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User Centered Design Methods as Applied to Manufacturing Methanol Cookstoves for Mushers in Arctic Climates

by

Aimee Ritter

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An undergraduate honors thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in University Honors and Mechanical Engineering.

Portland State University

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ABSTRACT

The role of user centered design (UCD) in the design process is to obtain user input when developing requirements and to build an understanding of a user's environment. In doing so, the designer can better create a product specifically for that set of users. This work will apply two methods of UCD, empathic design and co-design, to the specific case of building a methanol burning cooker for dog mushers in arctic climates. Thus far three cookers have been built using UCD methods and this work reflects upon how those methods were used to build a finished product. Additionally it reflects upon the result of involving the user in the design experience as well as how these methods can be applied in future iterations. The conclusion is that, while both empathic design and co-design have their limitations when applied to building mushing cookers, they build a strong groundwork for understanding a user's environment and needs which leads to a better product in the end.

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1 Introduction

User centered design (UCD) is defined as “the active involvement of users for a clear understanding of user and task requirements [and employs] iterative design and evaluation [techniques], [while using] a multi-disciplinary approach” [4]. UCD is a concept that has been used across a variety of disciplines to design products specifically for end users. For a little over a century, it has been implemented as a design method used both in business and product design, but only in the past forty years has it been written about within the scope of engineering literature. Within this work, two forms of UCD are explored as they apply to an engineering design approach. Both forms will be discussed in terms of how they have been applied to the specific case of building a methanol cooker for mushers in arctic climates. The two methods to be discussed are empathic design and co-design. Three cookers have been built using these two UCD methods. The goal of this work is to reflect upon how those methods were used to build a finished product in the form of a mushing cooker. Additionally it will reflect upon the result of involving the user throughout the design experience as well as how these two design methods can be applied to future iterations.

1.1 Motivation and Background

1.1.1 What is a Mushing Cooker?

The purpose of a mushing cooker is to provide hot water to add to dry kibble (dog food) or to thaw frozen dog food [5] for a musher’s dogs during the course of an outing or a race. Additional uses are to thaw frozen baggies of food for the mushers [6], to hydrate dehydrated food, and to boil water so it is

safe to consume [1].

Typical mushing cookers follow a very traditional design that has not been updated in many years. The motivation for building cookers using UCD is to update these traditional designs to increase efficiency and packability while also building stoves that are easy to use in harsh arctic environments.

1.1.2 Timeline of Involvement

Prior to my involvement with building mushing cookers, my advisor, Tom Bennett, had already built multiple cookers for multiple mushers. I joined forces with him in the spring of 2015 and have since built four cookers. The cookers I have built will be discussed within this work in the scope of how I have applied user centered techniques to create user friendly stoves for the mushers.

1.2 Reference Literature

This work will engage two distinct areas of engineering design. The first area will focus on the academic literature on UCD. It will be based on literature reviews of UCD and peer reviewed articles that discuss the various uses of UCD in practical applications. Having an understanding of the literature surrounding UCD will provide an academic understanding of how UCD is discussed in engineering design and will provide a basis for moving forward in discussing how UCD has been applied to the musher’s cookers.

The second area of reference material will come from personal experience and interviews with mushers and engineers who build cookers. The interviews with the mushers provide a first person account of how they engage with and work around their cookers. Obtaining this information is crucial in the pursuit of understanding what needs to be incorporated in the

cooker design to make it user-friendly as well as functional within all of the environments in which it will be used. The interviews with engineers will provide a more technical perspective on cooker building and insight when it comes to incorporating a user centered approach to the design process.

2 A Brief History of User Centered Design

User centered design (UCD) originally manifested itself in the fields of ergonomics and human factors. This was mainly due to a rise in technological demand during the Industrial Revolution of the United States and during both World Wars. During this revolutionary time in the early 1900's, technology was becoming part of the daily lives of citizens and workers. As such, ergonomics and human factors became important areas of research. This interest in improving a user's experience was the result of health and safety concerns in work practices and environments [7] in addition to "the growing realization that, as technological equipment became increasingly complex, not all of the expected benefit would be delivered if people were unable to understand and use the equipment to its full potential" [8].

Arguably the most influential work in the UCD discourse community is Norman and Draper's 1986 book *User Centered System Design: New Perspectives on Human-computer Interaction* which originally coined the term "User Centered System Design". Through their discussion they sparked the conversation about applying a user centered approach to creating user friendly systems across all fields in engineering. While their work focuses mainly on computer systems and human computer interaction, it

lays a groundwork for understanding the importance of quality human machine interaction. Additionally, it discusses ways for designers to take human interaction into account when developing designs for products. Norman and Draper emphasized "focusing on the user's needs, carrying out an activity/task analysis as well as a general requirements analysis, carrying out early testing and evaluation, and designing iteratively" as a means of ensuring that the final product was built for the user in an intuitive manner [7].

