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The Application of Retrospective Customer Needs Cultural Risk Indicator Method to Soap Dispenser Design for Children in Ethiopia

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ABSTRACT

We present here the design and analysis of a cost-effective soap dispenser that prevents bar soap theft in schools in developing countries. The intended region of deployment is within Ethiopia and surrounding areas. Lack of public hygiene is attributed to 1.4 million global deaths annually due to preventable diarrheal diseases. Using soap while washing hands is estimated to decreases death due to diarrheal diseases by half. Theft of soap from public wash stations, such as those found in schools, is believed to contribute to the spread of diarrheal diseases. Currently there exists no adequate cost-effective solutions to protect bar soap from theft although there appears to be a demand and there is a need for such a device.

An undergraduate student mechanical design team in a sophomore design course at Purdue University was tasked with developing a soap dispenser that prevents theft of bar soap. The project prompt was provided by Purdue Global Engineering Programs' Innovation to International Development (I^{2}D) Lab. Students were instructed to complete the first step (Product Concept) of the Lean Design for the Developing World (LDW) method to develop a Minimum Viable Product (MVP). The team then completed a retrospective analysis of the MVP using the Customer Needs Cultural Risk Indicator (CNCRI) method to determine potential shortcomings that may be identified in the second step (Validated Learning) of the LDW method. Several customer needs and their component and design solutions that need close monitoring during the second step of the LDW method were identified. The highest risk customer needs included: culturally appropriate design, aesthetic appeal, security, and durability.

Based on the experiences of the design team, several important lessons were learned that can both be applied to improving the secure bar soap dispenser product and to the broader field of product design for the developing world. These lessons include: Customers in the developing world may be more concerned with cost than durability, cultural appeal of a device is highly dependent on first -hand experience and can easily be misunderstood or misrepresented, the LDW method is an invaluable tool in identifying customer needs that may be overlooked due to cultural and socio-economic differences. The use of the LDW framework and the CNCRI method in an undergraduate design group was found to be useful, viable, and valuable to both the undergraduate student learning outcomes and the development of a product that can be deployed to its intended market. Further development of an end-to-end tool chain is needed to better integrate product development for the developing world into mainstream engineering curriculum.

I. INTRODUCTION

Diarrheal diseases cause 1.4 million deaths per year primarily in developing countries [1]. Many of these deaths would be prevented by the implementation of hand washing programs and the use of soap [2]. The use of soap in countries with high incidence of illness and death due to diarrheal diseases holds the promise of decreasing preventable deaths [2] and increasing worker participation in the economy. One barrier to implementation of handwashing and soap use is the prevalence of theft of publically accessible bar soap. While many communities impacted by preventable diarrheal diseases practice handwashing, soap use often does not occur at public wash stations due to bar soap theft (see ANNEX A). Prevention of theft of soap while maintaining availability of soap is important to contributing to disease prevention.

An undergraduate student design team in a sophomore design course at Purdue University was assigned as part of ME 263 – Introduction to Mechanical Design, Innovation, and Entrepreneurship the task of designing a low-cost, secure, and culturally appropriate product to prevent bar soap theft at public wash stations while maintaining soap availability. The team

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developed a Minimum Viable Product (MVP) within the Lean Design for the Developing World (LDW) framework and retrospectively analyzed the MVP for potential cultural misunderstandings of cultural needs using the Customer Needs Cultural Risk Indicator (CNCRI) method. It should be noted that the CNCRI was originally envisioned as an a priori design tool although in this case CNCRI was used after the MVP was developed but before deployment. The Global Leadership and Organizational Behavior Effectiveness (GLOBE) Survey [3] was used as the data source for the CNCRI method with awareness of the shortcomings of the GLOBE Survey as a source of viable data.

This paper provides a case study of both LDW and CNCRI in use in an undergraduate course, and gives insight into how to successfully deploy a product design for the developing world process into mainstream undergraduate curriculum. Much remains to be done to have an easily implementable process appropriate for undergraduates but the advances made in this paper illustrate the potential.

II. BACKGROUND

The project is geared towards contributing towards multiple Millennium Development Goals (MDGs) as stated in the UN Millennium Declaration. It primarily relates to Reducing Child Mortality and Ensuring Environmental Sustainability. Since the main goal of this project is to improve sanitation, it primarily falls under Ensuring Environmental Sustainability under Target 10, Indicator 31 which states, "Proportion of population with access to improved sanitation, urban and rural (UNICEF-WHO)" [4].

2.1 Handwashing and Soap Usage Importance in Disease and Mortality Prevention

The use of soap in hand washing is highly effective and essential for sanitation and preventing diarrheal diseases. An estimated one million lives per year could be saved if effective hand washing was a common cultural practice [2].

The major problem at hand stems from the fact that in poor regions of developing countries such as Ethiopia and other African countries, it is not common cultural practice to wash hands with soap and it is not always financially possible. However many relief services have attempted to solve this by encouraging hand washing and by providing bar soap and handwashing stations to school children. However many children still do not have access to the soap in schools due to its high perceived value. In these regions soap is a valuable commodity and is often stolen for dishwashing and to wash clothes. As a result of this constant theft, schools do not provide soap for their students because it becomes too much of a financial burden. The device needs to be designed for bar soap instead of liquid soap due to its low cost and availability compared to that of liquid soap.

