Linman He

Design Student

Integrated Product Design

Faculty of Industrial Design Engineering

Delft University of Technology

Design of a reusable canister for Laerdal's Compact Suction Unit.

0.1 General Information

Design of a reusable canister for Laerdal's Compact Suction Unit.

Conny Bakker

Project Chair

Design for Sustainability

Maaike Weber

Project Coach

Design for Sustainability

Ruud Balkenende

Project Mentor

Design for Sustainability

Linman He

Design Student

Integrated Product Design

Faculty of Industrial Design Engineering

Delft University of Technology

Shuai Li

Company Mentor

Laerdal Medical

Bram van Kireken

Industrial Design Manager

Laerdal Medical

0.2 Acknowledgements

Fig 0.2 Two Four Leaf Clovers

Firstly, I want to thank my supervisory team at TU Delft: my chair, Conny, and my mentors, Ruud and Maaike. When I was starting this project, I received kind help from Conny, and I was surprised to find out that Maaike, whom I had reached out to earlier, is also a member of Conny's research team. I also want to thank Conny for inviting Ruud to be my official mentor. I couldn't have asked for a better supervisory team at TU Delft. I always feel inspired during our meetings, and by the end of each meeting, I am fulfilled with the confidence of "I can do it!" When I am so struggling with the thesis writing, your encouraging words come to my mind and keep me working.

To my mentors Shuai, Bram, Mette, Wenting, and other Laerdal members, I want to extend a big thank you for all the support along the way. Special thanks to Shuai for your kind help and time dedicated to this project.

I am also grateful for the two visits to Stavanger, where Bram showed me around Laerdal's amazing factory. These visits provided me with the great opportunity to interact with Laerdal's team, receive invaluable feedback, and seeing how beautiful Norway is in May.

I would also like to thank all my amazing friends in Delft and across Europe. Your companionship, conversations, meet-ups, and explorations of the Netherlands nature with me during these months have been invaluable. Without you, I would have felt like a robot living a monotonous life.

As you are reading this, it means my study in Delft has come to an end, this is so emotional and such a beautiful journey, I appreciate all the people and challenges I have met along the way.

Also a big thanks to my parents, without you sacrificing financially, it would be possible for me to study abroad, I am lucky to have you.

Finally, a special thanks to myself! You are doing great this year. Even though this graduation project didn't go as planned, you put great effort into this project while also striving to find a job in a country so far from your hometown. Despite all the difficult times, you faced your emotions and continued to believe in yourself even when feeling low.

0.3 Abstract

Fig 0.3 Final design

This graduation project focuses on enhancing the sustainability of the Laerdal suction canister by developing a new reusable canister design for the LCSU, with a design emphasis on personal use. The design report comprises eight chapters, detailing the design research, iteration, and final proposed design.

The project was initiated by Laerdal with the assignment to "improve the sustainability of canister products used with Laerdal suction units." The research began with a context study of canister products, exploring their usage in various medical settings. This was followed by user studies through interviews and expert consultations. Based on the insights from these studies, the distribution of Laerdal's suction unit products across different contexts, and stakeholder analysis, personal users were identified as the target group, and the LCSU was selected as the target product, making this combination the most promising and impactful for the project.

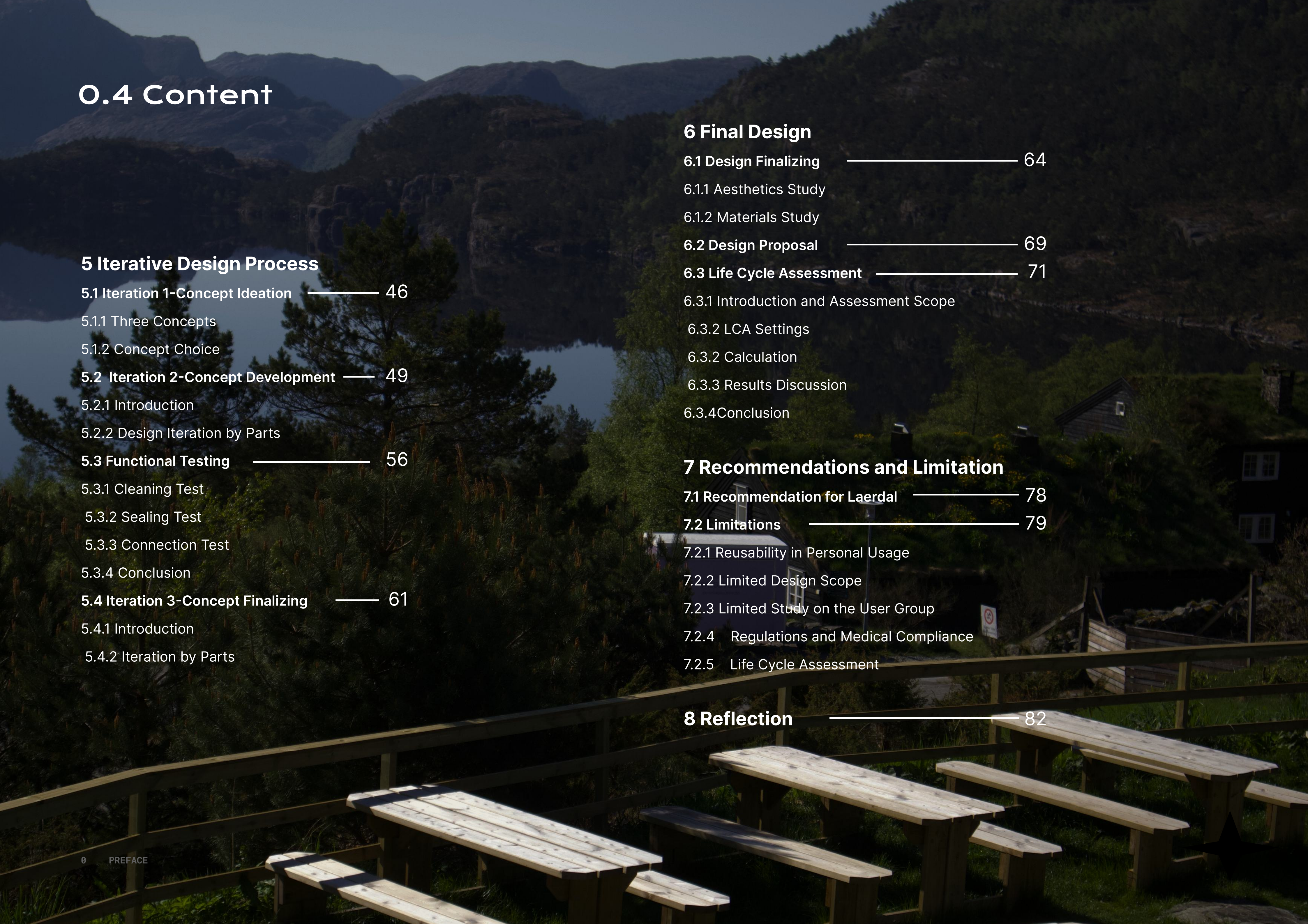
The insights and findings from the context and user studies, along with the sustainability goals derived from Laerdal's Circular Model, were synthesized into a list of design requirements and opportunities. These are summarized in Chapter 4, concluding the design research phase with a clear design vision.

Guided by the design criteria and the prioritized functionality of the canister, the design ideation process began. This iterative phase started with sketching and led to the proposal of three concepts, from which the most promising one was selected. The "compact reusable canister" emerged as the final design, presented in Chapter 6. This design addresses five key features: sustainability, reusability, ease of setup, ease of cleaning, and durability. A comparative Life Cycle Assessment of the proposed design and Laerdal's disposable canisters in Chapter 6.3 revealed that the new concept could reduce CO_2 emissions by at least 70%.

The project has a duration of six months, in Chapter 7, recommendations and limitations are included to address shortcomings and constraints encountered during the design process, providing potential design decisions and possible insights for future development and research.

Compact
Reusable
Canister

0.4 Content



0.4 Content

1-Project Introduction

This Chapter introduces the sustainable issues of current medical disposable products and explain how this collaboration is driven and conducted, the playground of this project: goal and scope.

1.1 Project Background

Around 80 percent of the health care industry's carbon footprint is a result of the single-use medical supply chain. (Greene et al., 2022)

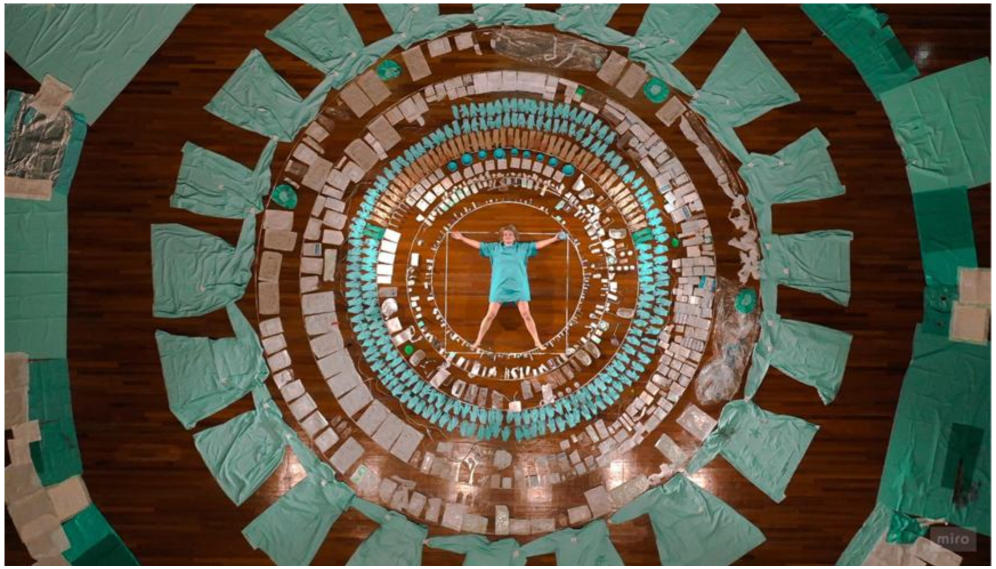


Fig1.1. Maria Koijck lying in medical waste from her surgery,2019

Disposable medical consumable products are widely utilized in various medical contexts. While medical professionals and patients appreciate the convenience offered by disposable products, it is important to realize the huge environmental impact they bring about. Fig 1.1 shows the medical waste from one full mastectomy surgery.

The healthcare industry, responsible for 4.4% of global net greenhouse gas emissions and toxic air pollutants (Karliner et al., 2020b), wields a significant environmental impact, while in the US the carbon dioxide emission of healthcare sector is 8% (Chung and Meltzer, 2009)

Among the carbon footprint generated by the healthcare industry, hazardous medical waste that requires extensive handling accounts for only 15% of global health-care waste, while discarded materials that are disposable rather than reusable comprise the remaining 85% of medical waste, which is at least 5 times that of hazardous medical waste. (Greene et al., 2022)

1.2 Collaboration

Laerdal Medical, our collaborator for this graduation project, is a Norwegian medical company headquartered in Stavanger. As a global leader in healthcare education and resuscitation training devices, Laerdal offers a diverse range of products, including online training courses, simulation and trainer products, and medical devices for Emergency Medical Services (EMS).

Laerdal Medical has set a goal to achieve a 70% reduction in carbon emissions by the year 2030. The impetus behind this project is driven by Laerdal's commitment to improving the sustainability of their medical consumable products, specifically canisters.

Fig 1.2 Laerdal Circular Model, Laerdal Impact and Sustainability Report

As shown in Fig 1.2 Laerdal implements a Reduce-Reuse-Recycle circular model, this model provides the basis of ideation and developing the reusable canister, which are featured as:

takeaways

1. Reduce the input of raw materials
2. Using quantitative methods such as LCA to optimize sustainability in product development
3. Minimizing waste through designing for recycling
4. Recycling materials internally and externally with partners.

1.3 Project Goal and Scope

This project specifically addresses the need for sustainability improvement of canisters that are used in conjunction with Laerdal Compact Suction Unit (LCSU). By focusing on enhancing the sustainability of canister, I aim to contribute to the broader goal of minimizing the environmental impact of healthcare practices.

The focus of this project will extend beyond materials exploration to incorporate design enhancements that optimize the canister's user experience and product life cycle. The project also discusses different design alternatives for the overall sustainability improvement among canister products, and analysis current existing products used in various context. The project aims to deliver a refined and environmentally conscious canister solution that aligns with Laerdal Medical's commitment to provide high-quality medical products.

To establish requirements and boundary conditions for the design of a reusable a cannister, a number of research questions was addressed as:

What is a canister and how are they used in different contexts? (Chapter 2)

How do personal users clean and reuse the canister now? (Chapter 3)

- What are the gains and pains for them?
- What can be improved for them in the reuse process?

Why do personal users tend to reuse the canisters? (Chapter 3)

- How can I design to make it safe and easy to reuse canister?

1.3.1 Project Deliverables

Deliverables

1. A proof-of-concept prototype for the proposed canister concept design
2. A design report documenting the graduation project process and design results

1.3.2 Project Approaches

Several approaches and design methods are used in this graduation thesis. Additionally, methods are introduced in detail at the beginning of each chapter or section.

Improving sustainability stands as the primary goal, to address this, approaches are taken as follows:

- An analysis of current canisters, focusing on how they are cleaned, reused, and disposed of at present.
- A conceptual design for a reusable canister intended for use with LCSU
- A sustainability study comparing the environmental impact of the proposed concept design and current design.
- A proposal for the reuse process of the current reusable canister and the proposed concept design.

(The project brief from Laerdal that this graduation collaboration started with can be found in the Appendix A)

The most important methods used in this study are briefly outlined here:

Literature Review
At the early stage of this project, I delved into canister-related academic essays and reports to gain insights into the project background and medical regulations related to canister products development.

Stakeholder mapping
To visualize the stakeholders regarding the Laerdal canisters, I utilized stakeholder mapping through a power-interest matrix, which is proposed by Aubrey Mendelow in 1991. This matrix combines colors and visual elements to depict stakeholder relationships and categorizations.