3 UCD Methods Used in cooker Design

3.1 Empathic Design Theory

Beginning with Norman and Draper's work, UCD has since branched out to include many different facets of design methodology. One such facet that will be discussed in this paper is empathic design. Originally popularized by Leonard and Rayport, the concept of empathic design was introduced in 1997 as a means of encouraging businesses to take users into account in their product development cycle. While most businesses at the time were using focus groups, usability laboratories, and other similar methods of market research to target their customer's needs, they lacked an understanding of the context of those needs [9]. The goal of Leonard and Rayport's concept of empathic design was to encourage designers to create a product that fit an implicit or explicit need based on a user's environment. By conducting interviews with users and by observing users in their working environment, a business could provide users with a product that seamlessly fit into their lives.

In the context of engineering, empathic design has been seen as a way of “allow[ing] the engineer to identify with the challenges of the end-user by observing the user in the context of use” while also allowing the engineer to “[simulate] the context of the end-user for better understanding” [10]. The methods used to gather data and information through empathic design follows a cycle of observing a user in his or her environment, conducting tests on prototypes that simulate the demands of a user’s environment, and conducting interviews with a user about their needs. One way to begin the empathic design cycle is for the engineer to observe and interview users prior to building a prototype. By taking this first step, an engineer can begin to develop an understanding of their user’s explicit and implicit requirements as well as how they can set up appropriate testing conditions for prototypes. Once a prototype has been built with a user’s environment in mind, the engineer can give the prototype to users and then conduct interviews and observations while the users interact with that prototype. These observations and interviews can provide additional insight as to a user’s requirements as well as further the engineer’s understanding of the environment in which the product must operate within.

3.2 Applied Empathic Design

This technique is expressly useful in the context of designing cookers for mushers since the purpose of empathic design is for the designer to experience a user’s environment in order to build a suitable product. A musher’s environment is vastly different than the one in which I, as the designer and engineer, operate. While I can draw on personal experiences of my own in arctic environments, gained through ex-

perience as a wintersport enthusiast and as a resident of the state of Alaska, I have not participated in the specific environment experienced by mushers. As such, using empathic techniques of observing and interviewing mushers allowed me to combine my past understandings of operating in sub-freezing climates to that of how mushers appear to operate in such environments. I was then able to apply that knowledge to creating a cooker appropriate for those conditions.

3.2.1 Personal Experience with Applied Empathic Design

As a means of understanding a musher’s working environment, I spent a weekend with three mushers who own three of the older generations of cookers built before I joined the project. I observed how they used their cookers and asked them specific questions about how their cooker served them during their mushing outings and what improvements could be made to future cooker iterations. I also able observed first-hand what their sleds looked like and how the cooker fit within the physical constraints of the sled, such as the one shown in Figure 1 below [11]. For Lisbet’s cooker in particular, I was able to ask her about the pros and cons of the cooker she used during her first Iditarod in 2014 and to see how the cooker withstood 30+ uses over the course of 1,000 miles.

Figure 1: Lisbet Norris’s fully packed sled that was used during the 2015 Iditarod [1]

In addition to observing mushers and performing interviews, I took the cooker to Mount Hood during the winter to perform field tests myself. In the context of testing cookers in Portland, Oregon, Mount Hood is an ideal location for testing due to its proximity to Portland, elevation, freezing temperatures, and abundance of snow. I took both an engineering approach and a user centered approach to testing the cooker’s performance. For the engineering approach, I collected data on burn time for the burners, volume of snow melt after the burners burnt out, temperature of the burn pan while the burners were lit, and final temperature of the snow melt after the burners burnt out. The setup for the engineering tests is shown in Figure 2. This information helps to provide a sense of efficiency improvements from cooker to cooker so that we (the engineers) have an idea of how the stoves are developing.

Figure 2: Test setup to test cooker and burner efficiency

For the user approach, I wanted to ensure that I was able to experience operating the cooker in the most authentic way I could manage (aside from actually manning a dog sled) and in conditions similar to those experienced by the users. To do so, I made sure

to wear thick gloves and many layers to simulate the attire a musher would use when operating the cooker. Additionally, I tried to induce fatigue prior to using the cooker by going for a long ski so that I would simulate some of the tiredness felt by the musher after a long day on the trail.

3.2.2 Other Engineer’s Experience with Applied Empathic Design

To better understand how others apply empathic design techniques when building stoves, I interviewed a local engineer, Zdenek Zumr. Mr. Zumr designed and built cookers for a highly competitive Iditarod musher during the winter of 1988. In order to create a product that fit his user’s needs, Zumr put himself in the setting of a musher by using the musher’s gear within the musher’s environment as a means of testing his different stove iterations. Keeping usability in mind, Zumr tested his cooker iterations using the musher’s own large mushing gloves to setup and take down the stove while also testing the stove in the 0°F to -50°F temperature range in the dead of winter [12]. By performing his testing in this manner, he experienced first hand what it was like to use the stove and make any necessary improvements prior to showing a finished product to the user.

