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

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A new design method for frontier contexts is given a classroom assessment. The method adds the formal consideration of the design context to traditional customer needs assessment. Testing under both controlled and classroom conditions shows the new method is extremely effective, easy to use and well received by students. Implementation at three US schools has shown positive results signifying broad applicability in education as well as field practice. Here we present the essence of the method, results of testing and examples.

Keywords: customer needs; latent needs; task clarification; design methods; developing countries; assistive technology

INTRODUCTION

CLASSROOM ASSESSMENT RESULTS show that a new design method is especially well suited for contexts that are frontier or foreign to the designer. Engineering educators are recognizing the value of exposing students to need-based engineering problems and pedagogies [1, 2]. A parallel interest is globalizing the scope of engineering education. These important topics are addressed by a service-learning approach to globally-based humanitarian projects [3, 4, 5]. 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 ('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). However, the majority of engineering students are not familiar with the contexts in which vast needs exist, such as among persons with disabilities or the 4 billion people living on less than $2 a day (PPP) [6]. These conditions represent formidable frontier design contexts, environments and situations outside the experience and expertise of most engineering designers, especially 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 is notoriously problematic within frontier contexts, where data and contextual experience are not readily available. This challenge resonates with 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 unfamiliar, frontier contexts. In response to this need, we have developed a basic but powerful Design for Frontier Contexts methodology [7, 8] to improve discovery and application of contextual information vital to successful frontier design.

Grounded in empirical product-context studies [9, 10], the Design for Frontier Contexts method supports gathering, documenting and applying contextual design information. By improving needs assessment, the methods 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 mainstream consumer products to provide greater benefit to humanity with lower consumption of resources. The method also enhances the use of context-specific resources and provides a common template for collaborative communication among geographically diverse groups.

Evaluation under controlled conditions suggests that 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 have sought to integrate the method into the design curricula of our departments, and conduct ongoing assessment for continued improvement.

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 currently performed in developed countries, 86 per cent of the world lives in a developing country [11]. 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 [12]). 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 [13]. 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) [6]. 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 stage 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 the application of formal methods for discovering, documenting and addressing the product design context during the design process. Understanding how context factors influence customer needs and preferences greatly enhances the chances of defining products which will satisfy and delight customers.

A first benefit of improved contextual understanding is to facilitate and organize the needs gathering process. This contextual 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 the people interviewed view the product need through lenses of different context scenarios, and thus report different and sometimes conflicting needs as a result. This difference in context scenario viewpoint can easily become muddled or go completely unnoticed if the interviewer is not adequately prepared to identify and document contextual information.

Second, improved contextual understanding results in better target specifications by illuminating contextual influences on 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, even where benchmarking is possible, it is left to the designer to translate the voice of the customer into a meaningful metric and target value. For example, the customer request for lightweight must be translated into a quantity such as mass in kg. Even more difficult than quantifying a target value is the problem of determining appropriate metrics for qualitative needs such as easy to use (possibly measured by "number of steps to operate", and/or "minutes") or "good beverage taste" (possibly measured by saturation and bitterness levels) [14]. The customer may clearly indicate the need for portability, but setting specifications accordingly for mass and volume depends heavily on the context of transportation method and frequency.

Third, improved contextual understanding better equips designers to leverage benchmarking data from known contexts in order to design for unknown contexts by understanding how the contextual changes 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 crossover 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 [15]. 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 frontier Kenyan context.

Cross-cultural design in the literature

Understanding and accounting for cultural factors is a classic and major hurdle in frontier design problems. The following sources reference the importance and implications of various cross-cultural factors.

Courage and Baxter [16] include a case study by Ann [17], *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. [18] 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 per cent of households use kerosene lighting, and 70 per cent 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 subjugated by a few dominant members,
2) holding surveys during the day for travel safety of participants,
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. [19] 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. [19] 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 (authors' adaptation from [20]). Ellsworth et al. [21] 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. Ellsworth et al. 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 [22, 23] 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. [24] 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 [25] 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,
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.

Terpenny et al. [26] report Virginia Tech's inclusion of assistive technology design for developing countries into the first year curriculum to excite engineering students and begin building their global and social consciousness. The work reports that students from diverse backgrounds and interests responded very positively to 'international awareness and human centered activities'.