2.2 Design for the Developing World

Before discussing design for the developing world, it is important to define our usage of the term "developing world." Paul Polak in "Out of Poverty" estimates that 90 percent of engineering designs focus on developing solutions for ten percent of the world's customers. We use the broad definition of the "design for the developing world" to encompass product design for what Polak calls "the other 90%" [5]. An economic definition of "the other 90%" is those who live on less than $10USD per day.

The engineering design community has made significant contributions to developing world contexts. Such contributions include the leveraged freedom chair, a specialized wheel-chair that enables people with physical disabilities to traverse rough terrain [6]; the provision of intervention strategies to assist remote off-grid villages in Mali with better energy solutions [7]; and provision of guidelines for the design of cook-stoves [8].

Furthermore, design for the developing world encompasses a range of design and customer/community interaction techniques and methods that are appropriate to developing world conditions. Many of the methods and techniques assist engineers in better understanding the cultural and societal conditions in which they are working. This is especially important for when engineers are working in cultures or societies that are very different than their own. Design methods such as the Human Centered Design (HCD) Toolkit developed by iDEO have made a big impact on engineers better understanding their clients and working with communities in a compassionate and holistic manner [9-10]. Other techniques and information such as the nine design for the developing world principals identified by Mattson and Wood [11] a product use context method [12] validated in a developing world contexts [13], and the common pitfalls that engineers often fall into and methods of avoiding those pitfalls [14] are important and useful tools for design engineers. Further methods that are specifically important to the work presented in this paper are described below.

2.3 Product Design Methods

A typical product design process consists of three broad phases: problem definition, concept generation, and detailed design [15-16]. The problem definition phase involves assessing the customer requirements often through surveys, observations, and various other techniques for gathering information [17]. These requirements are typically organized using the House of Quality (HoQ) which maps customer requirements to engineering requirements. Research is done on existing products to identify key benchmarks and to set targets for the engineering requirements defined by the engineer. Market research is often done to determine key trends and opportunities for the future of the product being developed. In the concept generation phase, techniques for generating physical solutions for the product ensue. Functional decomposition is often used to help the engineer think in more general terms about the overall function that their product should ultimately provide. Morphological analysis is used to convert the key functions identified into physical embodiments that can be combined to generate a variety of concepts [18]. Decision tools such as Pugh Matrices help the engineer evaluate their concepts with respect to a DATUM, often times an existing benchmark on the market. Engineering models are developed for the selected concept to determine product dimensions, performance measures, and other key design specifications. Where appropriate, a low-fidelity prototype is developed to gauge form characteristics. The selected concept then moves into the detailed design. Tools such as Design for Assembly, Failure Modes Effects Analysis, and others are used to refine the design. A higher fidelity prototype/proof of concept is typically developed at this stage. The Ullman textbook provides a great review of these key steps in a product design process [10].

2.4 Lean Design for the Developing World

The Lean Design for the Developing World (LDW) method developed by Pease et al. [19-20] was developed as a complementary method to HCD where much of the up-front investment in deep community understanding is instead replaced by an iterative design and product deployment approach adopted from the lean startup literature [21]. LDW is explicitly designed for use with new product development in developing world situations. The LDW method is built around the rapid deployment of a Minimum Viable Product (MVP) to the market that is developed in conjunction with three hypothesis used to quantify return on investment of the consumer and profit of the company, growth of the market segment, and net positive impact on the consumer. After an appropriate time in the market, the MVP is evaluated to ensure that the three hypotheses are satisfied. If the three hypotheses are not satisfied, additional work must be done to redesign the product to meet hypothesis targets or the product must be withdrawn from the marketplace. Nokero is one such company that uses a version of the LDW process (and was instrumental in formalizing the LDW process) in their work [22].

2.5 Customer Needs Cultural Risk Indicator

The customer needs cultural risk indicator (CNCRI) method is an early design tool that helps engineers understand where customer needs may be misinterpreted due to cultural differences between the customers and the design engineers [23]. CNCRI relies on cultural dimensions information from sources such as the GLOBE Study [24] or Hofstede's Cultural Dimensions [25-26]. There are limitations to the GLOBE and Hofstede dimensions such as only a small group of countries being represented in the datasets (only 62 countries for GLOBE and fewer for Hofstede), the data being collected from mid-level managers rather than a broader swath of society, and the resulting cultural dimensions being targeted at a business audience rather than an engineering audience. In spite of their shortcomings, the cultural dimensions of GLOBE and Hofstede are currently the best available and still provide useful insights.

The HoQ is the focus of the CNCRI's implementation where a new column is added to calculate the relative risk of a customer need being misinterpreted by the design engineers due to a cultural misunderstanding. When a customer need is identified as being high risk, several mitigating actions can be taken including bringing in an outside cultural expert, using HCD techniques to develop a better cultural understanding of that customer need, or using LDW to rapidly test that specific customer need. Initial testing at Purdue University (detailed in this paper) and the Colorado School of Mines has shown that CNCRI is useful to help students better understand potential cultural misunderstandings embedded within customer needs.