Interview
Expert interviews with medical professionals and various roles from Laerdal were conducted to gather insights. Additionally, I analyzed video recordings of user interviews conducted by Laerdal, meticulously reviewing the interview scripts to extract valuable insights.

Brainstorming

In the ideation phase, brainstorming sessions were conducted to explore a diverse range of design possibilities and expand the scope of potential solutions.

User Journey map

A user journey map, a valuable visualization tool in user research, was created based on facts and insights gained from user studies. This map facilitated the analysis of user pain points and elucidated the interactions between users and the canister.

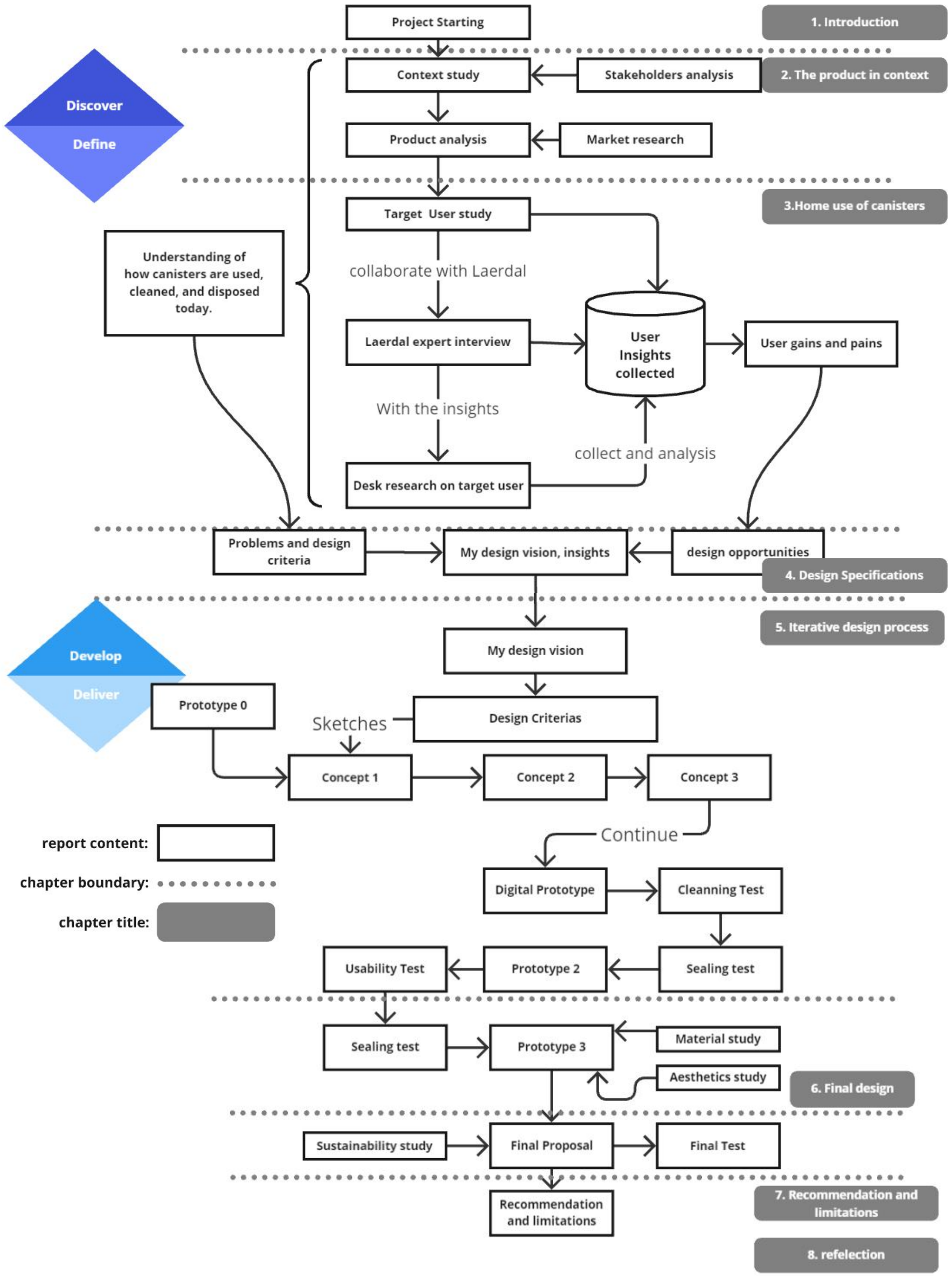
Granta EduPack

In the design finalizing phase, I used the Granta EduPack 2023 program as a tool to assess and compare the environmental impact of the materials chosen for my proposed concept.

IDEMAT and LCA

IDEMAT (short for Industrial Design & Engineering MATerials database) is a compilation of LCI data of the Sustainable Impact Metrics Foundation, SIMF, a non-profit spinn-off of the Delft University of Technology (Eco Costs Value, 2024). Life cycle assessment (LCA) is a methodological tool used to quantitatively analyses the life cycle of products/activities regarding their potential environmental impact.

This project uses IDEMAT 2024 as a database to measure the carbon dioxide emissions of the proposed concept design and current product, an LCA (Life Cycle Assessment) is conducted, and this quantitative method provides data evaluation into the sustainability of the canister concept.



Double Diamond

The project is divided into two major phases: design research and concept design. Figure 1.3.1 provides an overview of my project process. The black boxes on the right indicate where each phase is reflected in my design report.

In the first diamond process, I conducted context research and user research concurrently. This involved exploring the context surrounding current canister products and defining the problems I aimed to solve through my design. Through desk research and literature review, I established my design criteria and vision.

The second diamond process involved an iterative design approach, including concept and prototype iterations. Various tests on functionality and reusability were conducted to evaluate the design. Additionally, considerations such as materials, sustainability, and aesthetics were addressed to finalize the concept design. The report concludes with recommendations for the future development of the concept design for Laerdal.

Fig 1.3.1 Design research phase (Discover and Define) and Concept design phase (Develop and Deliver)of this project

2-The Product in Context

In the product study, I studied current canister products and identified their respective advantages and limitations. To start with, a stakeholders analysis is given. Furthermore, I analyzed Laerdal's two canisters, from them I concluded valuable design takeaways and insights. Through this process, I acquired valuable information into the specifications that must be considered before proceeding to the user study, and design phase.

2.1 Stakeholder Analysis

To gain a comprehensive understanding of the stakeholders involved in the canister product, I conducted interviews with various roles within Laerdal Medical. This stakeholder study aimed to uncover underlying issues and dynamics that could enhance the sustainability and usability of reusable canister products, also discover user pain points, and explore design possibilities. As a conclusion of this study, design criteria are listed in the end of this session.

A stakeholder mapping as shown in Fig 1.4.1 is created to illustrate the relationship around Laerdal canister product.

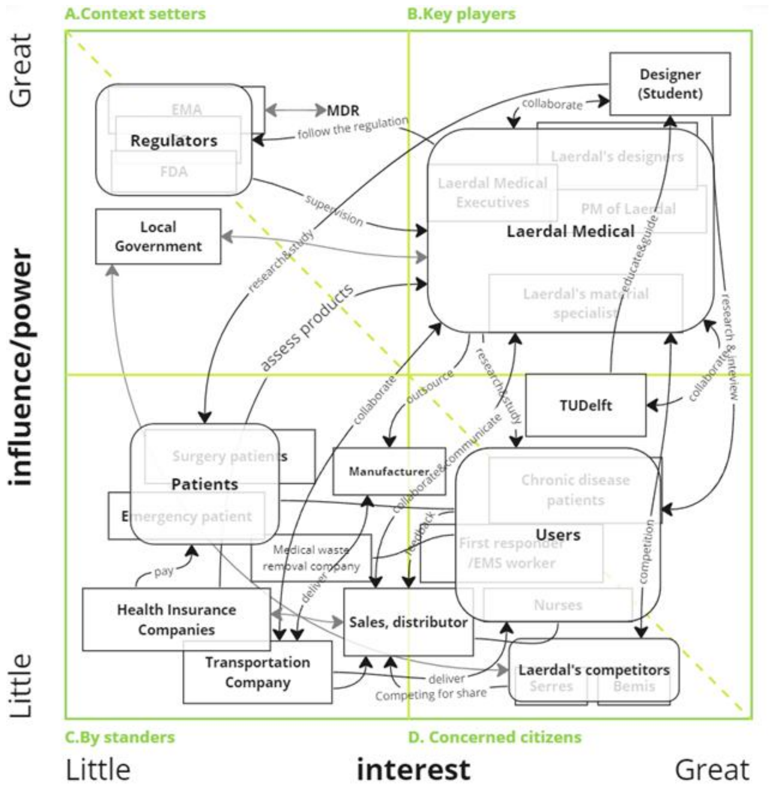


Fig 1.4.1 Stakeholders map of Laerdal canisters

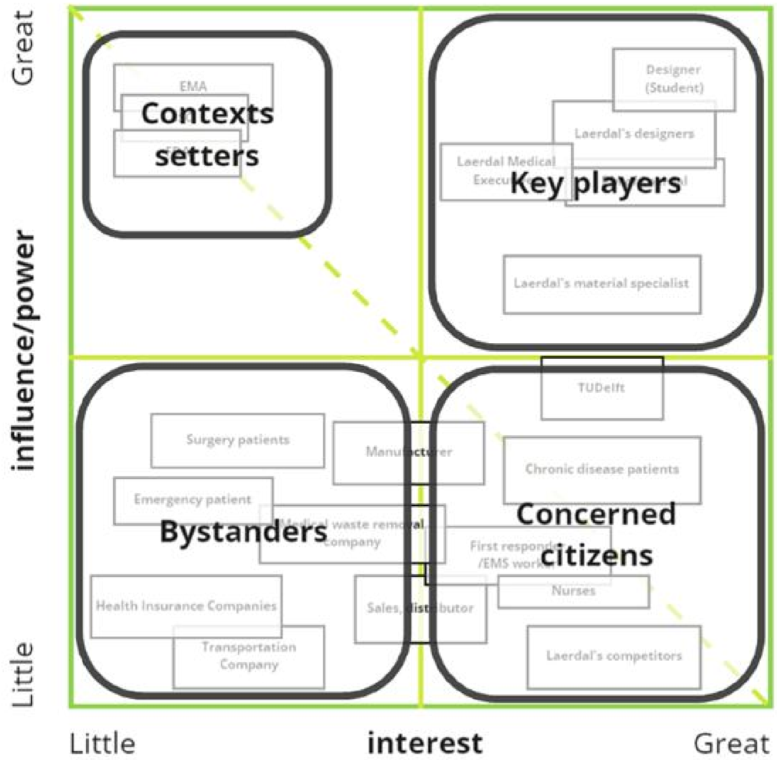


Fig 1.4.2 Stakeholders classification

Laerdal Medical

The biggest stakeholder of this project is Laerdal Medical, Laerdal's goal is becoming carbon neutral by 2030, advancing and implementing circular solutions.

Through this collaboration, we share the same goal to improve the sustainability of canister that works with Laerdal's suction unit products.

The proposed concept canister is designed to be compatible with Laerdal's suction units. Consequently, all target users are existing users of Laerdal's suction units and have experience with one or several canister alternatives.

Laerdal Medical oversees the design, manufacturing, transportation, and management of their suction units, along with two types of suction canisters. While these products are manufactured in China, they are shipped to Norway for assembly alongside canisters sourced from other manufacturers such as Bemis and Serre.

Despite the competition between Laerdal's own canister products and those from other suppliers, Laerdal remains committed to facilitating the integration of their suction units with alternative products.

Regulators (context setters)

Medical canisters are regulated by specific agencies and authorities to ensure their safe use in different regions. In the US, the Food and Drug Administration (FDA) is the regulatory for medical devices. In the European Union, medical devices are regulated by the European Medicines Agency (EMA) and local National competent authorities.

Under European regulations, manufacturers may need to engage with a Notified Body, which are independent organizations designated by EU member states. After qualified in the assessment from the Notified Body, the manufacturer can generate its declaration of conformity and label the product with the CE mark, which is required for sales and distribution in the EU.

Undergoing the medical compliance process is a large part of launching a new medical product. However, as this project is an early exploratory stage of one potential future product, it focuses primarily on design. Applying medical regulations and compliance at this stage could significantly restrict design possibilities, such as airflow rate standards for canister filters and high-temperature resistance requirements for canister materials. Therefore, relevant regulations for canister products are reviewed and provided in the appendix, but they do not heavily influence the concept design.

Personal users among these stakeholders

Personal users' voice is low in this business, for Laerdal Medical, personal users remain distant and unfamiliar. The primary customer base consists of distributors, who purchase batched assembled products from Laerdal. These distributors then distribute the products further down the supply chain.

Hospitals, as medical organizations, have the freedom to select the products they prefer. However, for individual users, accessing suction units and canisters directly can be challenging. They must first obtain a prescription from a medical professional justifying the necessity of owning a medical device (such as a suction unit) at home.

Additionally, they need to regularly purchase suction canisters, which are classified as medical consumables. Subsequently, they approach medical device distributors or medical organizations to order the necessary products, often at their own expense, which means they could have a limited range of choices. Direct purchasing canister from Laerdal's website is possible, however, this channel accounts for only a small portion of sales.