3.2.3 Limitations of Empathic Design in Designing Cookers

Empathic design stresses the importance of observing a user in their environment so that a product can be built to fit within it. However, as it applies to mushing cookers, this technique cannot always be fully realized. In regards to competitive mushers as users, it is unrealistic for me, as the design engineer, to observe a competitive musher use their stove during a

race. A more realistic substitute is to participate with a musher during a winter training session; however, much of the emotional and physical burden imposed by a long distance competition will be lost.

Another limitation within this approach in my case is the physical distance between user and designer. We are working with mushers based in Alaska, and while I am able to visit on occasion, I cannot observe the mushers in their environment on a day to day basis. As such, we are limited to communicating over the phone or email. While this method is appropriate for conducting interviews, it lacks the personal connection of face-to-face interactions and does not allow for first hand observation. While FaceTime and Skype are possible options if the musher is close to an area that has data coverage or wifi, phone calls, emails, and texts have been found to be the more reliable means of gathering information from the mushers.

Yet another limitation in my design experience is the designer's proximity to arctic environments. Empathic design encourages designers to test products in the environment in which it will be used by the user. While I was able to perform tests on Mount Hood in winter conditions, Oregon is a far more temperate climate than Alaska and so I was unable to thoroughly test the cooker in a sub-zero environment. As such, we must rely on the mushers to provide feedback on the cookers once the cookers are finished and shipped to Alaska.

3.3 Co-Design Theory

An additional form of UCD used for cooker building is called co-design. Co-design is defined as "collective creativity as it is applied across the whole span of a design process" [13]. Similar to the origin of UCD,

co-design also began in the realm of human-computer interaction. While much of the literature surrounding co-design speaks to software, the theories can also be applied to product design, especially in the case of a small scale production such as mushing stoves. The concept of co-design was born from the Northern European approach of participatory design [13] which introduced a focus on users actively participating in the design experience. Participatory design has since branched into a wider spectrum of user involvement with co-design as one such branch [14].

In the context of this work co-design will refer to the design process in which the designer works intimately with the user throughout the entirety of the project. Using this definition, co-design takes advantage of direct contact with users to understand the contexts of a product's use [15].

3.4 Applied Co-Design

Co-design, as it applies to mushing cookers, is another valuable tool in creating a reliable end product. By combining the users' experience and knowledge with technical engineering design knowledge and experience, a solution can be created that fits a users explicit wants and needs. While empathic design focuses on both implicit and explicit needs, co-design mostly focuses on explicit needs defined by the user throughout the design process.

3.4.1 Personal Experience with Applied Co-Design

The goal in co-design is to build a product that the mushers will actually use and enjoy using. As such, I have maintained contact throughout the building process with the mushers who will be using the final product. Since the mushers I am in contact with have

already had experience with past iterations of mushing cookers, they have an idea of what I am working towards as well as a familiarity with the design. This makes communication of new ideas and improvements easier on both ends. The methods of contact have been through email, text, and phone conversations. All three methods of contact have allowed me to keep the mushers up to date on the current status of the cooker as well as to get timely feedback on ideas for improvements.

3.4.2 Other Engineer’s Experience with Applied Co-Design

To learn more about how other engineers have applied co-design in their design approach, I interviewed Zdenek Zumr to further discuss his experience in using co-design to build his stoves. In his experience, co-design was the main form of UCD due to his close proximity to the musher he was working with (he lived with the musher over the course of his stay in Alaska) and his musher’s vast experience with building mushing stoves. Since the musher had a very clear idea of what he wanted from his cooker and since he had many years of experience testing and perfecting them, it was important for Zumr to take the musher’s previous stove building experience into account and to work with his expertise rather than relying only on his engineering knowledge. For example, Zumr initially suggested adding a mechanical component to try to adjust the intensity of the flames generated by the burning methanol. However, in talking with the musher he learned that mechanical components are extremely unreliable in sub-zero temperatures and in mushing, a failure in a cooker could be the difference between life or death [12]. This type of feedback is crucial when building a product that the user must

rely on in extreme environments.

3.4.3 Limitations of Co-design in Designing Cookers

As with empathic design, a limitation of co-design as applied to this project was physical distance between user and designer. To obtain input from the mushers about the cooker design, we used emails, phone calls, and text messages to communicate ideas about cooker improvements. While the mushers had older stoves to base ideas off of, they were unable to physically handle the new stoves throughout the process of manufacturing. Also, due to many of the mushers living in remote areas, lines of communication are not always consistent. Since the timeline of building cookers is so short due to the academic year and how it overlaps with training for the Iditarod, when we were unable to reach mushers while they were out training, we had to make executive decisions based on our engineering knowledge rather than musher input.

The distance and timeline constraints also limit some of the benefits that can be found in co-design. Co-design works best when the user can give immediate feedback on performance of the product; however, since the user is located so far away in this case we need to send the stoves to them for testing and they usually will not get back to us with feedback for a few months at a time. In the case of Iditarod mushers, we cannot fully know how well the stove performs until the musher has completed the Iditarod.