III. CONTEXT OF PRODUCT DEVELOPMENT

The following section describes the campus context in which the product development took place. This work represents an integration of a sophomore design course called ME 263 – Introduction to Mechanical Design, Innovation, and Entrepreneurship; partnership with the Innovation for International Development (I^2D) Laboratory part of the Global Engineering Programs (GEP) at Purdue University; and their partnership with a problem presented by the Catholic Relief Services (CRS), an organization based in Ethiopia.

3.1 Introduction to Mechanical Design, Innovation and Entrepreneurship (ME 263) at Purdue University

ME 263 is a cornerstone course in the School of Mechanical Engineering (ME) at Purdue University. It is the first of a series of design courses that mechanical engineering students take typically during their sophomore year. Each semester, a broad problem statement is provided based on a theme. Students then must then follow the process described in Section 2.3 to narrow the broad problem statement into a clearly defined problem and ultimately to a refined design.

In the Fall 2015 semester, the project theme for the semester was based on "Innovations to Baby and Toddler Devices". The team was inspired to do a project that involved providing more sanitary environments for infants in day care. However, when they learned of the design problem proposed through the I^2D Lab, they opted to work on it because "they wanted to do something that makes a real impact".

3.2 Innovation for International Development (I^2D) Labs Prompt Summary

The I^2D Labs is part of the Global Engineering Program at Purdue University. The GEP is responsible for study and work abroad opportunities for students and faculty in the College of Engineering. The mission of the I^2D Labs is to "*to foster a vibrant community of faculty, staff, and students working with international partners to address grand challenges in international development based on engineering innovations and market-driven approaches. This includes research, design, adaptation, and field-testing of appropriate technologies and* *services that have a strong scaling potential as solutions for energy access, healthcare, water and sanitation, labor-saving innovations, and disaster/humanitarian response."* [27]. Each year, they put out a call for proposals. Co-author Reid was aware of the topic ***"Re-inventing hand washing with soap in schools"*** (see ANNEX A) and presented it to the team.

Catholic Relief Services (CRS) has partnered with the I^2D Lab at Purdue University to create a project in which they have tasked students with designing a cost-effective solution that prevents bar soap theft in schools. If soap could be provided in schools, it would not only save lives because of improved hygiene, but it could also start a culture of handwashing and hygiene among children in these areas, vastly improving health and the quality of life.

IV. PRODUCT DEVELOPMENT

The next section describes the product development process used by the team during the semester long course. Since the customer needs were already presented through the design prompt (ANNEX A), the team began their design process with market research and benchmarks.

4.1 Market Research and Benchmarks

Market research was divided into three potential market sectors corresponding to three market visions for the project. These three visions for hand sanitation include the global market, local manufacturing, and relief service sustainability. It was important to research various market standards at each of these levels to get a full picture of the scope of the design.

The team found that at a global level, hand sanitation products generated an estimated $52 billion dollars in revenue. The current global market is seen as highly competitive with key trends supporting low-cost and foreign production. The U.S. market for soap products has decreased by .7% over ten years. The team has concluded that a global market vision for production in the U.S. may be unsustainable for the future product. However, Chinese production of soap products alone has increased by 13.2% over the past 10 years [28]. With new soap brands favoring foreign production, market research supports potential production in developing countries as a viable market option.

If instead the team focuses on local sustainability of the device, new factors must be included. At a local level, the most important factor for sale as well as use is public awareness. More than 95% of families in Uganda were reported to have access to soap in their households. However only 5% of these families used soap on a regular basis for handwashing. The use of water was only slightly higher with 57% of people observed to use water after using the restroom [29]. The team has concluded that at a local level, the device must encourage hand-washing with both soap and water as a large factor of the design. The team believes that a successful device must be placed very close to the water sources that are already in use. These social tendencies indicate that soap use could be dramatically improved at a local level with the right device. The team hopes to design a product that will meet these needs and target these market trends.

The team also considered the option of sustainability by relief services. There are currently many global service initiatives aimed at improving both access and use of soap. The global soap project alone has reduced the incidence of childhood deaths due to poor hygiene by an estimated 30% since 2009 [30]. The option to work with these service providers is appealing as they work to meet similar goals. However, research at the local level points to the best solution being a combination of both local and relief service support. The team believes that there is a large market with few barriers to entry at this level.

SOAP examined important benchmarking products at both a local and global level. Global benchmarking products included liquid soap dispensers (Soft Soap), foaming soap dispensers (U Line), Bar Soap (Dove), and Hand Sanitizer (Purell). Though many of these devices were cheap and made from easily acquirable and recyclable materials, none met standards for security. There is no current solution that uses solid bar soap. These devices do provide many ideas for mechanical means of dispensing soap. The team will be looking closely at these means as they relate to accessibility and convenience.

The team reviewed hand sanitation designs as they exist in Ethiopia. The tippy-tap is most common (bottom right of the figure). The other 3 are design concepts developed by Dogan Sekercioglu, a design student at the Institute of Umea. They are called the mrembo, twiga, and karai,. Below pictures of these devices in order in Figure 1.

Figure 1: Mrembo, twiga, karai, and tippy-tap

All of these devices utilize hanging bar soap on a string. Though convenient, the team will look for a more secure method of housing the soap on a similar device. By survey, the most popular of the four devices was the mrembo (pictured bottom left) [30]. However, the most common device seen locally was the tippy-tap (pictured bottom right). All of these devices utilize locally available construction material. The team will need to make sure that the ultimate device has these same qualifications as well as be potentially compatible with any of these devices. The team also did patent research. The results included conceptual devices in which soap was securely housed and soap was sliced off in thin portions. Although the designs were applicable, the mechanism for slicing the soap was not highly regarded by the team due to the complexity of the design [31].