Hariharan et al. [27] report two case studies suggesting student engineering design projects in developing countries and 'other culturally unfamiliar situations' greatly benefit from 'immersive experiences', such as creating and testing prototypes. (In these cases the prototypes were trials of a new method, rather than trials of a physical product.) The experience of prototyping the new method in the target context brought about a shared understanding across disciplines and cultures. These findings suggest the validity in some cases of an 'experiencing before understanding' approach.

Lewis et al. [28] seek an effective engineering design curriculum for developing countries, and thus open a line of research into the different design processes (reverse engineering, specification-based, needs-based, AI) best matched to the different types of design needs (such as product copying, government contracts, consumer products, and mature mass-market products.) Their focus is not so much design *for* developing countries, but effective design *within* developing countries.

Gordon [29] touches on the cultural nature of design from a sociologists' perspective, and the ways in which designed artifacts 'design'—or change—the users. This highlights the importance of design engineering possessing a thorough knowledge of users' characteristics, beyond interaction with the product to be designed. Gordon additionally notes that division of labor separates the product designer creating meaning in the product from end users who then attempt, perhaps unsuccessfully, to create and apply their own meaning.

Cannon and Leifer [30] strongly emphasize the importance of perception or 'seeing' in effective design, a skill best learned when students are mentored to ask their own questions rather than being spoon-fed exact requirements. Asking the right questions is a key, they suggest, to the vital design skill of judging (and vetting) creative idea alternatives. The overseas product-based-learning course presented stressed cross-cultural issues and enhanced student opportunities to 'see' new problem approaches and thus increase innovation.

Enderle [31] overviews three NSF funded capstone programs which design devices for persons with disabilities. In all three of the case studies, problem definition is lumped in as part of project selection, usually involving client interviews. The paper states that determining requirements is 'one of the most important parts of the design process', and notes that the process of preparing questions and conducting an interview is very time intensive, and may require follow-up trips. All three of these cases involve significant student contact with end users or those representing them. Even though the importance of problem definition is recognized, there is no formal support mentioned to guide students in formulating, asking and applying relevant interview questions. Although it may be assumed that students were given some verbal classroom guidance, an opportunity exists here for formal methods providing guidance on how to conduct a thorough, efficient interview and then translate interview results into requirements.

Context and design in the literature

Language context adds to word meaning, and in the same way design context adds to product 'meaning' in the eyes of the customer. ('product or system' is simplified to 'product' from this point forward to enhance readability). Therefore designers must understand and account for context, defined in this paper as: the circumstances or setting in which an object occurs and which influences its value.

Numerous authors reference the influence of context on product design, and many explicitly express its importance. Our previous work [9, 10], for example, presents empirical studies of the influence of product design usage context on customer preferences. 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. The empirical studies of two product families showed that:

1) different context scenarios exist within the same functional family and even the same products,
2) customers surveyed prefer different products for different context scenarios,
3) clear relationships exist between context factors and attributes of the preferred products.

In summary, customer preferences depend heavily upon product context.

Clarkson, et al. [32] 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'.

Sutinen, et al. [33] 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'.

Maier and Fadel [34] 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 [35] 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 'dos 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.

Moskal et al. [36] present the development of the Humanitarian Engineering program at the Colorado School of Mines, USA. One of the major program outcomes is that all students (2,500 impacted as of 2007) would be able to 'explain how engineering solutions are impacted by the surrounding economic, environmental and societal context. . .'.

Examples of context in design

A World Bank meta-study of village stove programs identified 16 major causes of failure (or success) [37]. Eight of these reasons appear to be directly tied to how well context is understood and addressed such as failure to: account for actual conditions of use, resemble the traditional cooking system, accommodate large pieces of wood, or use locally available materials The report highlights the importance of context [37 p. 28]: 'For assessing consumer needs . . . determine the existing patterns of stove use . . . utensils used and food dishes typically prepared . . .[and] regional requirements'.

Two guidebooks for persons with disabilities in developing countries illustrate the importance of context [38, 39]. Wheelchairs from wealthy nations are often abandoned in the different contexts of developing countries from a failure to satisfy customer needs. In contrast to wheelchairs commonly seen in the US and Europe, ground level cooking requires a low-riding solution (shown in Table 1), hilly terrain may require a donkey, and rocky terrain requires large wheels.

