, Industiral Design Society of North America (IDSA)*, New York.

16. Crawley, K., R. Holland and S. Gitonga, 2001, "Design, Development, and Marketing of Solar Lanterns," *Development by Design: 1st International Conference on Open Collaborative Design of Sustainable Innovation*, Boston, MA.

17. Chen, C.-H., L. P. Khoo and W. Yan, 2003, "Evaluation of Multicultural Factors from Elicited Customer Requirements for New Product Development," *Research in Engineering Design,* Vol. 14, No. 3, pp. 119.

18. Merriam-Webster On-Line Dictionary, http://www.m-w.com, January 29, 2002.

19. Ellsworth, K., S. Magleby and R. Todd, 2002, "A Study of the Effects of Culture on Refrigerator Design: Towards Design for Culture," *ASME Design Theory and Methodology Conference.*, Montreal, Que., Canada. American Society of Mechanical Engineers, New York, NY. Paper No: DETC 2002/EDC-34383.

20. Donaldson, K., 2002, "Recommendations for Improved Development by Design," *Development by Design: 2nd International Conference on Open Collaborative Design of Sustainable Innovation*, Bangalore, India.

21. Donaldson, K. and S. Sheppard, 2001, "Modification of a Methodological Design Tool for the Developing Country Scenario: A Case Study in Product Definition," *ICED01 13th International Conference for Engineering Design*, Glasgow, Scotland. Professional Engineering Publishing**,** pp. 505-512.

22. Donaldson, K. M., K. Ishii and S. D. Sheppard, 2004, "Customer Value Chain Analysis," *ASME Design Engineering Technical Conference*, Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY.

23. Donaldson, K. M. and S. D. Sheppard, 2004, "Approaches to Product Design in Kenya: Is Design Practice Universal?" *ASME Design Engineering Technical Conference*, Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY.

24. Clarkson, P. J., J. Ward, P. Buckle, D. Stubbs and R. Coleman, 2004, "Designing for Patient Safety: A Review of the Effectiveness of Design in the UK Health Service," *ASME Design Theory and Methodology Conference*, Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY.

25. Sutinen, K., G. Gustafsson and J. Malmqvist, 2004, "Computer Support for Requirements Management in an International Product Development Project," *ASME Design Engineering Technical Conference*, Salt Lake City, UT. American Society of Mechanical Engineers, New York, NY.

26. Maier, J. R. A. and G. M. Fadel, 2002, "Comparing Function and Affordance as Bases for Design," *ASME Design Theory and Methodology Conference*, Montreal, Que., Canada. American Society of Mechanical Engineers, New York, NY.

27. Norman, D., 2002, *The Design of Everyday Things*, Basic Books, New York.

28. Werner, D., 1987, *Disabled Village Children: A Guide for Community Health Workers, Rehabilitation Workers, and Families*, Healthwrights, Palo Alto, CA. Available: http://www.healthwrights.org/books/disabledvch.htm.

29. Werner, D., 1998, "Introduction 2 - Disabled Persons as Leaders in the Problem-Solving Process," *Nothing About Us Without Us: Developing Innovative Technologies For, By and With Disabled Persons*, Healthwrights, Palo Alto, CA. Available: http://www.healthwrights.org/books/nothingabout.htm.

30. Barnes, D. F., K. Openshaw, K. R. Smith and R. v. d. Plas, 2002, *What Makes People Cook with Improved Biomass Stoves? a Comparative International Review of Stove Programs*, World Bank.

31. Urban, G. and J. Hauser, 1993, *Design and Marketing of New Products,* 2nd Ed., Prentice-Hall, Upper Saddle River.

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

33. Rehabilitation Engineering and Assistive Technology Society of North America Homepage, http://www.resna.org, May, 2005.

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

35. Cox, D., S. Koshti, B. Jackson, A. Malish, M. Numan and D. Shipley, 1999, "Design of an Assistive Bowling Device," *Proceedings of the Rehabilitation Engineering Society of North America Annual Conference.*

36. Shimek, M., M. Van Wie, S. Kothawade, R. Subrahmanyam and M. Escobar, 2001, "An Assistive Technology Key Turning Device For Independent Entryway Access," *Proceedings of the Rehabilitation Engineering Society of North America Annual Conference*, Reno, NV.

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[i] "As a Professional Engineer, I dedicate my professional knowledge and skill to the advancement and betterment of human welfare …" (NSPE Code of Ethics for Engineers)

[ii] www.letu.edu/legs

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

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

[v] Specifically, usage context

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

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

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

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

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

Appendix A: Context Questions Template

Table 17: Context Questions Template – "How" Factors

HOW: Usage Application			
#	**Context Factor**	**Question Prompts v3.0**	**Response Notes**
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 18: Context Questions Template – "Where" Factors

WHERE: Usage Environment			
#	**Context Factor**	**Question Prompts v3.0**	**Response Notes**
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 19: Context Questions Template – "Who" Factors

WHO: Customer Characteristics			
#	**Context Factor**	**Question Prompts v3.0**	**Response Notes**
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)?	