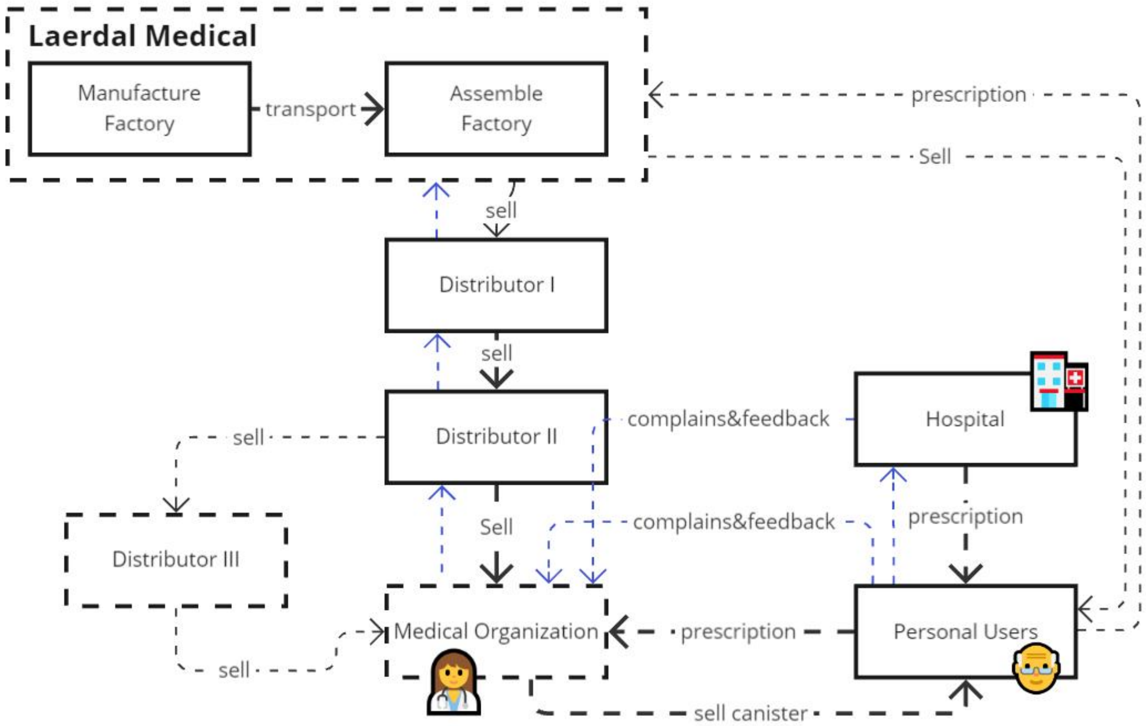


Fig 1.4.3 The distribution and sale process of Laerdal Medical

According to experts' interview, when medical professionals encounter issues or wish to provide feedback on the products, they typically communicate their concerns to the distributor. The distributor then periodically forwards these reviews to Laerdal. Consequently, there is a delay in the feedback received by Laerdal, there is an obvious absence of feedback from individual users regarding the canister product.

Stakeholders Insights

Observation: All medical products need to undergo the medical compliance process, and meet local medical product standards before go into the market. Given that the primary users of medical products are educated medical professionals, companies often find it challenging to cater to individual users within their target group from a perspective of medical compliance.

Insight 1: Developing medical products that take into account personal user preferences and behaviors, while providing product user guidance under medical regulations, poses additional challenges in this project. However, addressing personal usage of canisters can significantly fill gaps in the market.

Observation: Due to the limited coverage of insurance, personal users (in the US) have confirmed that cost of use is an important factor in their decision to reuse canisters.

Insight 2: A reusable canister with lower cost can be potential favored by personal users in terms of use cost.

Conclusion

Several stakeholders are involved in this project. Given that the highest goal of this collaboration is improving sustainability of canister product, and considering my personal design interests, the needs and values of the users are prioritized over serving company's business goals.

The proposed concept design, targeting personal users, can make up for the lack of canister products that cater to individual users in the existing market, discussing a more sustainable solution for Laerdal's canister solution.

Design criteria

1. The design should be compatible with standard tubing from other suppliers, as patient tubing falls outside the scope of this design.
2. Accessibility for personal users should be prioritized in the design.
3. The proposed design should be capable to be produced by Laerdal and assemble with LCSU, and at the same time available for separate selling.
4. The proposed design should align with Laerdal's sustainability goal.

PS:This graduation project, aiming at proposing a more sustainable concept canister design, can prioritize sustainability and usability over medical compliance and regulations.

2.2 How Do Suction Units Work

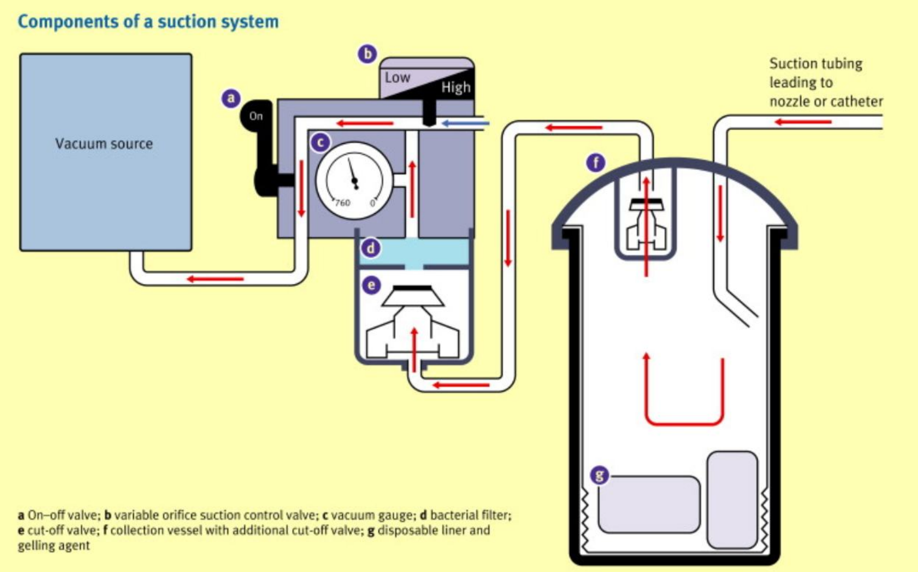


Fig 2.2.1 Components illustration of a medical suction system, (Shannon & Goldsmith, 2009)

A medical suction unit can be seen as a vacuum cleaner for human body. The suction unit, also known as an aspirator, is a widely employed medical device. It serves the purpose of removing secretions from a patient's airway, and is also utilized during surgeries and other medical contexts to get rid of human fluids or secretions, ensuring hygiene safety and a clear sight for the medical professionals. (Shannon & Goldsmith, 2009)

Operating on the principle of negative pressure, the suction unit creates a reduced pressure. When connected to tubes, it can effectively suck out diverse substances such as mucus, vomit, blood, saliva, serum, etc., or fluids from the patient's body, and even chips of bones, collecting them in a container known as the canister. (Shannon & Goldsmith, 2009)

Fig 2.2.2 A Laerdal Suction Unit with Laerdal Reusable Canister

These units rely on suction canisters as secure containers to collect human fluids and other secretions, yet the contents of these canisters are frequently infectious. Consequently, disposing of used canisters has become a long-standing user habit, in medical settings such as hospitals, discarding canisters with content is easier for the medical waste disposal process than emptying the canister and cleaning it, more discussion about canisters is given in Chapter 2.4.

2.3 The Suction Units in Contexts

2.3.1 Categories of Suction Units

Understanding the different usages of the suction units helped me grasp the fundamentals and of canister design, as they are assembled and work together.

To cater to diverse usage scenarios, suction units can be categorized into three types, excluding manual suction devices that operate without electricity. These variations in suction units accommodate different medical requirements and contribute to the versatility of the overall suction system.

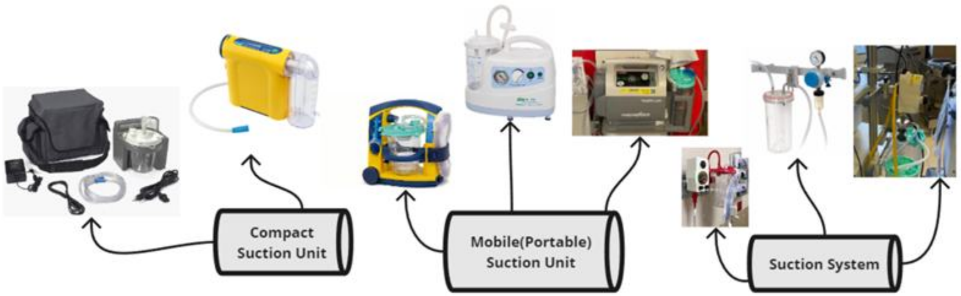


Fig 2.3.1 Three classification of suction units

Compact Suction Units - Patient care, home care

While medical professionals are the main users of suction units, some patients may also require a suction unit in their homes, this type of suction units are equipped with a battery, and are usually smaller in dimensions and light weight so they can be easily carried and moved.

Mobile Suction Units - Pre hospital

Mobile suction units are commonly found in pre-hospital contexts, such as ambulances. In Emergency Medical Services (EMS), responders prioritize checking the airway flow as the initial step, making suction units essential for clearing the patient's airway if needed. Mobile suction units in these contexts are expected to be stable and durable, usually affixed to the vehicle, and undergo daily checks before deployment.

Suction system - In hospital

Modern hospitals incorporate vacuum generation systems, where stationary suction units are connected to create one-way airflow. These suction units are typically affixed to the walls of hospital rooms, providing a fixed solution that ensures stability and consistency. With a lifespan of decades, these units contribute to maintaining a controlled and efficient healthcare environment.

2.3.2 Target Suction Product-LCSU

Laerdal Compact Suction Unit is the design target of this project. This project studied the LCSU from my field visit to Stavanger, Laerdal’s official website, the LCSU sample from Laerdal and Laerdal expert’s interview. The LSU and LCSU are the only two electric medical devices of Laerdal's Air Management category. These suction products, distinguished by their yellow-blue color combination, are widely used in different medical settings globally. (Laerdal Medical, n.d.)

The LCSU is a suction unit widely used in EMS, the C stands for compact, represents a compact option, portability is the key feature of it, it is also approved for personal home usage. LCSU is one of the smallest suction units on the market, comes with a weight of 1.5kg, even 2.5kg lighter than LSU, which is considered portable, Users can carry the LCSU out with the provided cross-body soft shell bag. This makes the LCSU an ideal choice for users seeking a more lightweight and portable suction solution, especially for personal usage. (Laerdal Medical, n.d.) As shown in Fig 2.2.2, the LCSU comes with a wire stand for holding the canister, creating an extra contact area on the bottom, and a handled feature on the top, these features adapt the LCSU for use in different contexts, such as outdoor and on a wheelchair.

Fig 2.3.2 The LCSU with disposable canister installed

Unlike the LSU, the LCSU does not currently offer a reusable canister solution. While approved for home use, the LCSU comes with an average lifespan of around 5 years, shorter than the LSU, according to Laerdal’s engineer, this is due to the different motor used in the suction units.

It’s worth noting that the LCSU has a battery life of 45 minutes, which is an average service time in the market, compared with the similar competitor Weinmann ACCUVAC with a battery life of 60minutes. (ACCUVAC Pro | WEINMANN Emergency, n.d.)

takeaways

1. All canisters that are used with LCSU are currently disposable.
2. The LCSU is primarily featured as compact and lightweight.
3. The LCSU is approved for home usage, which means it already has a certain personal users group basis.

2.3.3 Target Context

This project focus on design for home health care contexts, which refer to healthcare services delivered to individuals in their homes rather than in medical facilities. In these settings, suction procedures are often carried out by the users themselves or their caregivers, who could be family members or nursing professionals. It's important to note that the majority of users in this context are laypersons, individuals not formally trained or educated in the medical field. Their knowledge of healthcare is often derived from interactions with their doctors and self-learning. Consequently, their operational practices may not always align with established medical standards.

Despite this, staying in a home healthcare context is generally perceived as better for the well-being of the patient and more cost-effective, when compared to other medical settings.

Fig 2.3.3 A Community Nurse operates a suction machine on a profoundly disabled child in her bed at home, John Birdsall, 2007

2.4 Canisters

2.4.1 What is a Canister

Medical canisters are the container of contents from a suction machine, various canisters are available in the market, among them semi-disposable and disposable canister are medical consumables and will be discarded after use. Canisters are very common indifferent usage contexts, including home healthcare context, acting as containers for human fluids. (Peri et al., 2022) This role becomes especially critical when dealing with potentially infectious secretions from a patient's upper airway or surgical liquids that require careful management, especially during the pandemic time.

To enhance safety, canisters are equipped with bacterial filters and anti-overflow mechanisms. These features effectively collect and isolate the contents from possible contact with healthcare workers and contribute to the maintenance of a safe and clear medical environment.

According to my desk research on the current canister products market, I selected some common products. In Fig 2.4.1, these canister products are mapped according to their properties. The horizontal axis represents their usage contexts, ranging from critical medical applications to personal usage, with EMS positioned in the middle. The vertical axis shows the various capacities of the canisters.

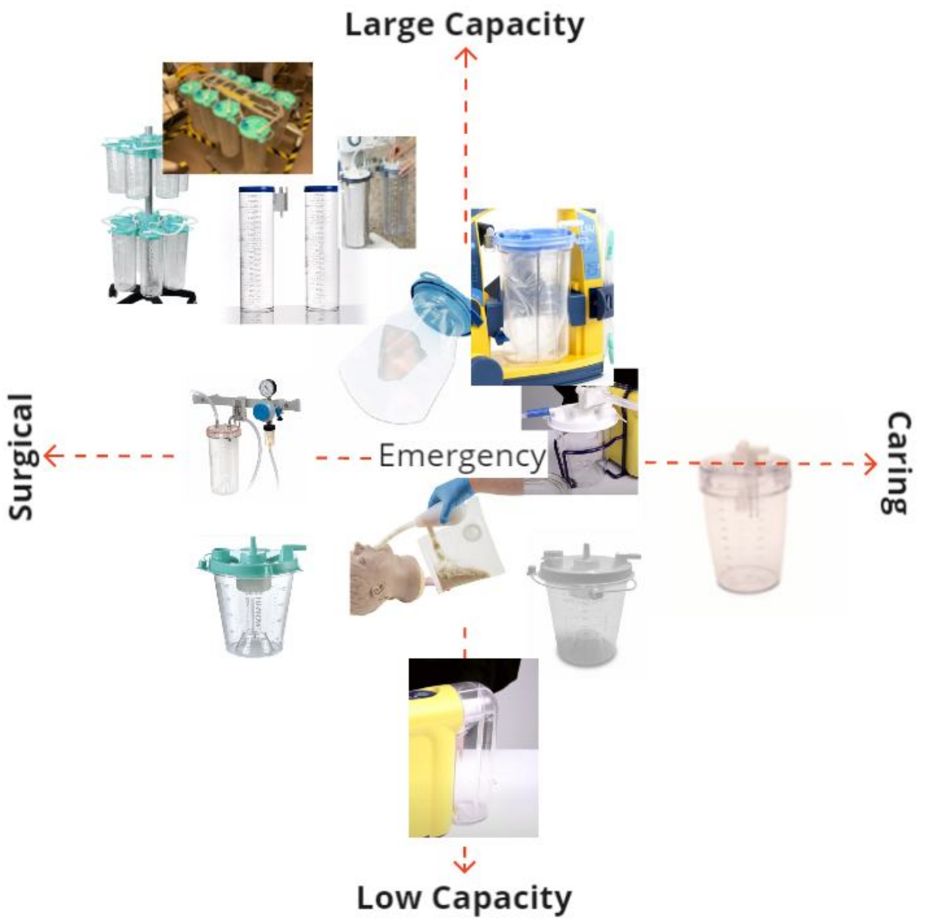


Fig 2.4.1 Canister products mapping

2.4.2 Categories of Canisters

Currently, medical canister products can be classified into three groups: disposable canisters, semi-disposable canisters, and reusable canisters. Each category offers advantages in terms of convenience, capacity. Fig 2.4.2 is created based on Fig 2.4.1 combined with their categories. It can be seen that disposable canisters are most widely used, while reusable canisters are more common in personal usage contexts.