Implications of context for product design

The previous sections detail the importance of a thorough understanding of design context, especially in cross-cultural or other frontier design situations. This importance is apparent in many literature sources and illustrated in the examples given of village cook stove programs and mobility

Table 1. Different mobility products for different contexts [39]

Design Need Context: Meals Cooked Low to the Ground

Context-Appropriate Product: Enables Reaching the Pot

Table 2. Product design context categories

Category	Sub-Category	Sample Context Factors
Usage Context	"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 • . . .

enabling devices. This information affirms the importance of accounting for contextual factors in order to design products delivering customer satisfaction. Without such contextual understanding, product development teams are at a marked disadvantage to competition that has obtained usage context insights. Just as importantly, in terms of the thesis of this paper, the potential success of student design teams is significantly diminished without an understanding of contextual information, for frontier design problems, but also any design problem given the typical limited experience of higher-education students. Methods for systematically and repeatably developing contextual information are thus needed. Such methods will arm students with a powerful tool in their engineering toolbox. These methods will also increase the potential success of student design projects, providing more rewarding and motivating higher education experiences.

CONTEXTUAL NEEDS ASSESSMENT METHODOLOGY

Product design context framework

Table 2 summarizes a framework for design context reported in prior work [9,10]. The framework sub-categories 'how', 'where' and 'who' conveniently organize the new contextual needs assessment method:

1) usage context factors include 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;
3) market context factors include aspects of competing products.

Benchmarking [14] 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 [14], a large gap remains for tools to accurately discover and apply usage context information.

Contextual needs assessment method

Fig. 1 summarizes the proposed contextual needs assessment method [7, 8]. The method improves 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 feasible by utilizing any of the factor identification techniques provided (Table 3, with detail in [8]). (Contextual factors are a single characteristic of a product's usage context such as 'usage frequency' or 'product surroundings.') Templates are the most basic and powerful technique provided for context factor identification, and a recent version is given in Appendix A (Current versions are available electronically from the first author). Step (2) of the method 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 such as like/

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)

Fig. 1. Contextual needs assessment methodology [7,8].

Table 3. 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

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dislike or articulated use. 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 segmenting the different factor value groups to be addressed by one or more products.

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 who are tackling a design need outside of their experience and expertise. More details of the methodology are available [7].

UNDERGRADUATE REVERSE ENGINEERING OF CONSUMER PRODUCTS

Design team background

The University of Texas at Austin Department of Mechanical Engineering undergraduate curriculum includes a senior design methods course followed by a semester of capstone design. Students apply design methods in a semester-long reverse engineering project re-designing a consumer product. The textbook [14] presents a three-phase design process:

1) task clarification (understanding the re-design need),
2) concept generation,
3) concept implementation (detailed design and prototyping).

In the first phase students use a number of tools to understand the redesign need such as: a mission statement, a checklist of technical questions, and articulated-use or like/dislike customer needs interviews [14, 40]. Additionally, students perform reverse-engineering steps such as prediction, product teardown and functional modeling to identify redesign avenues. Students choose one or two high-priority redesign avenues, based on the understanding gained of the redesign need. Accuracy and completeness of customer needs is critical

to maximize the redesign value added to the customer. This design methods course is 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 design engineers the proposed methodology is intended for.

Classroom delivery of the methodology

For this study, task clarification lectures used in past semesters are augmented with additional steps to enhance understanding of the redesign need context. Students are provided with the five-step method shown in Fig. 2 and an Excel template in which each worksheet tab corresponds to one step of the method. The method would ideally be presented step-by-step in an interactive class lecture format in which each step is illustrated live. After each step is partially demonstrated, a completed version of the template in Appendix A would be reviewed in a prepared example and distributed via a courseware website. However, classroom realities limit the time available, so in this case the methodology is 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.

Methodology results—customized context questions

Fourteen out of 20 design teams volunteered their data for this study. The data submitted are analyzed in detail to assess patterns and insights into how the teams customized the context questions template. A major purpose of this assessment is to glean insight to improve the generalized

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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 be answered, or may be better answered through research.

Fig. 2. Contextual needs assessment methodology—case study version.

Table 4. Four forms of context elicitation questions

1. *Question Form: What is _____ (context factor)?*
   Example: What is the cost & availability of possible energy sources?
   Analysis: This question is the most basic and direct type, 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?
   Analysis: This question bears similarity to a like/dislike interview technique and in the same way it is most effective when the current product is similar to the future product (as is the case with reverse engineering re-design).