4.2 Quality Function Deployment

"Quality Function Deployment serves as a powerful tool for capturing and translating customer needs into actionable engineering metrics" [21]. The team chose to create a House of Quality (HoQ) which is a form of QFD. It is a common tool among engineers. The "Who" vs. "What" portion of HoQ designed by the team can be seen in Table 1.

Table 1: HoQ -Who vs. What

HOUSE OF QUALITY	Who (Customers)		
What (Customer Requirements)	Children	School Staff	Relief Services
Cost		8	8
Security	2	10	10
Variability of Source		8	6
Durability	4	8	8
Sanitary		8	8
Ease of Installation		8	6
Aesthitic Appeal	8	5	5
Efficiency (soap life)	3	6	6
Safety	10	10	10
Ease of Use	9	8	8
Culturally Appropriate	7	6	5
Manufacturability (Local)		6	8
Maintenance		9	6
Consistent Dispensing		7	7

The "What" column shows the customer needs that the team identified. Due to limitations in gathering customer input weights were determined by students' intuition.

4.3 Functional Decomposition (FD)

The team created an initial basic user friendly design featuring a housing that contained soap, a grater that could be pushed along the soap to shave off an individual portion, and some guides and safety features at the base of the housing to allow the soap to exit the device into the user's hands while preventing access to the grater to prevent injury.

This design, although potentially effective, does not consider many of the other possibilities for the device. However this design allowed the team to hypothetically determine the physical features that the device would need to have. In order to determine the other possibilities the team created a function tree which outlines the basic functions that the device will have. The function tree can be seen below in Figure 2.

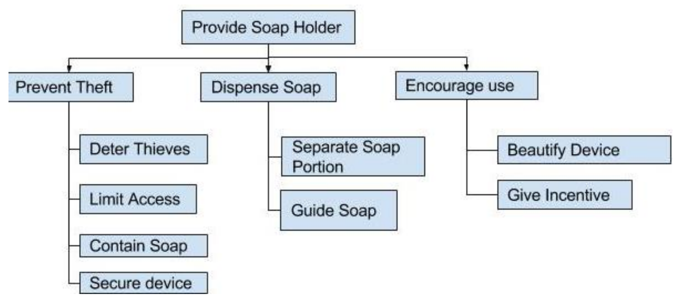

Figure 2: Functional Tree

4.4 Morphological Chart

Following the FD, the team created a morphological chart that included at least five different methods for achieving the desired functions. Students were encouraged to include at least one "outlandish" or different feature to ensure they were thinking outside of the box. The chart can be seen in Table 2.

Table 2: Morphological Chart

Functions	Methods 1	Methods 2	Methods 3	Methods 4	Methods 5
A) Deter thieves	Noisy	Light	Sharp edges	Make scary	Destroy before removal
B) Limit access	Limit time interval between uses	One-way loading	Lock and key	Electrify	Require key card
C) Contain soap	Put in box	Glue soap to device	Nail soap	Place on a rope	Partial exposure
D) Secure device	Bolts	Post	Clamp	Electromagnets	Glue
E) Separate soap portion	Shave	Crush	Grind	Blend	Rub
F) Guide soap	Gravity fed	Spring	Drawer	Electronic dispensing	Mixed with water flow
G) Beautify device	Color device	Create enjoyable texture	Scent soap	Include lighting	Include graphics
H) Give incentive	Dispense soap in shape of smiley face	Diagram steps of hand washing	Ring a bell when used	Dispense money with soap	Removable indicator/use counter

4.5 Concept Design Generation

The team then used the above chart to create 16 new design concepts that feature at least one different method for each function. This is kind of rapid brainstorming in which a design group is able to generate multiple ideas by avoiding mere application of brute force. These 16 "best" ideas were analyzed by gut-feel in which the more unrealistic designs were discarded.

4.5.1 Decision Matrix

During the first cut the designs were narrowed from 16 to 4. These final 4 designs were all very similar except they mainly differed in their method of separating the soap portion. Instead of using a decision matrix to narrow the designs down to one final design, a decision matrix was performed for function "E)" as seen in the Table 3.

As can be seen in the matrix in Figure 3, the five functions for separating the soap were weighted against the customer requirements to determine the best method. The "shaver" faired the best and was chosen for the final design. The "shaver" features perforated sheet metal in which edges on one side are raised. The end result is very similar to that of a cheese grater.

Table 3: Decision Matrix

		CONCEPTS				
CUSTOMER REQUIREMENTS	WEIGHTS	Shaver	Grinder	Crusher	Mesh	Unsecure Bar Soap
Low Cost	5	0	0	0	0	
Security	10	1	1	1	0	
Durability	5	0	1	-1	0	
Ease of Use	5	1	-1	-1	-1	
Safety	5	1	1	-1	0	
Ease of Installation	1	-1	-1	-1	-1	
Limited moving parts	5	1	-1	0	1	
Local Manufacturability	5	0	-1	-1	1	
Sanitary	1	1	1	1	0	
Total +		5	4	2	2	
Total -		1	4	5	2	
Overall Total		4	0	-3	0	
Weighted Total		25	5	-10	4	

4.5.2 Rough Design

Following the process in which the 16 designs was narrowed down to one, the team created a sketch in which the chosen methods were integrated. The sketch can be seen in Figure 3.