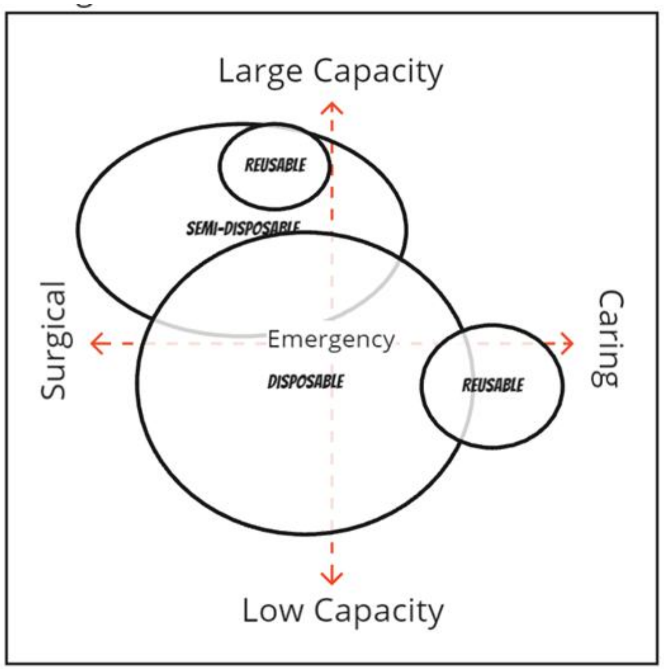


Fig 2.4.2 Canister products mapping in categories

Disposable Canisters

In larger medical organizations such as hospitals, disposable and semi-disposable canisters are the preferred choice due to their efficiency according to one interviewed medical professional (Dave.G personal communication, January 15, 2024), hygienic safety, and ease of disposal and management.

The individual components of medical suction and fluid collection systems are frequently contaminated and may become the source of infection. The overall risk of infection due to collected fluids is high if each component of the system is not well managed, maintained, and thoroughly disinfected or sterilized after each use. One case example illustrates that an outbreak of infection in the intensive care unit (ICU) was attributed to the reuse of suction catheters (Pillay et al., 1999).

Made from rigid plastics to withstand the negative pressure created by suction machines, these canisters feature a lid with ports for tubes—one connecting to the machine and the other to the patient. Post-use, both the canister and tubes are discarded as medical waste and will be sent for incineration process as their graveyard, but leaving their carbon footprint.

Semi-Disposable Canisters

Semi-disposable canister products series are common in the surgical fluid management market for years (Reusable Suction Canisters Serres, n.d.). The canister product is trusted for its durability and user-friendly design. (Dave.G personal communication, January 15, 2024)

Serres is a Finnish medical company producing semi-disposable canisters. The Serres semi-disposable canister consists of two parts: a suction bag and a canister. The soft polyethylene bag is designed for single use and is installed within the rigid, reusable canister in suction. The product's ease of use is widely acknowledged, and it has a straightforward connection system that is ready for use with just one connection, effectively minimizing the risk of misconnections. When the suction is finished, the suction bag can be easily disconnected from the canister while the bag will be strictly sealed.

In addition, multiple the suction bags can be multiple compressed and packed in one packaging, making it easier to store and transport.

Fig 2.4.3 Serres Suction Canisters Connected in a Row

The suction bag has capacities of 1l, 2l, and 3l, the itwhich can be connected in series to achieve a total volume of up to 36L, providing big flexibility to customize the total volume, and with that feature, Serres products are preferred in the surgical context.

Reusable Canisters

To withstand multiple usage cycles, the reusable canister is designed with robust and durable features. In comparison to disposable canisters, reusable ones typically feature thicker walls and are manufactured with durable materials such as high temperature PC(Polycarbonate), taking into account potential high-temperature sterilization processes.

Fig 2.4.4 Reusable ATMOS secretion canister

Furthermore, reusability implies that the canister will be opened and closed numerous times for cleaning and disinfection purposes. Therefore, the individual parts of the canister need to be removable, ensuring no inaccessible areas that could impede thorough cleaning.

2.4.3 Canisters from Laerdal

Two canisters from Laerdal are were analyzed and are discussed in this session, I conclude this study with a list of takeaways by the end.

Canister					
Unit	LCSU		LSU		
Reusability	Disposable (Laerdal design)	Disposable	Semi-disposable (Serres)	Disposable (Bemis)	Reusable (Laerdal design)
Capacity	300ml	800ml	1000ml	1200ml	1000ml

Fig 2.4.5 Canisters that work with Laerdal's suction unit

There are several canisters that work with Laerdal's suction units as shown in Fig 2.4.5 Laerdal designed the Click-on canister for LCSU and reusable canister for LSU.

Laerdal click-on canister

Laerdal has designed a disposable canister for the LCSU, named the Unique Click-in Place canister (abbreviated as click-on canister), with a volume of 300ml. A notable feature of the click-on canister is that it does not require a vacuum tube; it only needs to be connected to a user's end tube. Compared to other canisters that require an additional step of connecting suction tubing, the click-on canister is efficient in the setup procedure. The user only needs to click the canister into the LCSU, which takes a few seconds.

The canister is sealed and equipped with an internal rigid filter. Notably, when the filter becomes wet, it transforms into a gel-like substance, effectively preventing fluids from entering the pump. Another substance is included in the filter composition, in addition to the sintered porous polyethylene listed. These design features ensure a seamless and hygienic suction process for the suction unit, also making it impossible to reuse. The canister body is secured together with two caps, and the filter is fixed inside, making it impossible for the user to empty the contents without breaking the canister.

Front cap for 300ml Canister	PC Kotex K-30
Rear cap for 300ml Canister	PC Kotex K-30
Blocking filter for 300ml Canister	PE porous plastic
Angled connectorr	PP
Patient Tube	PVC

Table 2.4.6 Materials of Laerdal click-on canister

Fig 2.4.7 Laerdal click-on canister

Laerdal Reusable Canisters

Laerdal has designed a reusable canister for LSU, which is currently the only reusable canister for LSU.

This canister has a rigid PC body and comes with a lid that can be opened up for cleaning. With a total of 8 reusable parts (see Figure 2.4.8) The lid is designed with grooves to enhance grip, facilitating easy opening for pouring contents,. However, it is important to note that when rotating the lid, the tight fit between the lid and the canister may produce an unpleasant noise: imagine nails scratching a chalkboard.

Aerosol Filter, LSU Reusable Canister	PVC + ABS Styrene-Butadiene Copolymer (SBC)
Float Ball, LSU Reusable Canister	PP
Vacuum Plug, LSU Reusable Canister	Silicone
LSU Reusable Canister	PC - HT
Lid w/Floater Valve Cylinder, Gasket for Lid, LSU Reusable Canister	Silicone
Suction Catheter Adapter	PC

Table 2.4.7 Materials of Laerdal reusable canister

The canister has a capacity of 1000ml, while actually in my suction experiment with water, the suction will be affected when the capacity is not reaching 1000ml due to the overflow protection mechanism (the small ball will float).

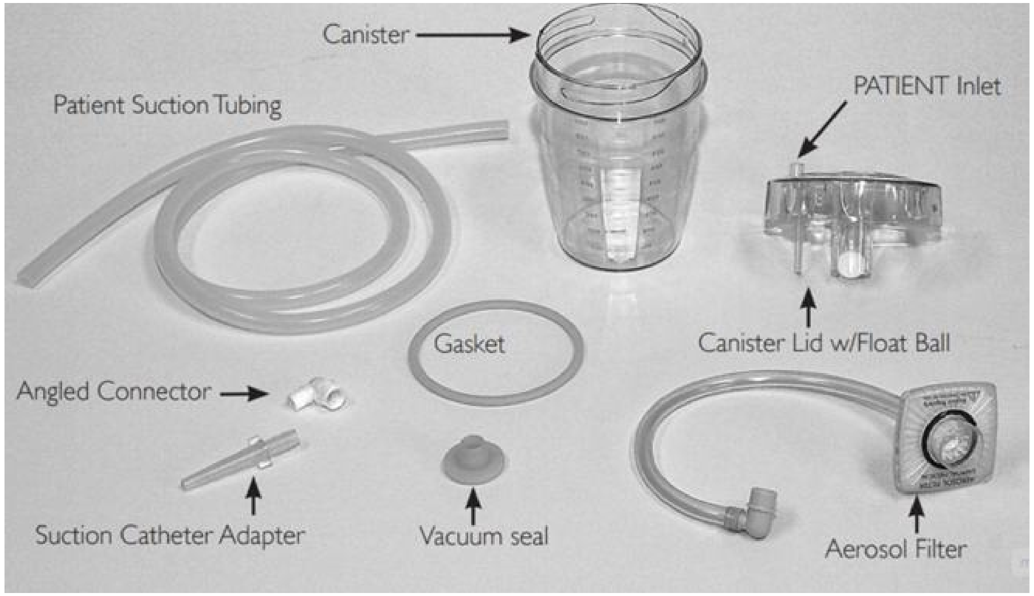


Table 2.4.8 Laerdal reusable canister parts

Within the 8 parts included, 6 materials are used. The material utilized for the reusable patient suction tubing, though not explicitly stated, has been determined to be silicone based on considerations of reusability and hardness, corroborated by interviews with Laerdal's expert (Shuai.Li, personal communication, March 18, 2024)

Laerdal has decided to discontinue the provision of reusable patient tubing in future canister products, a. As the lengthy design (150cm) of the tubing poses challenges for cleaning, disinfection, and drying, which increases the risk of mold and bacterial growth.

Furthermore, it should be noted that the aerosol filter (see Fig 2.4.8) is sourced from another supplier. Although categorized as reusable, no specific guidelines have been provided regarding the replacement interval for users, neither in the guidebook nor on the filter.

Table 2.4.9 User tubing (left) and extra suction unit tubing (right) in traditional canister

takeaways from Laerdal Canisters

1. The click-on canister integrated the filter inside, which can save the tubing (see Fig 2.4.9) between the canister and the unit, so no second tubing is needed
2. Only 3 parts are included in this canister system, by minimizing parts, and with the click-on structure, the time needed for setting-up canister is much shorter than traditional canisters that need one extra tubing (see Fig 2.4.9).
3. Rigid filter made from sintered porous Polyethylene can serve as the water valve, as the filter can form gel when it meets fluids, blocking ingress into suction unit.
4. 300ml cylindrical canister body is easy to hold with one hand, and is highly portable.
5. Guidance should be given clear on which parts on the canister are reusable, which should be replaced after use.
6. Canister users need to regularly purchase some medical supplies such as: aerosol filter and user tubing.

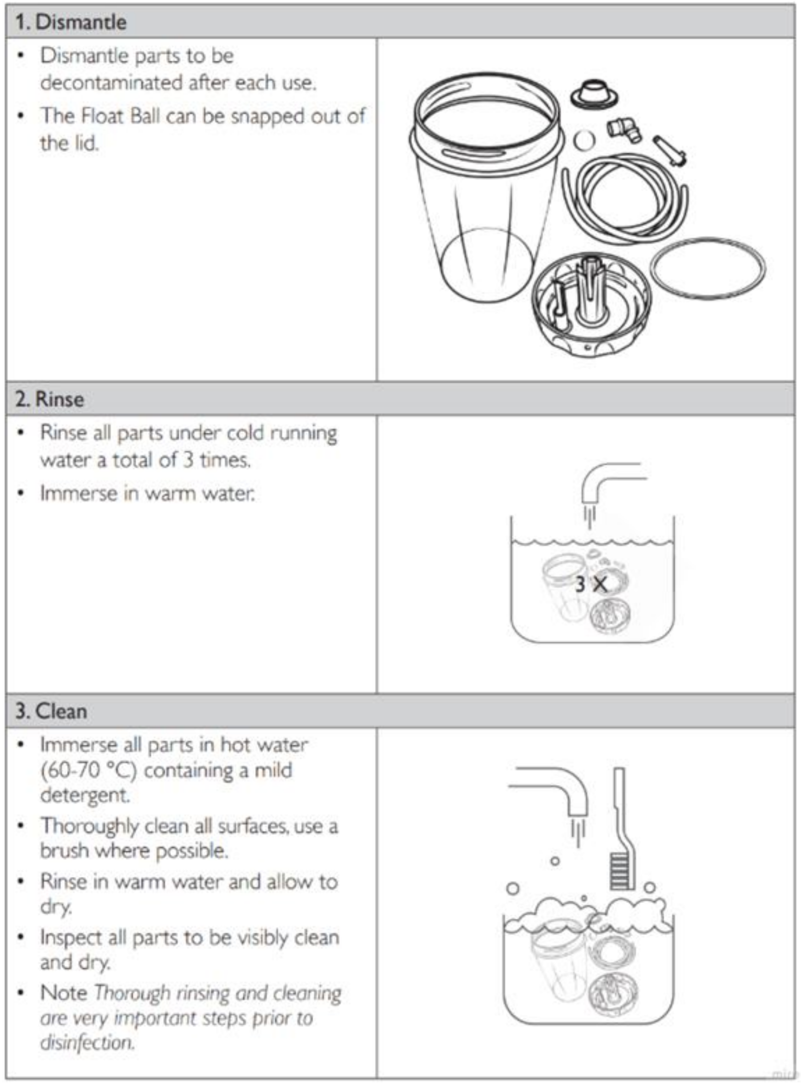
2.5 Use Cycle

The reusable canister is designed for multiple uses and can withstand numerous cleaning and disinfection processes. In this section, I analyzed the reuse guidelines provided by Laerdal for the reusable canister and summarized the key takeaways about the reuse cycle for my design.