3.5 Additional Limitations and Challenges of UCD in Cooker Design

While co-design and empathic design have their own sets of limitations due to the nature of their methods, UCD as a whole, regardless of method, has its own

set of limitations as it applies to the cooker building experience. The most notable limitation of UCD in this cooker design is lack of quantitative information provided by mushers on cooker improvements. The mushers we interact with do not have a technical background in heat transfer, fluids, manufacturing, or engineering design. As such, the feedback obtained is typically in the form of qualitative or anecdotal statements. The mushers cannot be faulted for this lack of qualitative information most especially because they have a much more immediate priority of maintaining and caring for a large team of dogs as well as seeing to their own health in extremely harsh climates. As such, many of the quantitative results must come from lab testing and field tests in Oregon prior to sending the stoves to the mushers. The limitations of these tests in Oregon tests been noted in Section 3.2.3.

Another limitation as it applies to this experience is the small number of mushers we are in communication with. UCD works best with a diverse sample size to pull from; however, in our situation we have only five mushers that we work with and only two that communicate regularly with us. This works well for building custom stoves for each musher, but if we were to take the cooker into production we would need a much larger base of information to pull from in order to create an optimal cooker for a larger mushing population.

One final limitation of UCD as it applies to mushing cookers is that “no amount of empathic or co-design would substitute for a good computer modeling of the airflow and burn efficiency achieved through different hole size and placement and burner number and placement” [16]. While the mushers can give us qualitative feedback, like burn color and com-

parisons between old cookers and new cookers, a better design approach to tackle efficiency would be to model the cooker in a physical simulation software to obtain a better idea of what can make a stove improve.

4 Users

To begin developing an idea of a design, a user’s needs and requirements must be taken into account, most especially at the beginning of the design process [15]. It is important to understand these user requirements as they apply to the context of the cooker so that we can better “understand how the future product can support users in achieving their goals in a specified context of use” [14].

The stoves have been built for four different categories of user. The first is the competitive musher, the second is the recreational musher, the third is for National Park Rangers in arctic climates, and the fourth is for a small arctic exploration team. While each of the four users share general requirements, such as the stove must operate in subzero temperatures, they each have their own specific requirements that must be met. Using empathic design and co-design methods allows me to work towards a final product that performs optimally in the conditions that each of these users specify.

4.1 Explicit Musher Requirements

In UCD, “the use of explicit user requirements forces the user to understand both the problem and the application” [17] which helps the user in assisting the designer in developing realistic requirements. When the user understands the scope of the problem and application, they can then better elucidate their needs

to the designer during the design process. Hence the importance of interviews and prototyping. Prototyping gives the user the hands on experience they need to decide their likes and dislikes as well as wishes. Interviewing allows the designer to understand these needs and how to apply them to future design iterations. In the scope of this work the explicit requirements were obtained through interviews with the mushers both before and after prototyping. The requirements listed below are the result of conversations with the four different categories of user.

Table 1 is a summary of the requirements set down by the mushers interviewed. The following sections will cover the differences between the mushers and their corresponding requirements in more detail.

4.1.1 Competitive Musher Requirements

The Iditarod is a nearly 1,000 mile race across the state of Alaska. The normal route begins in Willow and is shown in Figure 3 [18]. An alternative route that begins in Fairbanks is shown in Figure 4 [19].

This route has been used in the recent years due to

lack of snow and open water along the traditional routes.

Figure 3: Map of the traditional Iditarod routes

Figure 4: Map of the alternative Iditarod route

Table 1: Overview of User Requirements

User Requirements	Competitive Musher	Recreational Musher	National Park Rangers	Small Arctic Exploration Team
Packable	xxx	x	xx	xxx
Lightweight	xx	xx	x	xxx
Easy to use	xxx	xxx	xxx	xxx
Safe	xxx	xxx	xxx	xxx
Able to operate in subzero temperatures	xxx	xxx	xxx	xxx
Melt snow / heat up cold water	xxx	xxx	xxx	xxx
Durable	xxx	xx	xxx	xxx
Minimal moving parts	xxx	xx	xx	xxx
Water pan capacity	3 gal	2 $\frac{1}{4}$ gal	3 gal	1 $\frac{1}{8}$ gal
Use HEET (methanol) as fuel	xxx	x	xx	xx
Maximum dogs	16	12	16	6
Minimum dogs	6	4	6	4
Pack quickly	xxx	x	x	xxx
Light stove with single match	xxx	xx	xx	xxx
Bottles of HEET per use	2-3	2-4	2-4	1-2
Heat water in less than 1 hour	xxx	x	xx	xxx
Fit within footprint of sled	xxx	xxx	xxx	xxx

Key: "x" = low priority, "xx" = medium priority, "xxx" = high priority

The race is put on by the Iditarod Trail Committee and has run been running since 1973. Those who compete face temperature ranges of 35°F down to -60°F and wind chills that can get to -100°F. Therefore, the gear that the mushers use must be very durable and must be able to perform in extremely cold conditions. As a designer, I strive to understand the severity of the environment that the mushers experience on a day to day basis so that the product I build can fit within that environment. Keeping this in mind, the goal is to ensure that the cooker is easy to use in these harsh environments. Mushers experience temperatures in the low negatives which means they are operating with an exceptional amount of layers on their body. In these extreme environments a musher's thick gloves and clothing means they are not dexterous and so the cooker must be able to be used with large, clumsy gloves and with heavy, restrictive clothing (Figure 5 shows typical mushing attire [20]). Additionally, competitive mushers only tend to sleep only "two to three hours at each checkpoint about twice a day" [21] and while they can catch up during the 24hr required layover, the extremely harsh environment can take a toll on both the mind and body. As such, the cooker must be easy to use when the user is tired and cold.