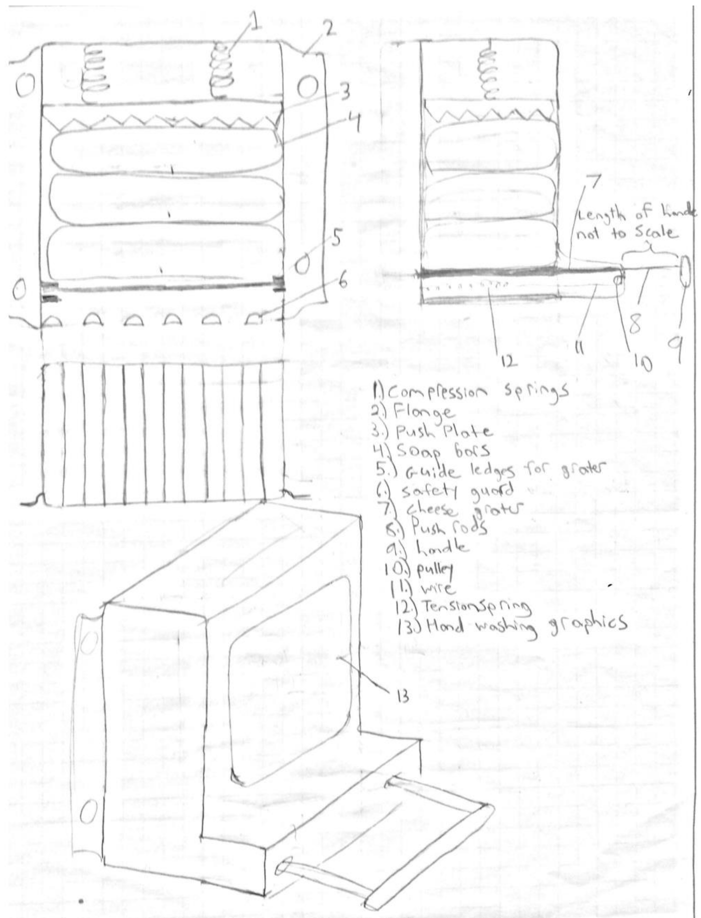

Figure 3: Rough Design

4.5.3 Low Fidelity Prototype

In order to create a proof of concept design the team created a low fidelity prototype in which they could tested the functions of the design that were perceived to be the most likely to fail. The team needed to determine whether or not soap could easily be grated using a cheese grater and whether those shavings could easily be used to wash one's hands. In order to create a housing the team recycled or rather "upcycled" a milk carton and cheese grater. The resulting prototype can be seen in Figure 4.

Figure 4: Low fidelity Prototype

A cheese grater that was cut down to size was inserted into a slit cut into the wall near the base of the carton. The actual was base was removed to allow the soap shavings to fall into the users hands. The low fidelity prototype worked as planned. By having one teammate hold the device on the sides another would hold a hand under the device while sliding the grater in and out of the device without actually fully removing it. The resulting shavings were small and easily dissolved in the users wet hands once lathered.

4.5.4 CAD Modeling

The team then began to invest the time in creating a high precision CAD model to use for both prototyping and manufacturing details. All team members had prior experience with CATIA a CAD software created by Dassault Systemes. The final results of the design can be seen in Figure 5.

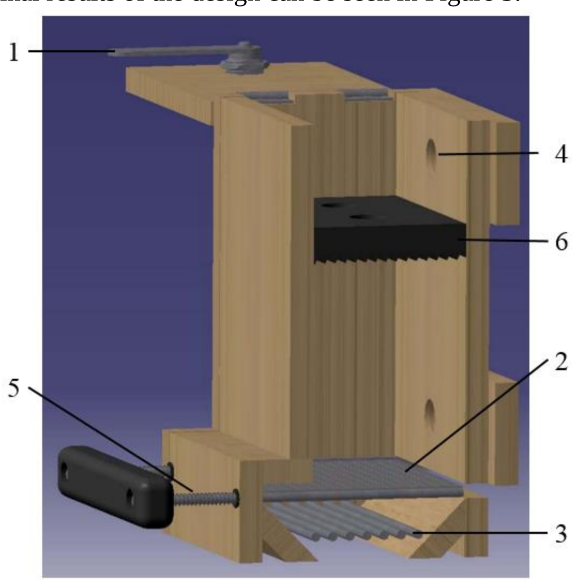

Figure 5: CAD Model

The design features a lockable wooden housing to control access (1), a soap grater dispenses soap (2), a safety grate at the base to prevent user injury (3), mounting holes in rear panel (4), springs to return handle and allow one handed operation (5), and a black plastic grooved plate (6), and a channel which guides the handle for smooth operation (not visible). The black plastic plate serves to prevent the soap from sliding inside the housing due to the high friction of the grater. The design easily allows a user to add a weight to the top of the device to increase the normal force against the grater. This will allow the user to control the size and quantity of the shavings to some degree.