The recommended cleaning process involves three steps: dismantling all parts, rinsing them, and then cleaning with hot water. According to the provided guidance, the user should prepare a brush, warm water, mild detergent, and a water sink. However, the guidance does not specify which detergents qualify as mild. After cleaning, the user needs to allow the canister parts to dry completely before proceeding to the disinfection process.

I followed the guidance to clean the reusable canister and observed that the water consumption was much higher than expected. The entire process took approximately 16 minutes. For the rinsing step, I used my kitchen sink. To fully rinse the canister in my sink, I needed at least 15 liters of water per rinse. Given that the process requires five rinses, I used a total of 75 liters of water just for cleaning. In comparison, a dishwasher typically uses only 13 liters of water per wash (Richter, 2011).

Note: In Chapter 6.3.2, I assumed that no sinking is needed in the cleaning process, which can reduce water consumption largely.



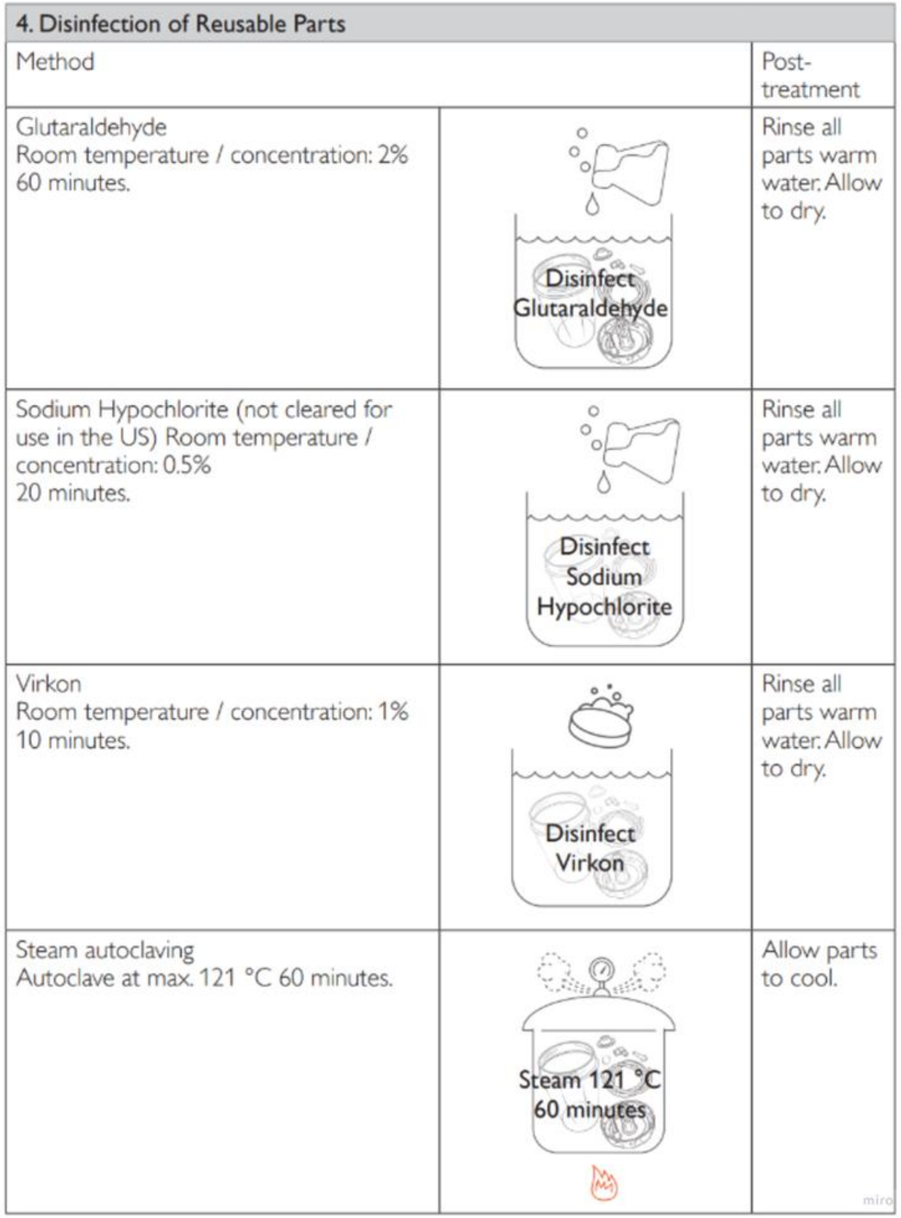
1. Dismantle	
• Dismantle parts to be decontaminated after each use. • The Float Ball can be snapped out of the lid.	
2. Rinse	
• Rinse all parts under cold running water a total of 3 times. • Immerse in warm water.	3 X
3. Clean	
• Immerse all parts in hot water (60-70 °C) containing a mild detergent. • Thoroughly clean all surfaces, use a brush where possible. • Rinse in warm water and allow to dry. • Inspect all parts to be visibly clean and dry. • Note *Thorough rinsing and cleaning are very important steps prior to disinfection.*	

Fig 2.5.1 Cleaning guide from Laerdal on reusable canister

There is no guidance on how to deal with the canister contents, however, draining down the sanitary sewer is a common practice to empty the reusable canister according to research(Siegel et al., 2007) and personal experience.

Laerdal offers four valid methods for disinfecting the reusable canister for medical professional users. However, the documentation does not specify whether users should select one method from the four options or follow all four steps in sequence. This guidance assumes that all users are medical professionals, among the four disinfection methods, only sodium hypochlorite is comparably easier to access for personal users, and its usage in the US region remains “unclear” (see Fig 2.5.2).

The reusable canister is tested safe for a use cycle (use-clean-disinfection) of 30 times according to in-company testing, based on the cleaning and disinfection guide provided, and the service life is extended into 100 times use cycle in new production batch. However, no guide was given in the user guidebook nor in the canister indicating the user should replace the canister after a certain time of usage.



4. Disinfection of Reusable Parts		
Method		Post-treatment
Glutaraldehyde Room temperature / concentration: 2% 60 minutes.	Disinfect Glutaraldehyde	Rinse all parts warm water. Allow to dry.
Sodium Hypochlorite (not cleared for use in the US) Room temperature / concentration: 0.5% 20 minutes.	Disinfect Sodium Hypochlorite	Rinse all parts warm water. Allow to dry.
Virkon Room temperature / concentration: 1% 10 minutes.	Disinfect Virkon	Rinse all parts warm water. Allow to dry.
Steam autoclaving Autoclave at max. 121 °C 60 minutes.	Steam 121 °C 60 minutes	Allow parts to cool.

Fig 2.5.2 Disinfection guide from Laerdal on reusable canister

3- Home Usage of Canisters

In the user study section, three medical experts’ interviews were conducted to gain insights into the experiences and perspectives of individuals with decades of medical background, during which suction units and canisters have helped them work safely and efficiently.

Additionally, two interview recordings from Laerdal Medical, featuring personal users utilizing suction machines at home, were thoroughly reviewed and analyzed.

In this section, user behaviors and preferences will be discussed, I try to reveal the underlying pattern and reasons, and a stakeholder analysis is conducted to explore the surrounding dynamics of the canister product while addressing personal users’ perspectives.

User Research Question:

To gain a comprehensive understanding of personal users' behaviors regarding canister products and to identify existing issues within current canister designs, two user research questions are proposed

How do personal users clean and reuse the canister now? (see 3.1.2 and 3.2.1)

- What are the gains and pains for them? (see 3.1.2)
- What can be improved for them in the reuse process? (see3.3)

Why do personal users tend to reuse the canisters? (see3.3)

3.1 Personal User Study

3.1.1 Personal users

Fig 3.1.1 Personal user's windowsill, from interview recording

The personal users refer to people who use the suction unit at home, some do the suction for their families, and some for themselves, they often do not have a medical background.

Patients with conditions affecting the central nervous system are typically reliant on medical suction (Ludlow, 2015), they may need suction multiple times a day. Their ability to swallow may be weakened, preventing them from independently managing their saliva. In these circumstances, the suction unit is indispensable to make sure their airway patency.

In many households requiring suction, there are usually multiple suction machines available. In the two personal users interview recording, both interviewees mentioned that they have more than one suction unit and several available canisters at home. This is because if the only machine malfunctions, it could be catastrophic for the individual requiring medical suction, as without prompt suction, there is a risk of suffocation.

To ensure uninterrupted suction, several clean or new canisters are also kept on hand for use with suction units. Different units may require specific canisters, and each canister typically undergoes a cleaning cycle and requires drying before reuse.

3.1.2 Personal User Interview

Laerdal's team conducted two online interviews with personal users located in the US. These interviews are an important resource for me to understand the personal user group. I watched the full interview recordings and read through the transcripts., Insights and user pain points are concluded from these recordings.

Fig 3.1.2 One user added one extra filter in the canister (the part in red circle)

Both families had a child who required long-term care. Their children were unable to swallow and needed to use a respirator while sleeping. During the day, their parents used a suction machine to clean up saliva, and this process occurred very frequently, approximately every 25 minutes. Additionally, both families mentioned reusing the disposable canister out of the concern of cost. Their criteria for replacing the disposable canister were when a white haze appeared on the transparent canister wall.

Generally, the disposable canister was replaced every month, and one user mentioned that she would clean it daily with Lysol bleach spray, and then wipe the bleach, the cleaning process differs a lot from Laerdal's official guidebook. Another respondent mentioned rinsing the canister parts with water and mouthwash during one night after cleaning it with bleach, and he has great confidence in the cleaning power.

At the same time, the same user noted a decrease in efficiency of the disposable canister's inserted filter due to frequent reuse. This led to moist, unfiltered airflow into the suction unit which can be harmful to the vacuum pump for a long-term. To address this issue, the user manually added an extra filter between the canister and the suction unit (see fig 3.1.2). T, this behavior is not advised officially, as the medical company assumes users will dispose the whole canister after one use.

Note: Both personal users living live in the US region, where the Laerdal reusable canister is not approved as a medical product.
Insurance has very strict rules for reimbursement of products related to suction units: only patients with tracheostomy can reimburse the cost of tracheal suction catheters, suction canister is not mentioned here (Local Coverage Determination, US government). It can be seen from this Determination that it is hard for users with rare disease patients in their families to reimburse the cost of disposable canisters in the region of US.

User Pain Points:

1. Personal users are aware of the necessity to clean and disinfect the canister, however, no guide or suggestion is given from the manufacturer's side,
2. The filter is durable for a certain time of reuse, however, there is a lack of indication about how long should the user replace can use the filter.
3. Sometimes the phlegm will stick in the inner patient tubing or the bottom of the canister.
4. User cannot afford the disposable canister to be disposable.
5. There are not many portable reusable canisters in the current market, however, users do have the needs to go out with the suction system.
6. Users sometimes need to modify the disposable canister to make it reusable.
7. Laerdal reusable canister is not approved for use in the region of US.

Quotes:

1. "If you could figure out a way to make the small canisters (click-on canister for LCSU) reusable. It would be fabulous!" -Personal user
2. When asked how often do people use suction machine at home, "Probably a hundred or more, on average per day" -Personal user "Every 25minutes during day time" – Personal user
3. "I can't replace that canister every day. It's too expensive."-Personal user who would reuse the disposable canister for one month

Design Criteria

1. Use guidance and suggestions should be provided and tailored for personal users.
2. Suggestion should be clear regarding the use and replacement of filter.
3. Canister's portability should be considered.
4. Canister design should take into account wheelchair usage.

3.1.3 Online Research on Personal Usage of Canister

Throughout the project, Laerdal's and my efforts to engage personal users of suction canisters residing in Europe for interviews proved challenging. Despite collaboration with Laerdal's sales team and several distributors, we encountered difficulties in locating suitable candidates for interviews.

In light of this, I conducted extensive desk research to hunt obtain insights into user experiences with reusable canisters. By searching on platforms including: Amazon (online shopping website), Reddit (online-forum), Quora (knowledge sharing platform), and SMA forums (forums for SMA patients, typical users of suction unit), I used keywords such as "reusable canister," "medical suction machine," and "reusable canister cleaning" to gather user opinions and complains regarding canister reusability. While the information obtained lackeds the rigor of direct interviews, it nonetheless furnisheds valuable practical insights for my design process.

Here are some insightful quotes from online users:

Under the question: [Doctors and nurses: what piece of medical equipment is most disturbing? Maybe you even keep it out of a patient's line of sight.]

Quotes1: "I suction a large amount of snot, blood, pus, earwax, and occasional stomach contents. Patients do not need to see this accumulation." (Quora user, 2019)

Under the question: [Does blood/gore stop bothering doctors and nurses? What still grosses you out no matter how much exposure you've experienced?]

Quotes2: "Phlegm...Want me to empty the suction canister...nope. Mostly kidding, I do what is needed of me but it will still gross me out" (Quora user, 2021)

In the 34.99 USD Laerdal click-on canister Amazon reviews.

Quotes3: "Wish there was a way to clean it and reuse. Come on people? Great compact unit for travel but can't clean it out, gets expensive"

Takeaways

1. Empty the canister filled with vomiting or other human fluids can be of high cognitive burden for user.
2. The click-on canister is appreciated for its portability, and users wish it to be reusable.
3. Seeing The content in the canister makes user feel uncomfortable

3.2 Usage Scenarios

With the information I gained from user study and context study, I defined 4 typical scenarios for personal users. These scenarios illustrate the using use environment, and the interaction between user, product, and patient.