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?
   Analysis: This question bears similarity to an articulated use interview, and requires both customer and interviewer to have a clear mutual understanding of the solution being discussed.

4. *Question Form: What product attributes are needed in light of (context factor)?*
   Example: How long should the batteries last for jogging?
   Analysis: 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.

template (an earlier version of Appendix A) for future use. Virtually all of the customized questions written by the teams take one of the four forms listed in Table 4.

Modifications which depart from form #1, although helpful for the team's specific project, are often not appropriate for a template intended to be generalizable across products and types of design other than reverse engineering and redesign. 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 [7], including details of each change made to the template as a result of this case study.

Many teams included suggested responses in the wording of questions (e.g. leading questions) to facilitate both correct interpretation and consideration of multiple possibilities. Listing suggested responses in the customized template clarifies the question and can make it more specific to the design problem. The drawback is potentially bias-ing the interviewee with suggested responses to the point of suppressing an accurate response.

The use of a scale was included in one team's data ('rate needed durability on a scale of 1–10'). Such a numerical scale provides some value, and semantic scales hold even greater potential for future work.

In the final analysis, design teams found that the questions provided in the template matched their perception of important contextual issues, and new questions introduced are distilled into generalizable form and incorporated into newer versions of the template.

Survey results—designer perceptions of the method

An online survey measured designer perceptions of the contextual needs assessment method. The survey reports data on participant background, perceived value of the methodology and reuse likelihood and perceptions of the usability and usefulness of the methodology. Survey results for the reverse-engineering class are extremely positive in all aspects.
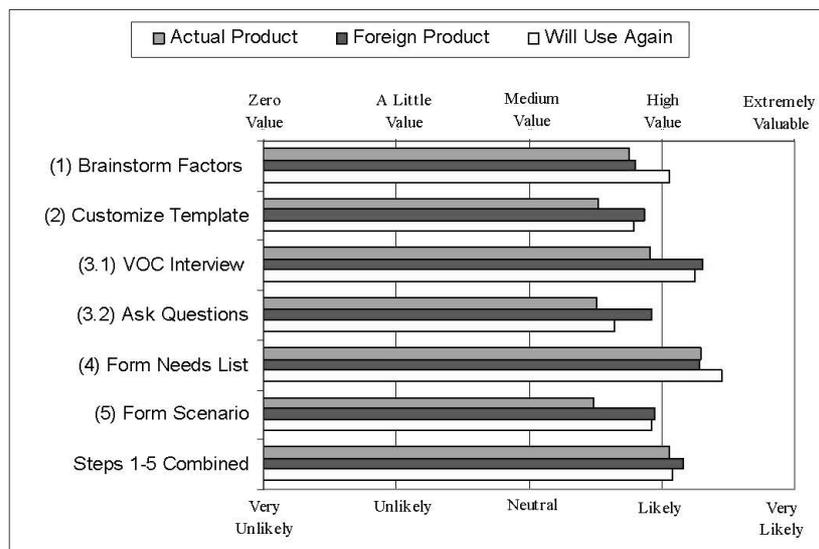

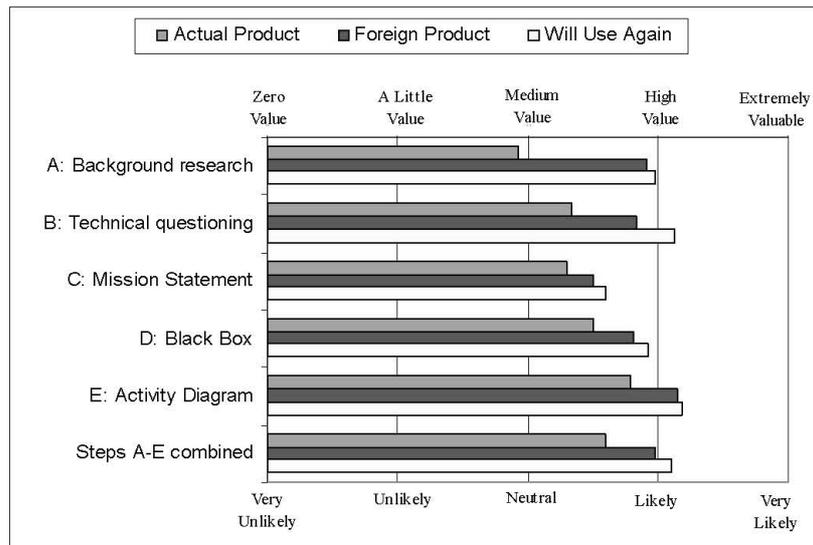Fig. 3. Experimental methodology—perceptions and reusage likelihood