Figure 5: *Typical heavy layer attire for cold weather during a mushing outing*

For the mushers who compete in the Iditarod their cookers must fit within the following requirements set down by the Iditarod trail committee [22]:

- Under Rule 16: A musher must have with him/her in the front sled, at all times one operational cooker and pot capable of boiling at least three (3) gallons of water at one time
- Cooker must use methanol (in the form of HEET) as fuel
- Cooker must provide enough hot water to heat up dog food for a dog team with a maximum of 16 dogs and minimum of 6 dogs.

These requirements are specific to the Iditarod Race and are some of the first requirements used when determining the initial constraints of the cooker design for those mushers.

Four stoves have been built for competitive mushers who race the Iditarod. Three have gone to Lisbet Norris, and one to Monica Zappa. The following requirements that are specific to competitive mushers were obtained from face-to-face, email, and phone interviews with these mushers and are listed and explained below:

- Cooker must pack down quickly and easily

The nature of being a competitive musher is that they are always pressed for time. During a race, the cooker should not add additional time to the process of setting up and breaking down camp. Additionally, should the musher face a dangerous situation in which they must move camp quickly, the cooker should not be a limiting factor.

- Cooker must light with minimal effort

As was mentioned previously, during a long race mushers can become tired and with thick layers

restricting motion, lighting a cooker with multiple matches has been found to become cumbersome and irritating. To cut down on time and energy, the cooker should be able to be lit quickly and easily with a single match regardless of the temperature of the environment.

- Cooker must be as efficient as possible to save time during race

Older versions of cookers would take anywhere from 30 minutes to an hour to heat up or boil three gallons of water. This time range is dependent on several factors - the particular cooker used, outside air temperature, snow or water temperature and the wind. When the musher is competing, every second counts and so having a cooker that heats up water quickly is imperative to a successful design.

- Cooker should heat up water to be warm to the touch

Not only should the cooker warm water up quickly, it must also warm it up to the point that it can melt frozen dog food. Since mushers do not have thermometers on hand during the race, this requirement is qualitative rather than quantitative.

- Cooker should use a maximum of 3 bottles of HEET per use

Older designs not only took an hour or more to heat up three gallons of water, they also used at least three to four bottles of HEET per session. To improve upon old designs, the cooker must heat up water quickly using a smaller amount of HEET. Not only does this decrease the amount of HEET a musher needs to add to the cooker to keep it going, it also decreases the amount of fuel a musher needs to carry

and can therefore end up providing additional weight savings.

- Monica requires cooker to fit within a sled bag with the dimensions of 14"x13"x17"

The above requirement is specific to Monica due to the nature of how she packs her sled. The picture in Figure 6 shows how the cooker fits within a bag she uses on her sled.

Figure 6: Monica's old cooker in sled bag

- For future iterations: cooker should only need to be filled with snow once per use

One problem that mushers have with the current design is that the cooker must be filled with snow multiple times in order to fill the water pan with three gallons of snow melt. Preferably, the stove would be able to handle a mound of snow and melt all of it without the need to be replenished.

4.1.2 Recreational Musher Requirements

A recreational musher typically has a smaller number of dogs and usually go on shorter outings than those who compete in the Iditarod. As such, they have less of a demand for a high performance stove. Two stoves have been built for recreational type mushers and while most of the requirements are the same, they are much less stringent than those of a competitive

musher. These requirements are listed and explained below:

- Cooker must melt snow / heat up water in a reasonable amount of time

While it shouldn't take hours, the cooker does not need to be as efficient as a competitive cooker. Recreational mushers do not operate within the time sensitive environment that competitive mushers and so a quick burning stove is not as high of a priority.

- Cooker provides enough water for a team of four to twelve dogs

Recreational mushers do not travel as far as those who are competing in the Iditarod and so do not need as many dogs for their outings. Depending on the length of the outing, a recreational musher will operate with between four to twelve dogs and will need a cooker that can handle the demand of twelve dogs.

4.1.3 Park Rangers

In Denali National Park, rangers are not allowed to use motorized vehicles in most of the park. Therefore, dogsleds are used in place of ATV's and snow-machines during winter. These dogsled teams are used both for public educational purposes as well as a means of transportation and freighting for the Denali Park Rangers when they are working in the park during winter. Their requirements are listed below:

- Cooker must melt snow / heat up water in a reasonable amount of time

Similar to the requirements of recreational mushers, while it shouldn't take hours, the cooker does not need to be quite as efficient as a competitive cooker. That said, the Park Rangers did mention that a faster

burning cooker was preferable over a slow burning cooker since it would save on time spent waiting for water to warm up.