4.5.5 Design for Assembly

The team then completed a design for assembly analysis to ensure parts were designed with assembly in mind. The main result of this 13 step process was that the handle for the device was changed from a U-shaped bent piece of steel which would be permanently mounted into the device to a removable handle design seen in the CAD image above which increased or maximized component accessibility.

4.5.6 Engineering Modeling

In order to determine that the device would operate as expected the team performed three engineering models and an experiment. The experiment determined the force required to grate a standard bar of soap. One of the models was used to determine the spring force required to return the handle once fully pressed into the device. A second model was used to determine the force required to plastically deform the handle by applying a load on the end of the handle while it is fully extended. The final model was used to determine the force it would take to fracture one of the faces of housing based on its thickness.

4.5.7 High Fidelity Prototype

The culmination of the design process resulted in the final prototype seen in Figure 6.

Figure 6: High Fidelity Prototype

As can be seen the final model closely resembles the CAD model. The overall construction went as planned, however due to poor tolerancing the internal alignment of the c-channel which guides the grater and handle assembly is less than ideal. This results in more friction than expected and prevents the springs which were selected for their spring constant and size from returning the handle to the starting position. This prevents one handed operation by the user. However the results are still very promising for the future of the design.

4.5.8 Discussion

The results of the engineering process yielded favorable results. The high fidelity prototype was functional and the design was seen as simple yet effective. The needs in the HoQ were all addressed however on-site testing is needed to determine how well needs were met. The primary criticism voiced by a variety of industry representatives from a poster session was that the handle is less than secure to due exposed fasteners. The team, in an effort to reduce the risk of vandalism, has decided that plastic plugs which form a friction fit with the two exposed holes in the handle could be inserted to hide the nuts and create a slightly cleaner design. Another criticism is high cost. The final cost of the end design was $18.32, but the team believes that an economy of scale and potential material changes, such as a cheaper safety grate, will reduce the cost to around $10 or less. The team is making plans to receive customer feedback from CRS in late January 2016 in order to determine if the team met the customer needs satisfactorily.

V. EVALUATION USING CRCNI METHOD

5.1 Introduction to the CNCRI Method

When designing for the developing world, many obstacles prevent themselves. The most notable of these obstacles is the clear risk involved when trying to design for a customer whose culture may drastically differ from one's own culture. This has created many issues in the past in which good designs were promptly dismissed from the market due to lack of popularity among the target customers. In order to develop designs which could be successful Van Bossuyt and Dean co-authored a paper in which they developed a method for assessing the inherent risk involved in designing for other cultures. This method allows a design team to determine where the greatest risk lies while choosing and ranking customer needs. The cultural data used to determine where the most difference lies between the design team's and customer's culture comes from the "Global Leadership and Organizational Behavior Effectiveness" (GLOBE) Study" [21].

5.2 Retrospective Analysis of Customer Needs

5.2.1 Develop an Understanding of Customer Needs

The customer needs have already been established as seen in Table 1.

5.2.2. Correlate Customer Needs to the Nine GLOBE Categories

Due to its high value the use and availability of soap can be categorized in two separate GLOBE categories. Since it can be used to benefit both the individual's health as well as the overall health of society, it can be categorized as "Uncertainty Avoidance". However because of its high value it can be used to demonstrate "upward social mobility" and be categorized as "Power Distance". This may account for the consistent theft of it.

As can be seen in the Table 4, the customer needs were ranked by the sum of the three customers weights for each category. This accounts for the different order when compared to Table 1. Most importantly a GLOBE category was assigned for each Customer Requirement.

Table 4: GLOBE categoriztion of CR's

Rank	What (Customer Requirements)	⟷ Globe Categories
1	Safety	Uncertainty Avoidance
2	Ease of Use	Uncertainty Avoidance
3	Security	Future Orientation
4	Durability	Future Orientation
5	Aesthetic Appeal	Power Distance
6	Culturally Appropriate	In-Group Collectivism (Collectivism II)
7	Cost	Future Orientation
8	Sanitary	Uncertainty Avoidance
9	Efficiency (soap life)	Future Orientation
10	Maintenance	Humane Orientation
11	Variability of Source	Uncertainty Avoidance
12	Ease of Installation	Humane Orientation
13	Manufacturability (Local)	Institutional Collectivism (Collectivism I)
14	Consistent Dispensing	Future Orientation

5.2.3. Determine the Differences in the Cultures of the Engineers and Customers

Due to the lack of GLOBE data for all countries Zambia was chosen to represent Ethiopia due to two factors. It was the one of the two closet countries to Ethiopia for which there was GLOBE data and it was the closer to the Eastern Coast when compared to Nigeria. Countries for which there is GLOBE data can be seen in Figure 7 and a map of African the countries for which there is GLOBE data in which distances can be seen in Figure 8.