Fig. 4. Benchmark methodologies—perceptions and reusage likelihood

Fifty-seven students responded to the survey, 61 per cent of the class. The survey participants self-reported demographics indicate 84 per cent are male and 16 per cent 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 per cent of the respondents agree they were personally 'very involved' in using the contextual needs assessment method.

Perceived value of methodology and reuse likelihood

Fig. 3 shows the perceived value of the contextual needs assessment methodology compared with other benchmark methodologies shown in Fig. 4. (These students have not yet used traditional needs assessment methods, so other aspects of design methodology familiar to the students must be used as a comparison.) Comparing Figs. 3 and 4 show that the new methodology has an equal or higher perceived value than the benchmark methods shown. Both figures distinguish between perceived value for the respondent's actual class design project and 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 between neutral and likely.

Perceived usability and usefulness of methodology

Table 5 presents survey data rating the perceived usability of the contextual needs assessment method. The data show a high level of agreement with all statements related to usability, and neutral agreement on whether the method needs improvement. Table 6 similarly shows a high level of agreement for the perceived usefulness of the method.

Participant free response comments regarding methodology

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

- '[The method] really helps in organizing all of the data . . . It is very effective in identifying our customer needs'. Analysis: Some students commented positively on the effortless organizational structure the template provides.

Table 5. 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.*	0% (0)	14% (8)	28% (16)	**49% (28)**	9% (5)
The above method does <u>not</u> need improvement.*	0% (0)	24% (13)	**49% (27)**	22% (12)	5% (3)
The above method is <u>not</u> difficult to understand and use.*	4% (2)	12% (7)	18% (10)	**58% (33)**	9% (5)

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

Table 6. 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.*	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.*	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)

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

- '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 [customer needs]'. Analysis: Perceived redundancies of the method are noted; however many experts agree needs assessment should give a very thorough coverage due to the high cost of missing needs.
- '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'. Analysis: Students may find this method initially very tedious, but will (hopefully) see its benefits later.

The free response results also show that some 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 . . . So as students when we are given such a defined sheet we loose some of the learning by not thinking of these questions ourselves'. Analysis: This student did not understand that brainstorming questions is part of the method (steps 1 and 2).
- 'Minimize context questions and let interviewer feel more free to ask questions based on how the interview is flowing'. Analysis: 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'. Analysis: This student did not understand that the method specifies that the like/dislike (or similar) interview technique (step 3.1) should be used prior to the context questions (step 3.2).

Conclusions

The above case 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.

GRADUATE STUDENTS ORIGINAL DESIGN OF ASSISTIVE DEVICES

Design team background

The second case study was conducted within the graduate Product Design and Prototyping class at the University of Texas at Austin in 2005, which culminated with students delivering fully functional prototypes to local 'customers' with physical disabilities. Projects required the novel synthesis of $100–$300 of low to medium technology, following the product development process [14] taught in the class. For example, the switch activated ball

Fig. 5. Switch activated ball thrower [41].

thrower (Fig. 5) is a portable device enabling students with limited mobility, strength and coordination to participate in ball throwing activities integrated with their peers [41]. Since 1994, over twenty teams from UT Austin have presented at the annual RESNA conference as winners of the international student design competition [42].

The contextual needs assessment method is delivered for the graduate prototyping class in essentially the same way as for the undergraduate reverse engineering course (Fig. 2). The graduate class is divided into three teams of 5–6 students each, and all three teams submitted their contextual needs assessment data for the study. The three projects addressed:

1) fold clean laundry for storage (with portability and switch activation),
2) automatically provide a rocking motion to a chair to soothe students with cerebral palsy,
3) provide multi-sensory rehabilitative stimulation when activated by visually impaired students in a classroom.

Methodology and survey results: customized questions and designer perceptions

Similar to the reverse engineering undergraduate teams above, virtually all the customized template questions students developed in the graduate study take one of the four forms previously listed in Table 4. Again modifications which departed from form #1 in Table 4, although helpful for the specific project, were often not appropriate for a template intended to be generalizable across a variety of design projects. 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 [7], including details of each change made to the template as a result of this case study.