- For future iterations: prefer larger burn pan

While the Park Rangers like the square design of the current iteration they have as it fits nicely within their sled, they would prefer a larger sized burn pan. The Denali Park Kennel Manager, Jennifer Raffaelli, wrote to use saying that "it would be ideal to have a slightly larger external pan so that the snow filled pan could sit deeper in and have some air space between the two to allow flames to come up and warm the sides of the pan" which would allow snow to melt faster [2].

4.1.4 Small Arctic Exploration Team

The small arctic exploration stove is meant for one human and a small team of six dogs. Most of the requirements overlap with those of the competitive musher with the exception of the size of the cooker. The cooker only needs to cook for six dogs, therefore a smaller sized cooker is more appropriate as it can be lighter, pack down smaller, and use less fuel.

4.2 Implicit Musher Requirements

As an engineer, a very important part of the design process is to understand a user's unspoken requirements. These requirements are ones that come from extensive interviews with the users and from observation of how users interact with a product. The goal of a final product is that the product should be useful and used often. The user should not experience frustration with using the product and, if possible, the user should also have a positive emotional response when using the product. One such way to take that

into account is to make the final product personal. In the case of the cooker, we achieved that by personalizing the lids to the cookers with the musher’s name and logo. An example of some personalized lids are shown below in Figures 7a and 7b. The mushers had a very positive response to having a personalized lid and it made them feel as if the product was theirs especially since they chose some of the images on the lids.

(a) *Lisbet Norris’ lid for Iditarod 2016*

(b) *Monica Zappa’s lid for Iditarod 2017*

Figure 7: *Example lid designs for mushing cookers*

5 Cooker Designs

5.1 Background

The first cooker to come out of Portland State University was built by Tom Bennett and was sent to Lisbet Norris for her first Iditarod race. I joined Tom’s cooker building team shortly after he sent off a second stove to Lisbet. Together, we began improving upon his previous design by getting feedback from Lisbet through email, text messages, and in person.

The goal of the first cooker was to use re-purposed pre-engineered materials that would be easy to come by for those interested in following our design. Another goal was to ensure that the manufacturing of the cooker did not use complicated methods unavailable to those without access to a machine shop. As such, many of the tools and manufacturing methods used to build the cookers incorporated commonly available hand tools and materials that are easily accessible at local hardware stores. As the cookers developed, we were also able to extend our goal into using recycled materials such as the Base Camp beer bottles and Vienna Sausage cans used for the burners.

5.2 Traditional Cooker Design

Traditional mushing cookers used in the Iditarod typically look like the cooker shown on the right in Figure 8 and Figure 9. The traditional cookers typically are comprised of a 5 gallon metal bucket with holes punched into the bottom, a burner (two different types are shown below in Figures 10 and 11), and a cookpot with lid that is used to warm up / boil water or melt snow.

One of the most common types of burner used is shown in Figure 10. This burner is simply an aluminum pie tin. The pie tin is placed on the bottom of the 5 gallon burner bucket and the fuel is dumped into the tin along with either bits of straw or pieces of toilet paper to act as kindling. Once the fuel is ignited, the musher puts the cook pot on top with either creek water or snow in it to heat up.

Figure 8: On the left is the traditional cooker design and on the right is the cooker Tom Bennett sent to Denali National Park [2]

Figure 11: Lisbet Norris's traditional burner: welded steel

Figure 9: In the foreground is a traditional cooker and in the background is Lisbet Norris's first cooker done by Tom Bennett [1]

Figure 10: Heather Siirtola's traditional burner: aluminum pie tin with straw for kindling

There are many problems with these types of cookers. The most immediate problem that mushers face is its footprint within the sled. According to many of the mushers I have interviewed, the cylindrical shape of a traditional cooker creates challenges when packing into rectangular sleds. Another problem is that of efficiency. These traditional stoves produce a lot of soot when they burn which is a large indicator that they are inefficiently burning fuel. While they do perform the task of melting snow or warming up water, they can be slow, taking anywhere from 30 minutes to one hour to produce 3 gallons of boiling water (depending on the type of snow used to melt). They also uses between 3 to 4 bottles of HEET per session. When time is short, this becomes an issue for mushers and their dogs alike. An hour spent waiting for food in the cold and wind can be time wasted.

5.3 Modern Design

5.3.1 On the Market

There are few stove designs currently on the market that have similar designs to our product. One such cooker is a product based out of Norway called the TROLL HEIT produced by TROLL Hundefôr & Utstyr. This stove is shown below in Figure 12. This cooker is sold for 2190kr (Norwegian Krone) which is currently equivalent to about \$262.37. This stove only comes in 4L or 10L (roughly equivalent to 1.05 gallons and 2.64 gallons respectively) meaning neither of which meet the 3 gallon requirements set down by the Iditarod. However, this stove would still be suitable for the recreational and small arctic exploration team categories of users.