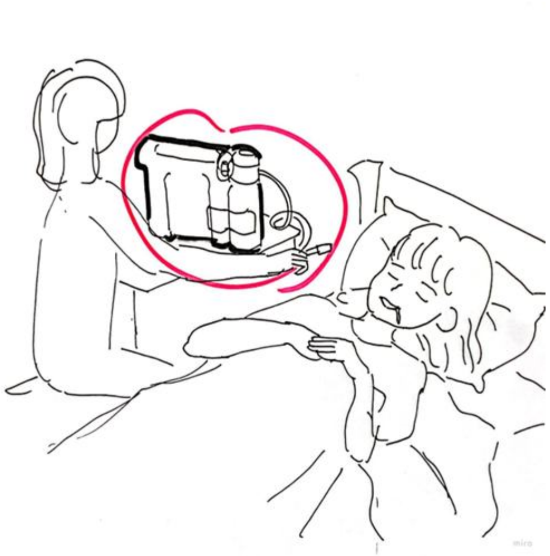


Figure 3.2.1 Illustration of home usage

Home

Home is the main scene where suction takes place, with beds and wheelchairs being common areas where the patient often stays. Suction units are typically placed on tables, which may also hold other items. Given that users often possess multiple suction units, these devices can be placed in various areas within the home, such as beside the bed, in the living room, or in the storage room. Once the suction unit is set up, caregivers may use it multiple times per day, depending on the patient's needs. In addition, the suction unit needs to be recharged regularly, and the canister is reused in this process.

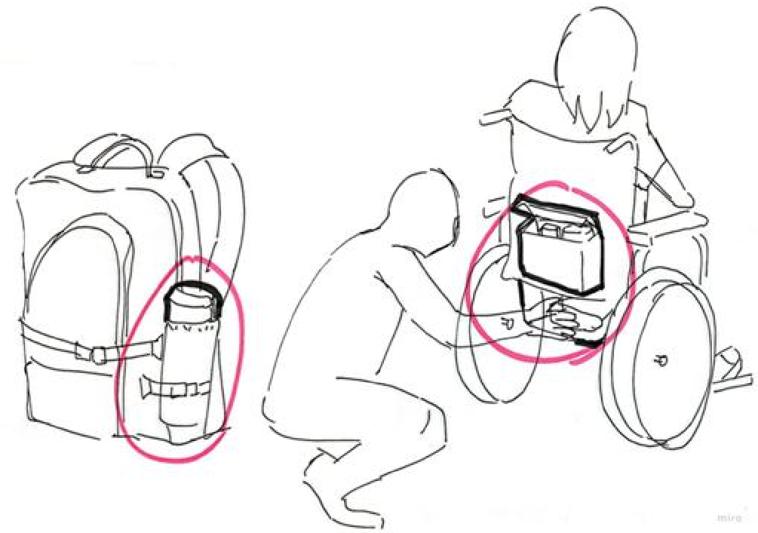


Figure 3.2.2 Illustration of suction unit usage in wheel chair

Wheel chair

Wheel chair is also a possible scenario for suction canister usage. Travelling with wheel chair is a challenging task for user, as there is no structure in the wheel chair for storage things. Additionally, individuals who require frequent suctioning often also face mobility issues, particularly when they need to bring along a suction unit.

For example, one user shared her experience of redesigning her daughter’s wheelchair to accommodate a suction unit. This modification was necessary because her daughter requires constant suction both at school and throughout the day.

Hand washing

Personal users also clean the canister themselves, as primary location for conducting cleaning tasks, in the kitchen sink is where the user would clean the canister parts, as it is equipped with cleaning tools, warm water and detergents, the sink in the toilet is generally not big enough for cleaning canister parts.

Dishwasher

Cleaning with a dishwasher is also an option for cleaning canisters, and it can reach a temperature of around 60 Celsius degrees, which can kill most of the daily bacteria (Michael, 2020), at the same time, a dishwasher can save more water than hand wash on average (Venkatesh, 2022c).

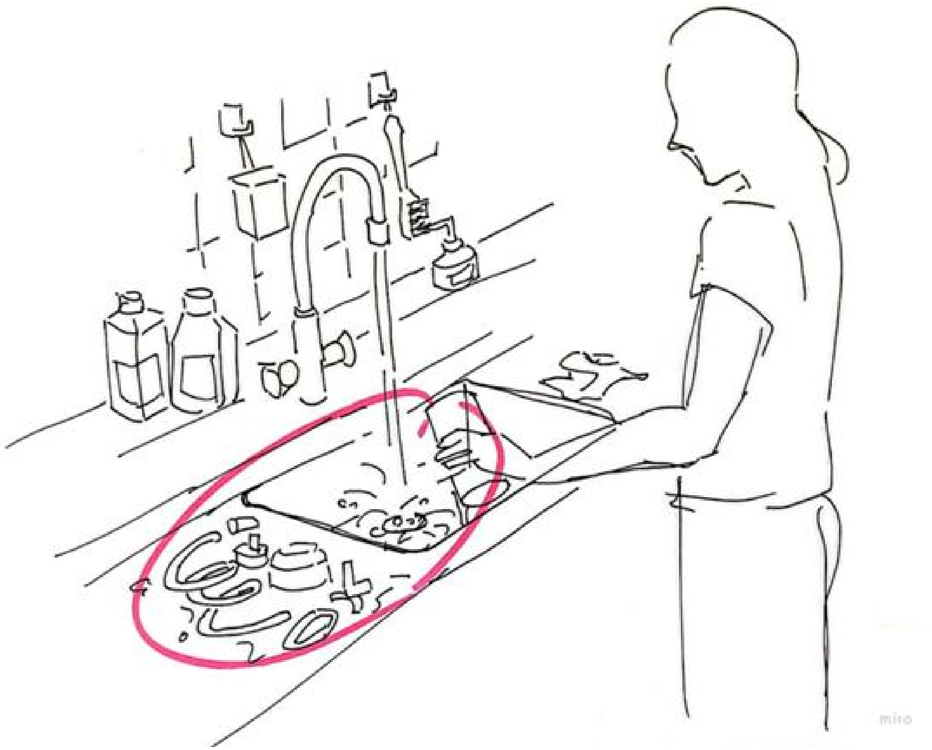


Figure 3.2.3 Usage in the kitchen

3.2.1 User Journey of Reusable Canister

Based on user interview videos, consultations with Laerdal experts, and information gathered from desk research, I created a persona for the user journey mapping, the target user Stan. **Stan** is depicted as a single father responsible for caring for his daughter Julie, he lives in Belgium, and during day time, he works for one high school as a sports teacher, after work, he takes care of his 9-year-old girl with a helper from the government.

[Stan's day]

[Stan wakes up at 8:30 and helps Julie get ready for the day. At 9:00, he gathers all the parts in the kitchen that he cleaned the previous day. He feels a sense of joy knowing that Julie's condition is good and all the parts of the suction machine are clean and dry.

Stan sets up the suction unit, ensuring the machine is functioning properly. He assembles the canister and replaces the old tubing with a new one, as the old tubing was slightly loose. He also prepares a glass of water beside the suction unit because, in the morning, Julie's snivel and saliva often stick to the inner walls of the tubing. The dryness causes secretions to adhere, and sucking of water helps flush them away.

The day passes quickly as Stan checks Julie's needs every 20 minutes to ensure she is feeling well and her shirt remains clean. At 21:30, Stan prepares Julie for bed. He detaches the canister and takes it to the toilet. As he empties the contents, he checks them emotionlessly, seeing those content is not such a pleasant thing but he is used to this routine, ensuring there is no blood or oddly colored mucus, maybe this is the most unwilling work of the entire day.

Stan then takes the canister to the kitchen sink, wears gloves, and uses a brush with dishwashing soap to carefully clean all the corners. Once all the parts are shining and spotless, he feels a sense of achievement. He places all the parts on a dry tea towel to dry before he goes to bed.]

User name: Stan
Age: 33
Region: Antwerpen, Belgium
Occupation: High school sports teacher

About Stan:

Stan is a single father, he has a 9-year-old daughter Julie, who is unfortunately diagnosed with the rare disease SMA, she couldn't swallow on her own.

Stan has a carer from the government to help him take care of his daughter when he has to work in the hospital. Stan takes most of the responsibility for caring for Julie.

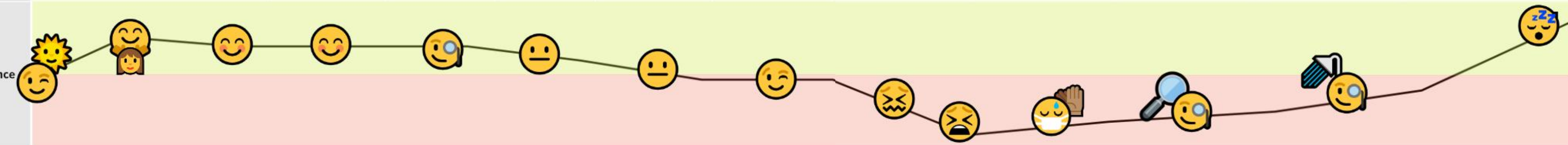
	Set-up the suction unit and canister			Use suction canister				Clear Contents	Prepare for cleaning	Cleaning	Disinfection	Drying
Stan's actions	8:30 Get up and check on Julie	9:00 Collect the canister parts cleaned yesterday	9:10 Assemble the canister and suction unit, test the negative pressure	9:20 Wipe Julie's mouth and conduct the first suction	10:00-21:00 Check Julie every half hour and suction as appropriate	21:30 After conducting the last suction, Stan realized the canister was full	22:00 After Julie went to bed, start to cleaning the canister	Disconnect the canister from unit	Take all the parts to the washing sink in kitchen	Flush all parts, use a small brush to scrub all parts with Dreft detergent	Rinse all parts in water, add bleach to Sodium hypochlorite 0.5%.	Rinse solution off surface
	8:50 Help Julie get up and wash up							Open the canister lid, pour the content into toilet	Put on gloves	Rinse away foam	Rinsen for 1 hour	Place all parts on a dry towel
Stan's goals	All the parts are dry		Make sure the unit is working right	The unit and canister work smoothly		Clealy see how much capacity is used	The canister seals the content safely	Quickly clear the content	Safely move all the parts	Clean away visible content	The water in the sink looks clear	The parts are easy to air dry
Contact Point	Canister Parts		• Suction Unit • Canister	Suction Unit	Suction Unit	Suction Unit	• Charger • Suction Unit	• Caniser • Suction Unit • Canister Lid • Holder	• Gloves • Canister Parts	• Brush • Canister Parts • Detergent • Sink	• Canister Parts • Bleach • Sink	• Towel • Canister parts
Pain Points	Find some places were not cleaned properly		Misconnect canister parts, lead to weak vacuum power	Because the tube is too dry, the phlegm sticks to the inner wall of the tubing.	1. The unit was tipped down accidently and the contents were leaked. 2. The contents fulfill the canister and are sucked into the unit 3. Secretions stuck in the tubing			1. The contents were accidentally spilled out on the ground during dis-connect 2. Hands touched the content	The contents were spilled out on the ground when moving all parts	The phlegm stick to the bottom of canister and is hard to remove	Accidentally added too much bleach	Ran out of dry towels
Opportunities	Canister parts are less than 8, so user can easily count the number, check if any part is lost		The canister can be easily connected, and set-up	First wet the inner wall with water	• Julie doesn't need to see the content cleary • The tubing can be hold somewhere	The canister shows how much capacity is used clearly	The canister remain sealed when disconnected from unit	• The holder can be easily disconnected • Doesn't need to clean the holder • Canister safely contain the contents	• Canister safely contain the contents	• Smooth inner surface • Simplified structure	• Smooth product surface • Simplified disinfection process • No dead corner to contain water	• Smooth product surface, easier for dying
Experience												

Figure 3.2.5 User Journey of Reusable Canister

3.2.2 Conclusion

Conclusion:

Individual users typically clean the canister once per day on a daily basis, with each day forming a usage cycle. Prior to the initial suction of the day, users must complete the setup and testing procedures. If all functions properly, they will utilize the suction unit multiple times throughout the day according to the patient's needs.

After completion of the final suction of the day or when the canister reaches full capacity, users disconnect the canister, and might replace it with a new one if the user finds the canister body is becoming fuzzy, like there is a layer of white dirt (User interview recording, 2023 October). The contents are then emptied into the toilet and ultimately disposed of in the sewer. The cleaning process occurs at the kitchen sink, as its size accommodates all components of the canister, allowing for thorough water flushing and rinsing.

According to one suction device instruction from Mayo Clinic, the canister can be: "Wash with hot soapy water or wash in the top rack of dishwasher." From this, it can be seen that the dishwasher is also an option for some users, in this case, the user might have several reusable canisters at home, and they would need to disassemble and assemble the canister and filter regularly.

3.3 Experts Interviews

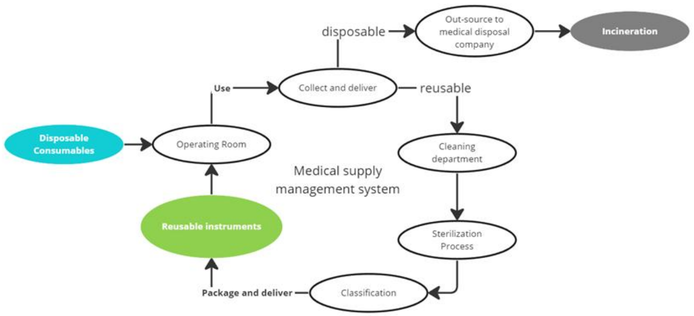


Figure 3.3.1 The process and management flow of medical supplies in a hospital

To supplement the user study, and learn about personal users from another perspective,. I conducted three online interviews with medical professionals: an experienced anaesthetist, an emergency doctor, and an emergency responder, all of whom have extensive experience working with medical suction canisters. The question list can be found in the appendix-Expert Interview.

Our conversations centered around the user experience of various canisters in practice, and the pros and cons of canisters. I gained many insightful findings from these interviews that will inform future design decisions.