An online survey measures designer perceptions of the contextual needs assessment method, essentially identical to the survey discussed above. The survey data included participant background, perceived value of the methodology, reuse likelihood and perceptions of the usability and usefulness of the methodology. Similar to the undergraduates survey, results for the graduate students are extremely positive in all aspects. Most respondents and their teams report being 'very involved' in using the contextual needs assessment method. Data show that participants have a high level of previous design experience and virtually all believe in the importance of design in both education and engineering practice.

Perceived value of methodology and reuse likelihood

Fig. 6 shows that the contextual needs assessment methodology has equal or higher perceived value than the standard 'benchmark' methodologies shown in Fig. 7. Both figures distinguish between perceived value for the respondent's
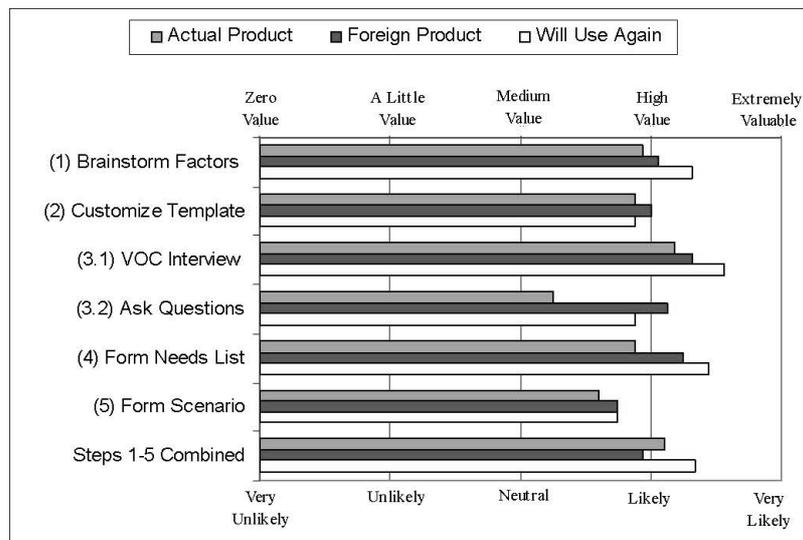

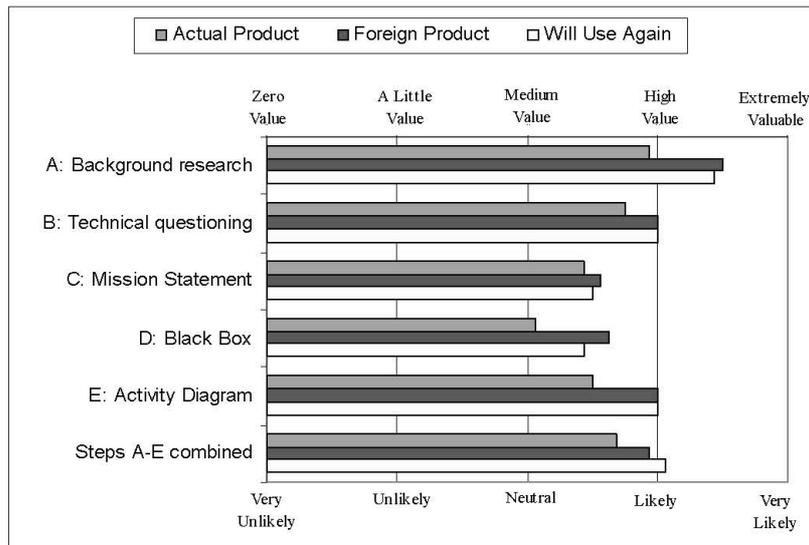Fig. 6. Experimental methodology: perceptions and reusage likelihood

Fig. 7. Benchmark methodologies: perceptions and reusage likelihood

actual class design project and 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 between neutral and likely.

Perceived usability and usefulness of methodology

Table **7** presents survey data rating the perceived usability of the contextual needs assessment method. The data show 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.

Participant free response comments regarding methodology

The free response comments in the online survey are very positive regarding the contextual needs assessment methodology. The graduate students surveyed rated the method even more positively than the undergraduates, perhaps because they were performing more challenging original designs

in a frontier context and thus the value of the method was more obvious. Sample characteristic responses are listed below with analysis comments:

- '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.
- '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 . . .'