Figure 12: *TROLL Heit 10 vannkoker-10L Maker*

Another company that sells mushing cookers is Cold Spot Feeds based in Fairbanks, Alaska. They sell the cooker shown in Figure 13 which follows the more traditional cooker design. This type of stove runs for \$279.99 USD.

Figure 13: *Cold Spot Feeds cooker package*

These cookers are potential competitors for our final product; however, since we have been using our cookers as experimental devices we have not put our stove on the market and offer our stoves to the mushers free of charge.

5.3.2 DIY Resources

Zen Stoves is a website that provides tutorials on construction of mushing cookers. An example of their cooker is shown below in Figure 14. This cooker design was the original inspiration for Tom Bennett's first cooker due to the benefits of the rectangular design as it applies to ease of packing into a sled.

Figure 14: *Zen Stoves DIY mushing cooker*

5.3.3 First Iterations of Iditarod Stoves

The first iterations that Tom Bennett built were based on a challenge from Lisbet Norris to build an efficient mushing cooker to test against the traditional cookers. His first design, as shown in Figure 15 used

two two-third size steam pans, one for the burn pan and one for the water pan. The first burner design was a cupcake pan, as shown in Figure 16a, that allowed the musher to slish HEET into each of the cupcake cups and to light with one match. The largest problem with the cupcake pan was its small size and therefore small fuel capacity. Therefore, the next iteration used muffin pans, as shown in Figure 16b, which had a much larger fuel capacity.

Figure 15: *Tom Bennett's first stove design that was sent to Lisbet Norris to use in her first Iditarod*

(a) *Cupcake Pan*

(b) *Muffin Pan*

Figure 16: *The first two original burner iterations*

5.3.4 Current Design

There are currently three designs being used for different purposes. The first design, known as Lisbet's cooker, is comprised of two two-third size 6" deep stainless steal steam pans, four burners, and a lid. One steam pan is used as the burner pan with eighteen holes drilled around the bottom to allow airflow. The burner pan holds the burners and the burners then hold the water pan within the burner pan.¹ The configuration of the burners is shown below in Figure 17.

Figure 17: *Burner configuration used in Lisbet Norris' third Iditarod cooker*

The burners used in Lisbet's third Iditarod cooker are shown below in Figure 18. The burner is made of a Libby's® 9oz Vienna Sausage can with approximately 16 1/4" holes punched around the top. Inside the Vienna Can is a small nest of carbon felt, normally used in welding, which acts as a wicking material. Nestled inside the carbon felt is a 1/4" thick aluminum pipe with a 1/4" hole drilled into the top to allow airflow.

¹See Appendix A for full list of materials and tools used to manufacture the current stove design.

Figure 18: Close up of burner used in Lisbet Norris' third Iditarod cooker iteration

The second design, known as Monica's cooker, is comprised of two two-third size 8" deep stainless steel steam pans, five burners, four carbon felt bridges, and a lid as shown in Figure 19.

Figure 19: Monica's stove

Like Lisbet's, one steam pan is used as the water pan and has chain handles to allow the musher to pick up and manipulate the water pan when it is full of snow or hot water. The other steam pan has twenty-two holes drilled into it and works as the burn pan to hold the five burners. Another difference between Lisbet's and Monica's stove is the use of the carbon felt bridges between the burners (shown as the black bridges in Figure 20). These bridges allow the musher to use a single match to light all of the burners. The configuration is shown in Figure 20.

Figure 20: Burner configuration used in Monica Zappa's Iditarod cooker

The burners used in Monica's cooker are based off of the one's used in Lisbet's third Iditarod stove in that they use a Libby's® 9oz Vienna Sausage can with approximately 16 1/4" holes punched around the top and a sheet of carbon felt. Where they differ is in the central burner nested inside the Libby's® 9oz Vienna Sausage can. Rather than using an aluminum pipe, Monica's uses a recycled Base Camp® 22oz aluminum beer bottle. This newest burner type is shown below in Figure 21.

Figure 21: Closeup of burner used in Monica's stove: Libby's® 9oz Vienna Sausage can, carbon felt, and Base Camp 22oz aluminum bottles

The third and final design is for the small team arctic exploration type mushers. This cooker is a smaller scale version of Lisbet's stove and uses two half-size steam pans, four burners, two thirds of a muffin pan, and a lid and is shown below in Figure 22. This stove is smaller than the other stoves since

the musher uses less dogs and has a higher priority in decreasing the weight of the stove.

Figure 22: Cooker built for small team arctic exploration musher

The burners used in this case are made of four recycled Base Camp 22oz aluminum bottles nested into a muffin pan. This allows the musher to just pour fuel into both the muffin pan and the Base Camp bottles to provide maximum heat output and easy, single match lighting.

6 Future Applications of UCD

As discussed previously, both empathic and co-design methodologies were applied to previous cookers. Both methodologies allowed a basic understanding of a musher's environment and how it effects their requirements of a cooker. However, due to a few inherent limitations in communication, there was still room to improve understanding of how the current products should perform in the environment in which it was built for.