From our conversations and research, I created a flow chart of the medical supplies management chain in a hospital (see Fig 3.3). It can be seen that reusable supplies experience a longer route than disposable supplies. Hospitals pay extra effort to recycle these medical supplies, usually expensive surgical instruments. Therefore, it is easier for hospitals to use disposable devices for cheaper items, such as canisters. (Dave.G personal communication, January 15, 2024)

Personal home is an ideal context to implement reusable medical devices, as there is a lower risk of cross infection, and cost of use is an important factor for individual users (Paola.M, interview, January 25 2024)

Insights

1. For disposable medical supplies, price is the first consideration.
2. Personal users tend to clean the canister according to their user behaviors rather than company suggestions.
3. For large medical organizations, it might take some time and strong incentive to transfer into a more sustainable system, personal home is a comparably easier context to implement reusable devices.

3.4 Conlcusion

Designing a canister that is easy to reuse, clean, disinfect, durable, and portable can help personal users better caring for the suction object, while also enhancing the sustainability of such products.

Insights from user study:

1. Healthcare industry's reliance on disposable materials is born out of pursuing for efficiency and safety
2. Personal users have a trust in the safety of reusing canister, and they are aware of that the canister is disposable.

4- Design Specifications

Before goes going into the design process, this chapter present a summary of my design research phase (Chapter1-3)., I related and transferred the findings, insights and problems noted in the previous chapters into a list of requirements, and proposed my design vision.

4.1 Design Requirements

Among all the insights I gained, these three insights are most valuable for my design and readers:

Insights

1. Personal users tend to reuse a suction canister, and reuse it according to their own experience and behaviors.
2. There is no reusable canister for the LCSU now, and users expect one.
3. Portability is a key feature for LCSU and the Laerdal click-on canister, which should also reflect on the concept design.

Personal users have not been the primary customers and users for medical company for years, designing a new reusable canister for them mean spotting their needs and user behavior, and at the same time taking medical device standards and requirements into consideration.

Based on the design research I have completed, I addressed several design challenging that I would face in the design phase. I, in this session, I concluded them as:

Challenges

1. Design a canister that suits with personal users' use behaviors and medical knowledge, while addressing its properties as a medical device
2. Design a canister that can be easily reused, including cleaning and disinfection in home contexts.
3. In the aspects of materials and parts properties, priority sustainability while addressing the durability and reusability.
4. How to dDesign the canister to be easily attached and disconnected from the LCSU while ensure its airtightness ?
5. Align the canister design with LCSU, including style and dimensions.

From the Design research phase, I concluded the following problems in current canisters:

Spotted Problems

1. The capacity of click-on canister is small
2. There is no reusable canister for LCSU
3. Existing canisters are too big for carrying out
4. Disposable click-on canister is not affordable in daily use
5. Users tent to reuse the disposable canisters
6. Storing rigid disposable canisters take too much space
7. The lid of disposable canister is hard to click on
8. Different tubings are easy to mess up
9. Personal users don't know if the canisters are reusable
10. Too much time for setting the disposable canister up, mainly on the lid tightening process
11. Personal users tend to clean the canister in a way they like without following the suggested methods
12. User guidebook is hard to follow for personal users
13. Existing canisters for LCSU are hard to carried/installed on a wheel chair
14. The LCU reusable canister creates noise when tightening the lid
15. No indication on the limited usage times for different parts

And further expanded design criteria into 3 categories of design requirements.

Design Requirements-Usage

1. The canister is portable, can be easily carried with
2. All parts can be assembled and disassembled in 1 minute
3. No tubing needed between canister and machine
4. The canister can be opened-up for cleaning
5. Can be cleaned in 15 minutes by a user without a medical background
6. The canister will not create unpleasant sounds
7. The canister is visually reliable and user-friendly
8. Use guidance and suggestions should be provided and tailored for personal users.
9. Provide guide on the replacement and recycle of canister parts
10. Accessibility for personal users should be prioritized in the design.
11. Canister design should take into account wheelchair usage.

Design Requirements-Properties

1. Reusable canister can be reused for more than 100 times
2. The canister has a larger capacity than 300ml
3. robust, safe from falling at 80cm
4. The canister is sealed with content, fluids-proof mechanism/ structure for the suction unit
5. A tubing parker/holder for the canister
6. The design should be compatible with standard tubing from other suppliers
7. The proposed design should be capable to be produced by Laerdal and assemble with LCSU, and at the same time available for separate selling.

With the Laerdal Circular Model described in 1.2, I highlight four sustainable approaches for my concept development, and I expanded them into six design requirements.

Design Requirements-Sustainability

1. Use environment friendly/recycled materials
2. The proposed design should align with Laerdal's sustainability goal
3. Minimizing the materials involved in manufacture process
4. Use Eco Audit tool to assess the environmental impact
5. Reduce the materials used on canister
6. Design the usage process for involving less energy and source

In this page, I further distinguish two categories: hard requirements are those that must be completed and met in the concept design, while soft requirements are desirable features that are good to realize in the design or in the future.

Hard requirements

1. The canister is portable, can be easily carried with
2. All parts can be assembled and disassembled in 1 minute
3. No tubing needed between canister and machine
4. The canister can be opened-up for cleaning
5. Use guidance and suggestions should be provided and tailored for personal users.
6. Provide guide on the replacement and recycle of canister parts
7. Accessibility for personal users should be prioritized in the design
8. Reusable canister can be reused for more than 100 times
9. The canister has a larger capacity than 300ml
10. robust, safe from falling at 80cm
11. The canister is sealed with content, fluids-proof mechanism/ structure for the suction unit
12. A tubing parker/holder for the canister
13. The proposed design should be capable to be produced by Laerdal and assemble with LCSU, and at the same time available for separate selling.
14. The proposed design should align with Laerdal's sustainability goal
15. Use quantitative analysis tool to assess the environmental impact

Soft requirements

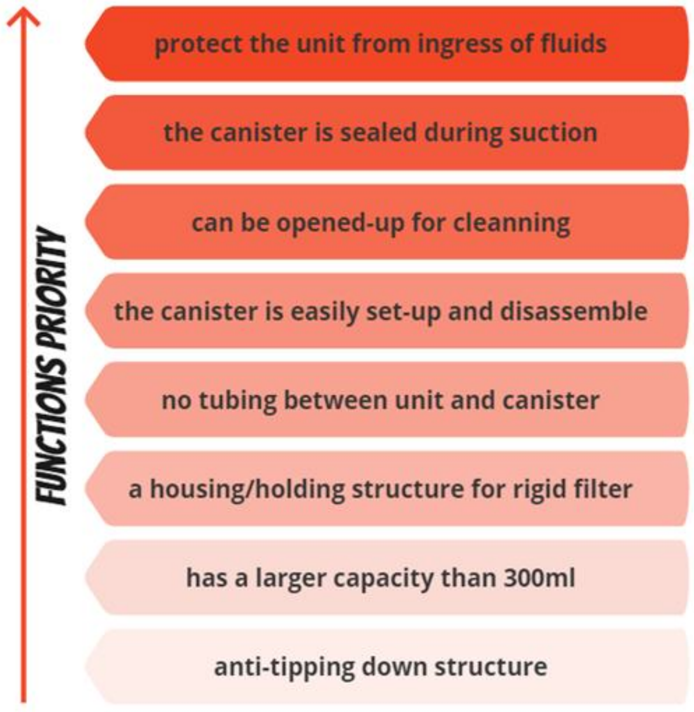
1. Can be cleaned in 15 minutes by a user without a medical background
2. The canister will not create unpleasant sounds
3. The canister is visually reliable and user-friendly
4. Canister design should take into account wheelchair usage.
5. The design should be compatible with standard tubing from other suppliers
6. Use environment friendly/recycled materials
7. Reduce the materials used on canister
8. Design the usage process for involving less energy and source

4.2 Functions Priority

With the design criteria and requirements defined, a functions priority chart was made to illustrate the importance of different functions of the canister, this can help me balance the design choices when there is a design conflict between different parts.

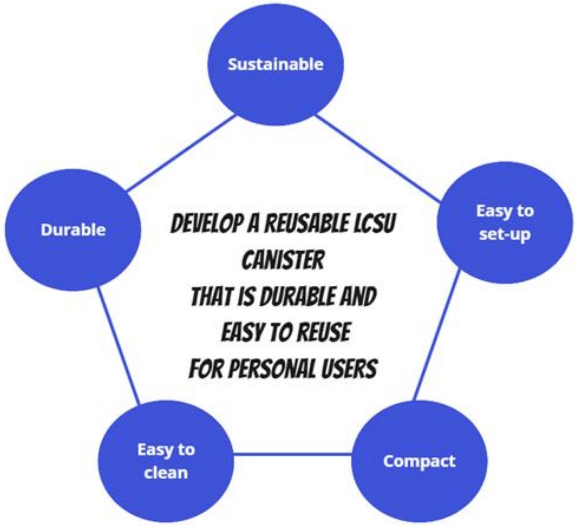
1. the unit from the ingress of fluids
2. The canister is sealed during suction
3. Can be opened up for cleaning

Above are the 3 most essential functions for the concept design, which ensure the reusable canister works properly. During the development process they are given priority consideration



4.2 Functions priority

4.3 Design Vision



4.3 Design vision with five features

Revised Design Assignment

To summarize all the expectations for the design, I proposed my updated design assignment:

Develop a reusable LCSU canister more sustainable than a disposable canister, which is durable and easy to clean for personal users.

Design Vision

My wish is to improve the canister reusing process, making it an easy and efficient experience for personal users. I aim to design a solution that instills confidence in users that they are making a positive impact on the environment.

And the design vision comes with five aspects as:

Sustainable: the proposed design is more sustainable than a disposable canister, and sustainability is addressed throughout the design

Durable: the concept design is robust for long-term use (100 days) and can withstand daily drops and crashes.

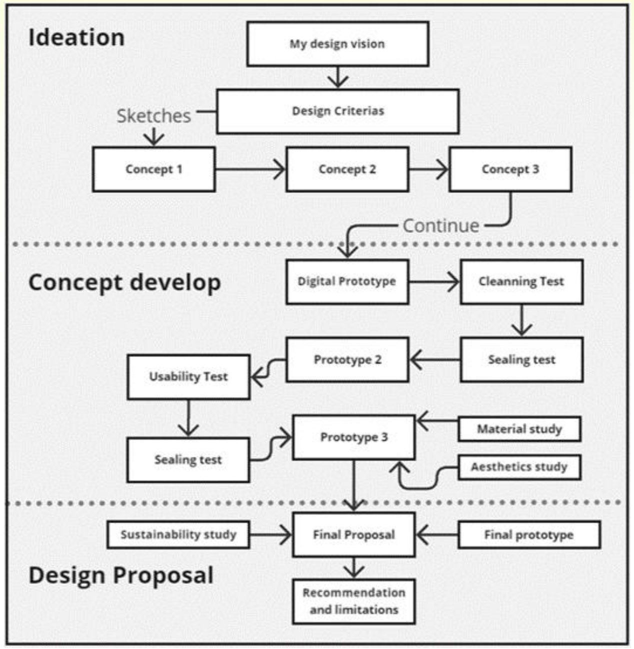
Easy to set-up: the concept design can be easily set-up by users without medical background

Easy to clean: the concept design can be easily cleaned by personal users in home context

Compact: the concept design is portable, and can be carried out in a bag.

5 Iterative Design Process

The design phase of this project can be conceptualized as a linear process, consists of numerous iterative cycles. The flow chart provided illustrates the three stages of my design approach: ideation, concept development, and concluding with the design proposal. While the flow chart simplifies the process into distinct stages, in reality, it often involves simultaneous activities such as sketching, prototyping, and testing. However, for clarity and coherence, my design report will follow the sequential order as presented in Fig 5a.



5.1 Iterative design process overview

5.1 Iteration1 Conceptation

5.1.1 Three Concepts

In the ideation process, 3 concepts were proposed, this section will introduce each concept. More details of the ideation can be found in Appendix-ideation

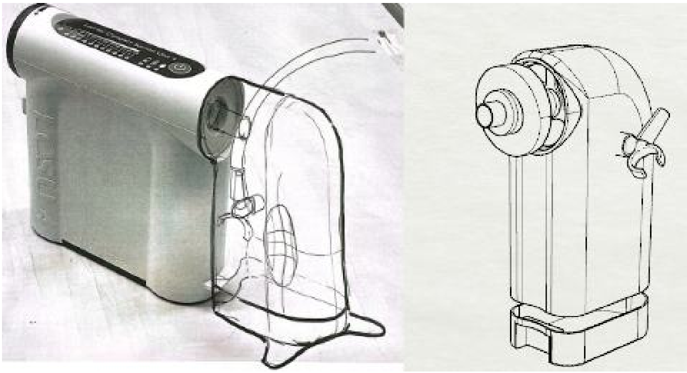


Figure 5.1.1 Concept 1 sketch and digital prototype

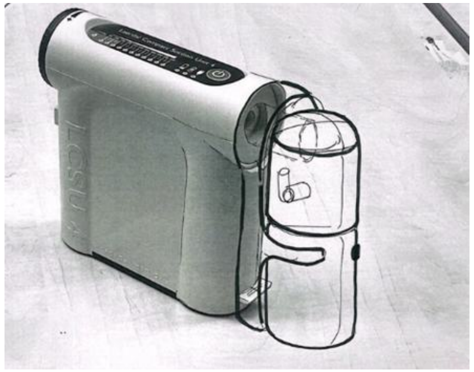


Figure 5.1.2 Concept 2 sketch

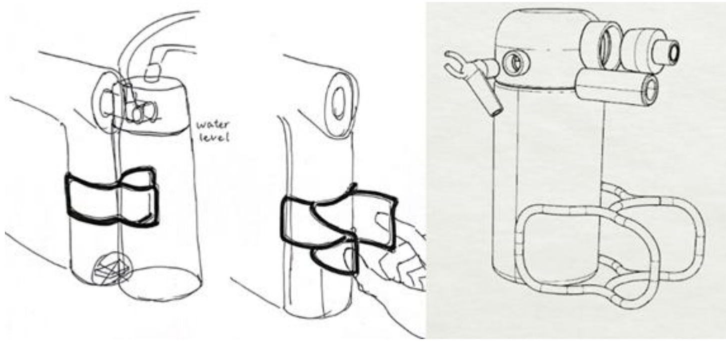


Figure 5.1.3 Concept 3 sketch and digital prototype

Concept 1

The first canister concept consists of five parts. It can be attached to the suction unit by clicking on a small step, similar to the Laerdal click-on canister. The capacity of the canister is significantly expanded by increasing its width. To compensate for the increased size, depressions are added on the sides for easier grip.