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)	0% (0)	6% (1)	**69% (11)**	25% (4)
I like using the above method.*	0% (0)	0% (0)	6% (1)	**62% (10)**	31% (5)
The above method does not need improvement.*	6% (1)	19% (3)	**62% (10)**	12% (2)	0% (0)
The above method is not difficult to understand and use.*	0% (0)	0% (0)	19% (3)	**69% (11)**	12% (2)

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

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.	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 <u>do not</u> still feel uncertain about the design need.*	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 <u>not</u> have been the same even without the <u>above</u> method.*	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)

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

- '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'. Analysis: This is a classic weakness of customer self-reported information. The articulated-use portion of the interview prescribes observation when feasible, but when no comparable product exists this is limited to observing the environment.
- ' . . . some customers who do not think of a product in such detail . . . tend to get annoyed or bored'. Analysis: Some teams prioritize questions and adapt the list to the customer's attention span.
- 'an initial discussion with the customer . . . may facilitate forming a much more effective questions template'.
- '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]'. Analysis: 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 analo-

gous product . . .' Analysis: This is an important avenue for future work, and can be addressed in large part by the development of semantic inquiry scales.

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 illustrate application of the method, and provide data for continued improvement of the usefulness and generality of the method.

Table 9 summarizes the outcomes of the two case studies discussed here. The first 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. 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. The second case study demon-

Table 9. Case study outcomes summary

Case Study	Outcomes
Case 1: UT Reverse Engineering	• validation of the method in an undergraduate reverse engineering application • template revisions to increase usefulness and generality
Case 2: UT Assistive Technology	• validation of the method in a graduate original frontier design application • template revisions to increase usefulness and generality

strates very similar results for graduate student teams performing original design in a frontier context. 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.

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 assessment method is not only classroom-ready, but also project-ready. As data are 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. To foster this community, a web repository will archive the most recent general templates along with completed project templates to facilitate information re-use.

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APPENDIX A

CONTEXT QUESTIONS TEMPLATE V3.0—ONE-PAGE REFERENCE VERSION

HOW: Usage Application			WHERE: Usage Environment			WHO: Customer Characteristics		
a0	task application	What specific purpose(s) will product be used for? How will the product be used?	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?	c0	user	Who will use the product? (Choose it? Buy it?) What user characteristics affect what the product must be like?
a1	task function	What major function(s) should the product provide?	e1	surroundings (sound)	How noisy are product surroundings? How much noise from the product is acceptable?	c1	user skills & education	How skilled/experienced is the user with the task? What is the user's education level?
a2	task quality	What quality of the primary function is needed?	e2	weather/climate	What weather/climate will product be exposed to?	c2	physical ability	Does the user have any physical conditions that may cause difficulty performing the task? (strength, control, range-of-motion, vision).
a3	task process	What is the current usage process? How will product change the current usage process?	e3	environment ruggedness	What objects and substances will product interact with? Will product be exposed to any unusual substances or conditions?	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?
a4	task frequency	How often will product be used?	e4	space (when in use)	How much space is available for using product?	c4	relevant customs and practices	Are there any cultural practices or expectations related to this product?
a5	task duration	How long will product be used each time?	e5	space (storage)	How and where will product be stored? How much space is available for storing product?	c5	cost expectations: (purchase)	About how much is the buyer willing to pay to purchase this product?
a6	task quantity	How much quantity of the product's output is needed? At what rate should the product perform?	e6	aesthetics of surroundings	What do the product surroundings look like? How should the product interact w/ the surrounding aesthetics?	c6	cost expectations: (operation)	How much is the user willing to pay/work monthly to operate this product?
a7	task ruggedness	How roughly will product be handled/treated?	e7	maintenance & parts cost & availability	What is the cost & availability of maintenance & parts?	c7	cost expectations: (maintenance)	How much is the user willing to pay/work monthly to maintain this product?
a8	transportation type & amount	How often, how far, and in what way will product be transported?	e8	energy availability & cost	What is the cost & availability of possible energy sources (human, battery, gas, electric, biomass)?	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?
a9	operator position	What physical position will the user be in (standing, sitting, hands occupied)?				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?
a10	cleaning	How and where might the product be cleaned?				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)?

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