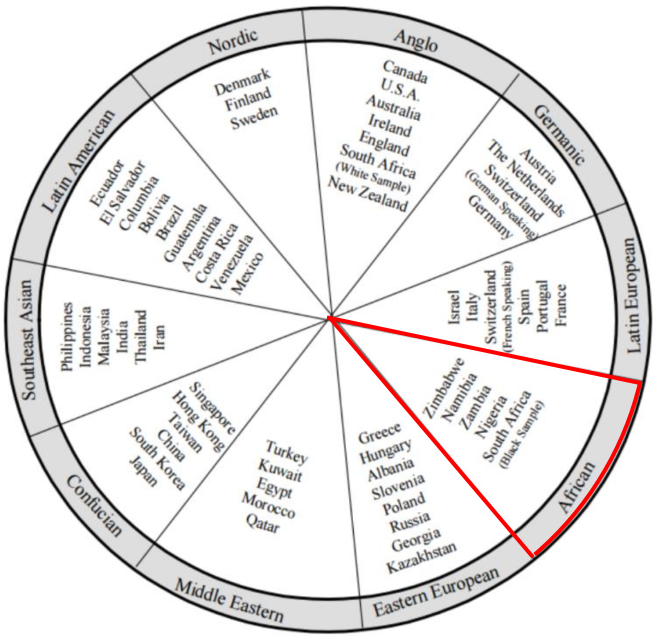

Figure 7: GLOBE Country Clusters [24]

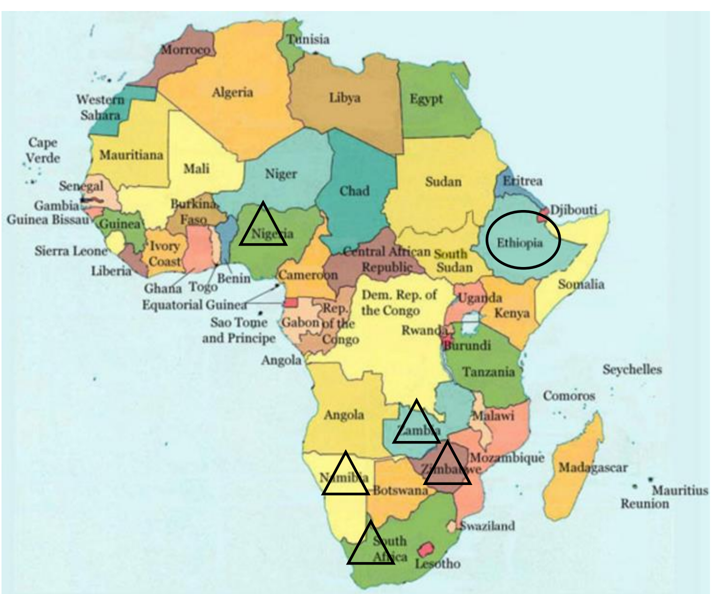

Figure 8: Map of African GLOBE countries [32]

The differences for each of the 9 GLOBE categories for the USA and Zambia can be seen in Table 5. The left most 5 columns were taken from GLOBE data and the differences were calculated. The values in the GLOBE study are based on a 1 to 7 scale with 1 referring to a low score and 7 a high score [24].

Table 5: GLOBE Category Differences [24]

GLOBE Category	Mean	Standard Deviation	Anglo Cluster (USA)	Sub-Saharan Africa (Zambia)	STDEV of GLOBE Mean Difference
Perf. Orient.	4.1	0.4	4.49	4.16	0.83
Future Orient.	3.8	0.5	4.15	3.62	1.06
Assertiveness	4.1	0.4	4.55	4.07	1.20
In-Group Col	5.1	0.7	4.25	5.84	2.27
Institutional Col.	4.3	0.4	4.20	4.61	1.03
Gender Egal.	3.4	0.4	3.34	2.86	1.20
Humane Orient.	4.1	0.5	4.17	5.23	2.12
Power Distance	5.2	0.3	4.88	5.31	1.43
Uncertainty Aviod.	4.2	0.6	4.15	4.10	0.08

5.2.4. Calculate Risk Indicators

After the number of standard deviations of the difference between the USA GLOBE category values and the Zambia GLOBE category values are calculated as in the Table above, then the raw cultural risk indicator values can be calculated. These values can then be normalized on a scale of 1 to 10 with 10 indicating a higher risk as seen in the Table 6. The weights assigned in the HoQ were multiplied by the standard deviation data of the GLOBE mean difference corresponding to the GLOBE categories assigned in Table 4 to calculate the raw cultural indicator risk values.

Table 6: Risk Indicators

Customer Need	Weight	STDEV of GLOBE Mean Difference	Raw Cultural Indicator Risk	Normalized Cultural Risk Indicator
Safety	14	0.08	1.17	1
Ease of Use	13	0.08	1.08	1
Security	12	1.06	12.72	6
Durability	11	1.06	11.66	6
Aesthetic Appeal	10	1.43	14.33	7
Culturally Appropriate	9	2.27	20.44	10
Cost	8	1.06	8.48	4
Sanitary	7	0.08	0.58	0
Efficiency (soap life)	6	1.06	6.36	3
Maintenance	5	2.12	10.60	5
Variability of Source	4	0.08	0.33	0
Ease of Installation	3	2.12	6.36	3
Manufacturability (Local)	2	1.03	2.05	1
Consistent Dispensing	1	1.06	1.06	1

5.2.5 Understanding the Source of Risk Indicators

An updated "Who" vs. "What" section of the HoQ can be seen in Table 7. As seen in the table, although safety is the most important customer need it also has the least risk of being improperly understood by a design team in the U.S. However the cultural appropriateness of the device is the most likely to be misunderstood by the design team.