Reflecting upon how UCD was applied to the past stove iterations, there are some suggestions that can be made for the future. One such suggestion is for the designer to experience the conditions faced by mushers in a more intimate manner. For example, the designer should try and join the musher on a long distance expedition to better observe how the musher

uses the stove within that environment as well as to better understand the environment in which a musher works. There are limitations in this approach, one being that it is impractical for the designer to accompany the musher during the Iditarod and so the designer is then unable to truly gain an insight as to how the stove is used in that high pressure situation. However, any sort of interaction or observation of a musher within that extreme environment would likely benefit the designers approach to building their final product.

7 Next Steps in Engineering Design

Outside of UCD, there are a few next steps that should be taken in future iterations. One such step would be to perform comparative testing with on-the-market cookers. The test that we have established to compare our iterations to each another in a lab setting is to use one bottle of HEET to warm eight liters of water. We then compare cookers based on the time it takes for the burners to burn out to the final temperature that the water reaches. This test gives us an idea about which cookers show improvements in burn time and heat output. Based on our previous findings of stove efficiency, our stoves have only reached about 50% efficiency. This means there is still room for improvements. One such improvement would be to insulate the burn pan to prevent heat from escaping the inner pan to the environment and to focus that heat directly on to the water pan.

The next step would be to communicate with Aprovecho Research center, a cookstove research center based in Cottage Grove, Oregon. While their focus is on coal and woodburning stoves, they may have

valuable input for both UCD and engineering building techniques.

8 Conclusion

User centered design as it applies to building cookers for dog mushers is a very practical design approach. When designing a product that a user's life depends upon, it is crucial to obtain their input when developing a final product to fit their needs. As such, both empathic design and co-design are applicable methods to this design process. Empathic design provides the designer with a first person experience of the needs of the user, both through interviews and through observations. Co-design allows the designer to pull from a user's expertise and for the designer to create a final product that the user has had a hand in helping to create. Both techniques have their own benefits and challenges; however, the benefits far outweigh the challenges since the final product is one that the user is familiar with and is willing to rely upon when they need it most.

9 Suggestion for Additional Research

A suggestion for additional research is to look into safety measures for methanol (HEET) use and ways to mitigate the dangers of using methanol as a fuel. Iditarod mushers are not required to attend a safety briefing about the dangers of methanol but are expected to know how to use it during the race [1]. This means that many mushers go through a trial and error period when learning what they can or cannot do with methanol while it is burning. For some, this leads to the potential of exploding a cooker or

burning clothing and hair. Another significant problem that has been noted by many mushers is the danger of using HEET during the light of day because, when HEET is ignited in the daytime, it is nearly impossible to see as it burns. If HEET is then accidentally spilled onto clothing, this can become a very dangerous issue. Some mushers have lit their gloves and parkas alight without knowing it and others have actually blown off their eyebrows [1]. Another significant problem that Lisbet Norris has noted are the dangers that can arise with opening the HEET bottles during cold weather. While the bottle is normally opened using a safety cap that must be pressed down and turned to open, this can present difficulties when attempting to open the bottle with large gloves. A solution that Norris has come up with is to just cut off the bottom of the bottle with a knife. However, this is conducive to spillage which can become dangerous if that spillage is onto clothing and then paired with fire. Further research would be required to come up with viable solutions to prevent spillage, make opening HEET bottles easier, and to provide training material for mushers on the dangers of methanol as a fuel.

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Appendices

A Building the Cooker

A.1 Materials

The materials used in the cooker are outlined below:

- Two 2/3 size 6" deep (or 8" deep) stainless steel steam pans

Figure 23: Stainless steel steam pan used for both burner pan and water pan

- Carbon felt

Figure 24: Carbon felt used for wicking and insulation

- Aluminum piping (for Lisbet's third cooker)

Figure 25: Aluminum piping used for Lisbet Norris's burners

- Base Camp 22oz aluminum beer bottles (for current cooker design)

Figure 26: Base Campe 22oz Bottles used in burners for Monica's cooker

- Plastic sheet

Figure 27: Plastic sheet used as insulation on the bottom of the burn pan to prevent the pan from sinking into the snow

- Libby's[®] 9oz Vienna Sausage cans

Figure 28: 9oz Vienna Sausage can used for burners

A.2 Tools

Many of the tools used were provided by Tom Bennett and the Maseeh College of Engineering Machine Shop. The tools used to build the cooker are outlined below:

- Drill press
- Hand drill
- Spot welder
- Lathe
- Band saw
- Hole punch

B Photos of the Cookers at Work

B.1 Iditarod Cooker

Figure 29: Lisbet Norris's 2015 Iditarod cooker during the Copper Basin 300 [3]

B.2 Denali Park Cooker

Figure 30: Cooker being used in Denali National Park [2]

C Undergraduate Research and Mentor Program Poster

Link to URMP poster for previous mushing cooker performance information: http://pdxscholar.library.pdx.edu/mcecs_mentoring/6/

D Contact Information for Questions or Inquiries

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