5.2.6 Driving Down Risk Indicators to Acceptable Levels

In order to reduce this risk indicator the design team will need to do some in depth research into Ethiopia's culture with particular attention to culturally appropriate design, aesthetic appeal, durability, and security. The team may employ multiple means in order to accomplish this aside from basic research. One option is to contract out the work to a local specialist or a company who specializes in this work. A second option is to contact a local contact and bring them into the design discussion. A final option is to send a prototype overseas or possibly a survey only and collect customer feedback with particular focus within the concerned areas.

Table 7: HoQ "Who" vs. "What" with RI's

HOUSE OF QUALITY	Who (Customers)					
What (Customer Requirements)	Children	School Staff	Relief Services	Who vs. What Summed	Who vs. What Ranking	Normalized Cultural Risk Indicator
Safety	10	10	10	30	1	1
Ease of Use	9	8	8	25	2	1
Security	2	10	10	22	3	6
Durability	4	8	8	20	4	6
Aesthetic Appeal	8	5	5	18	5	7
Culturally Appropriate	7	6	5	18	6	10
Cost		8	8	16	7	4
Sanitary		8	8	16	8	0
Efficiency (soap life)	3	6	6	15	9	3
Maintenance		9	6	15	10	5
Variability of Source		8	6	14	11	0
Ease of Installation		8	6	14	12	3
Manufacturability (Local)		6	8	14	13	1
Consistent Dispensing		7	7	14	14	1

VI. BEST PRACTICES FOR USE OF CNCRI IN DESIGN CLASSES

The CNCRI method is conducive for both sophomore and senior level design teams working on projects for the developing world. Although this work was done retroactively, it is recommended that teams be provided with this tool at the onset of the project since the problem definition phase is important in design especially for creativity [33]. In the future, it is recommended that this method be presented in lectures relevant to customer needs analysis and using the House of Quality. In the case presented here, the first author was able to implement the strategy by directly reading the Van Bossuyt and Dean paper [23]. Thus, this method can be easily integrated as a course deliverable and included in their first or second progress reports.

VII. CONCLUSIONS AND FUTURE WORK

To summarize, the final design is robust and functional, but further research is needed to ascertain whether it may fail to meet certain customer needs.

Using GLOBE data has certain drawbacks such as not having data on very many countries. However, it does serve as a good source of cultural data for several different clusters such as African countries and Anglo countries. The use of Zambia's GLOBE data in place of Ethiopia may need further analysis. Alternatives could have included another African country's data or an average for all the countries in the African GLOBE cluster.

Following the design work, the team performed the Customer Needs Cultural Risk Indicator method of analyzing the customers' needs to determine which contained the most risk. The top four customers' needs with the most risk are listed in order of decreasing risk; culturally appropriate design, aesthetic appeal, security, and durability. These areas need to be further investigated before the project advances to the next stage.

Future work involves refining the design and testing it onsite in Ethiopia.

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ANNEX A
Design Prompt from Catholic Relief Services shared with i2D Lab [27]

Re-inventing hand washing with soap in schools

Partner: Catholic Relief Services

Preferred modality: Undergraduate project or graduate research

Worldwide, 1.4 million children die each year from preventable diarrheal diseases, of which 88% are related to unsafe water, inadequate sanitation, or poor hygiene (WASH)[9]. The impact of poor WASH also has severe and long term consequences in both child health and development. In schools, poor WASH practices and associated diarrheal disease has been associated with absenteeism. It is estimated that washing hands with soap and water could reduce diarrheal disease-associated deaths by up to 50%.[10] Unfortunately, the common practice of hand washing with water alone is less effective than hand washing with soap and water because fecal pathogens get lodged in the natural oils of hands and water alone cannot dislodge them.

Schools can play an important role in promoting better health by engaging children to change behaviors. Children are receptive to new ideas, they are curious and eager to learn, they easily influence other children and they are excellent change agents in communities. For of these reasons, Catholic Relief Services promotes school WASH programs across East Africa (Figure 2). Key aspects of school WASH projects include improved access to safe water and latrines, construction of hand washing stations and hygiene education.

Unfortunately, despite improved access to infrastructure to promote good hand washing practices, CRS frequently observes that hand washing stations do not have soap. This is even the case in schools where teachers and students have a high level of knowledge about the importance of washing hands with soap and water at critical times. Common reasons given by school teachers and management include the high cost of soap as compared to their meager budgets and the fact that soap is commonly stolen when made available to students. The truth is that in most areas where CRS operates, soap is considered a precious commodity so it is often prioritized for bathing and washing clothes and dishes.

Figure 2. Example of hand washing station in schools (CRS)

The challenge is to develop a low-cost, culturally-appropriate device or modality for dispensing soap in schools so that access to soap is not a major barrier. The device should be designed so that soap is dispensed in the appropriate quantity needed for hand washing. Because soap is a precious commodity, the soap dispenser should prevent theft of soap (and the device). It would also be beneficial if soap within the device could be produced locally at a low cost and the device easily refilled. Last but not least, the device should be visually attractive to the user so that people are inclined to use soap when washing their hands.

This issue of poor access to soap in schools is not isolated to one area, country or even continent. There is significant scope for this culturally- and cost-effective device to spread across countries and continents. There is also the potential for this device to be used in other institution settings like health facilities or in a smaller version at a household level. If everyone in the world washed their hands with soap and water, a million deaths a year could be prevented.[11]