The canister can be opened from both sides, with the upper part featuring a circular lid for connecting to the suction unit and holding the filter.

Concept 2

The second concept can be viewed as a combination of a canister and a holder. The holder is attached to the suction unit while the canister has no direct contact with the unit. The simple-shaped canister is secured by the holder, which creates a smooth curved surface for the canister.

The canister is connected to the vacuum pump through a short rigid tube, which is part of the reusable canister lid.

Concept 3

Building upon Concept 2, Concept 3 simplifies the holder into a wire structure reminiscent of a hair clip. This design simultaneously clamps both the unit and the canister. The canister, resembling a water bottle, features a lid that can be unscrewed for easy cleaning.

5.1.2 Concept Choice

Concept 3 was chosen for further iteration because it has the most potential. The reasons for this will be explained in this section. To assess the pros and cons of each concept, I used the Harris Profile as a tool. To compare three concepts in the same criteria, I put myself in the users' shoes and wrote down pros and cons of each concept.

	Concept 1	Concept 2	Concept 3
Cons	• The durability of the bottom part is challenged by the way of it attching to the canister • The little step on the suctio unit making its contact surface with the canister uneven, creating dead corners in canister for cleaning • To hold the canister, the structure on the canister making it hard to clean • The canister is not compact	• The holder has contact with the canister, and thus should also be cleaned, resulting in extra work • The concept is not appearance simple • Two connections between unit, holder, canister, causing much deviation,can make the canister unstable	• Connecting the canister to the unit with the holder attached can be challenging • The holder is made from PVC coated steel, which is not recyclable
Pros	• Less materials are involved • With the click-on structure, easy to connect	• The canister can be a simple shape with the smooth surface from holder, making it easier to clean • With the click-on structure, easy to connect • Compact and portable	• The canister is in a simple shape, making it easier to clean • Compact and portable • Appearance simple

Table 5.1.4 Pros and cons of each concept

To compare three concepts in the same criteria, I put myself in the users' shoes and wrote down pros and cons of each concept.

Concept 1 has major shortcomings in durability and ease of cleaning. The opening at the bottom can be risky after multiple uses. Additionally, the canister has an irregular shape, creating many right-angle dead corners that would require extra work for cleaning and disinfection. However, Concept 1 has advantages in the setup process and recycling. It doesn't need an extra connection tool and is compatible with the little step from the LCSU. Except for the rigid filter, Concept 1 can be manufactured with only one material, making it easy to recycle.

Concept 2 shares the same shortcoming as Concept 1: when disconnecting the canister from the LCSU, the contents may stick to the holder and get "dirty," creating extra cleaning work. Concepts 2 and 3 have similar canisters but differ in their canister holders.

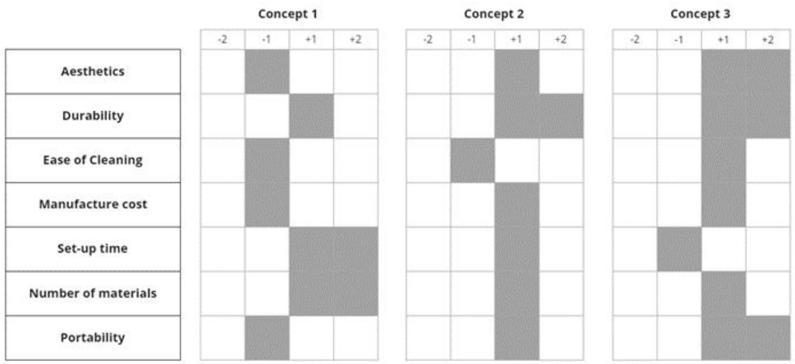


Table 5.1.5 Pros and cons of each concept

Concept 3 offers advantages in durability, portability, and ease of cleaning. The holder in Concept 3 is significantly improved, requiring less material for manufacture, and the metal holder is more durable than the plastic holder. Additionally, the holder in Concept 3 aligns with the original LCSU holder for the 800ml canister, making it easier to fit into the product style. The canister in Concept 3 is designed with a regular cylindrical shape, making it easier to clean and disinfect. Additionally, the holder is positioned far from the canister opening, reducing the likelihood of the holder getting dirty during use. These design details enhance the ease of cleaning and disinfection for Concept 3.

I transferred the pros and cons of each concept into a Harris Profile(Table 5.1.5). Each concept is scored based on seven aspects, which are defined from the design requirements list and functional priority list in Chapter 4.3. Concept 3 stands out in aesthetics, durability, and portability. There are many potential improvements in Concept 3 as well. The development process of Concept 3 is explained in the next section.

5.2 Iteration 2 Concept Development

5.2.1 Introduction

Table 5.2.1 Process sketches of concept 3

This section explains the process of developing concept 3, design arguments are given for design choices. During the process. with the sketches, I create 3D digital prototype to modify the dimensions, then I use 3D printing technology to create all the prototypes.

5.2.2 Design Iteration by Parts

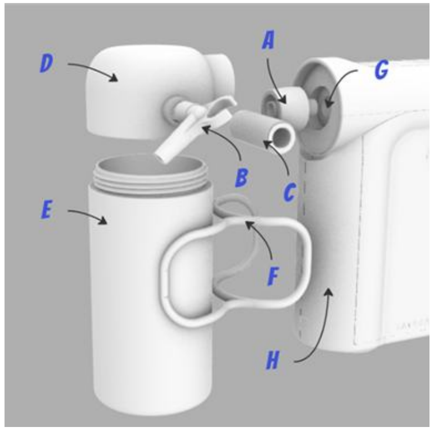


Table 5.2.2 Iteration-2 concept 3 digital prototype

Fig 5.2.2 is an exploded view of concept 3, parts A to F are the canister parts, while G refers to the inlet of the suction unit and H refers to the suction unit body. The design argument will be given in this section by for each part.

A: Filter connector, connects the rigid filter and is inserted inside G while using.

B: Angled connector, inserted in D, and connects user tubing.

C: Rigid filter, inserted in A during use

D: Canister lid, connected to E by threads

E: Canister body

F: Canister holder, attached to H, and holds the canister

G: Entrance of the LCSU, made from soft silicone material, allowing a certain tolerance in the connection.

H: LCSU surface, curved and smooth surface

Parts A&C-Filter and fluids-proofing

During the design process, the possibility to replace the rigid filter with a film filter was explored, and the design decision is to keep it rigid.

A medical film filter is inserted in a film housing, or a plastic shell for holding the film, and can reach a diameter size of 50mm, it works independently from a suction canister. At the same time, it needs to work with an effective water valve, because the film itself is not sufficient for preventing fluid flow into the pump. Besides, I wish to keep the design that no tubing between the machine and the canister is needed, so I need to integrate the function of filtering and fluids-proofing inside the canister while the space inside the canister is limited for a film filter.

In addition, if keeping the film filter, which is less effective in preventing ingress of fluids, then there has to be other structures (see fig 5.2.2b) inside the canister to implement the fluids-proof function, and it has to be more effective than the current solution. This could be quite challenging, since if the fluid-proof structure is not effective enough, it can also affect the airflow from the patient's end to the suction unit.

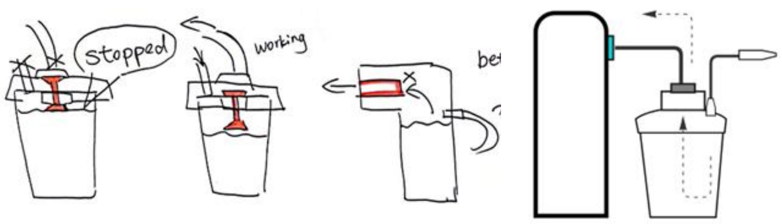


Figure 5.2.3 Sketches of canister filter, and working principle illustration of suction unit (right)

The disposable click-on canister is the only canister that implements a rigid filter, and there are several reasons for keeping the rigid filter. In regular canisters, the exit of airflow is on the top lid, so once the water level goes up, the water stop valve will block the airflow to prevent liquids from going into the suction unit.

In the LCSU disposable click-on canister, the airflow goes horizontally, so a traditional water valve is not applied in the canister, more details can be seen in Chapter 5.1.1. At the same time, the rigid filter is made out of a special porous polyethylene material, once wet the filter forms a gel which prevents ingress of fluid into the pump. (Sintered Porous PE Filter - Medical - Cobetterfiltration, n.d.-b) However, if it remains dry, it can be reused. Thus, the designer of the canister has taken two complementary approaches to protect the machine from fluid ingress.

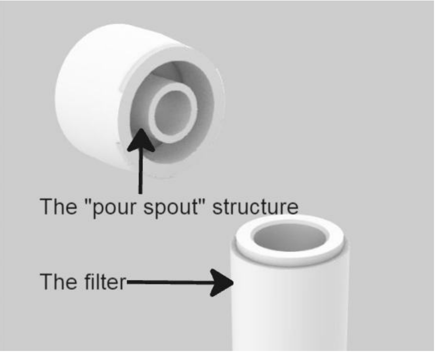


Figure 5.2.4 Structures of filter and filter connector

As a result, asides from keeping the rigid filter, a “pour spout” structure (see Figure 5.2.3 right figure) is designed in the connector for holding the rigid filter while serving as a flow restrictor for fluid proofing. However, testing of the prototype showedn that this connection is not strong enough; the filter tends to drop if the canister is uneven or shaking.

Conclusion:

1. The rigid filter works better for the concept than the film filter regarding the anti-ingress function.
2. The Rigid filter is easier to replace for personal users than film filter.
3. The rigid filter is easier to implement in the concept with limited space
4. The pop-out structure is added, together with the rigid filter to protect the suction unit.

Part B-Angled connector

Part B is the connector used for joining the canister and the user tubing. The shorter end is inserted inside the canister, while the longer end is inserted into the soft end of the patient tubing. It is shaped at a right angle, ensuring that the patient tubing does not protrude. The right connector in Fig 5.2.2e represents the final version. In this design, I improved the shape of the “ring” to make it more aesthetic and durable. Users can insert their finger into the “ring” or hold it to remove the angled filter.

Figure 5.2.5 Angled connector iteration 1 (left) and iteration 2 (final design)

Given that the suction unit can be used multiple times throughout the day, during periods of non-use, the patient tubing should be placed in a clean and stable position. For instance, it should not be left in contact with the ground or a desk. It is common to find a small "tubing port" on the lid of a traditional canister, used for holding the tubing. The “ring” holds the patient tubing when not in use.

Parts D&E-How is the capacity set?

The proposed canister has a capacity of 430ml, however, disposable canisters typically used in personal homes have larger capacities ranging between 0.8l and 1.2l. Laerdal's reusable canister officially holds 1L, while the click-on disposable canister has a smaller capacity of 300ml.

The total volume of saliva secreted by a healthy adult human per day is estimated to be approximately 0.6l. The flow rate of unstimulated/resting whole saliva in healthy persons during the day is in the range of 0.3–0.4 ml/min but with a large standard deviation (Dawes et al., 2015). Given this, if a person requires suction every 25 minutes during the day, then the content of one suction canister should have a capacity of at least 10ml. Assuming a constant saliva production rate throughout the day, and considering an individual's bedridden status for 8 hours, they would produce approximately at least 384ml of saliva during day time.

Apart from saliva, other secretions in the human airway may occur. When these secretions adhere to the tubing, users may flush them away with water. Hence, 430ml might not suffice as an inclusive capacity, nevertheless, it represents a 43.3% increase over the current Laerdal click-on canister, and covers the needs of most suction objects.

Parts D&E-How is the canister shaped?

With the cross-section in a regular circle, the canister can be seen as a cylinder. A cylinder has a consistent cross-sectional area, which means it can efficiently utilize space and maximize the capacity while minimizing the amount of material needed for manufacture.

At the same time, the circular cylindrical shape of a cylinder allows for an even distribution of pressure, which can be important when working with negative pressure, and also makes the canister stronger when receiving an outer impact.

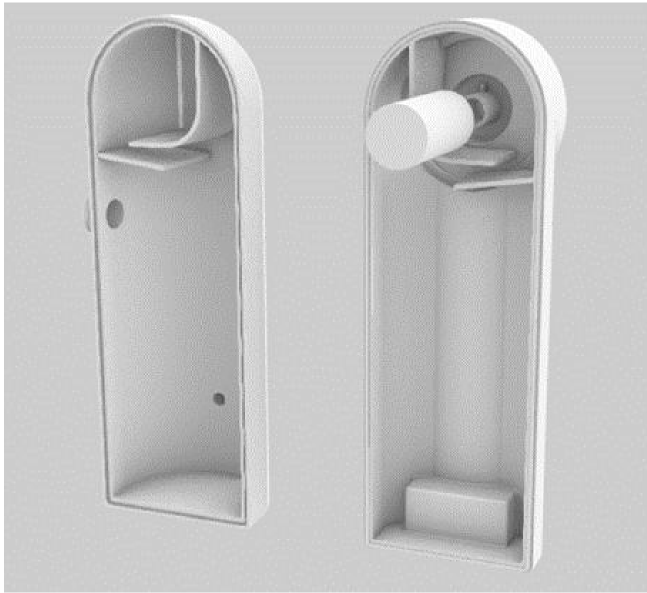


Figure 5.2.6 The structure of Laerdal click-on canister

Parts D&E-How is the wall thickness set?

The proposed concept has a wall thickness of 3.5mm, compared to Bemis disposable canister's thickness of 1.2mm, Laerdal click-on canister's thickness of 3.5mm, Laerdal reusable canister's thickness of 3mm.

While the proposed design initially considered a 2.5mm wall thickness, the decision to use 3.5mm was made to ensure durability and robustness. Although the 3.5mm version results in a canister mass approximately 40% larger than the 2.5mm version, the increased weight offers a safer and more reliable design. (Note: further testings might lead to an adjustment on the wall thickness)

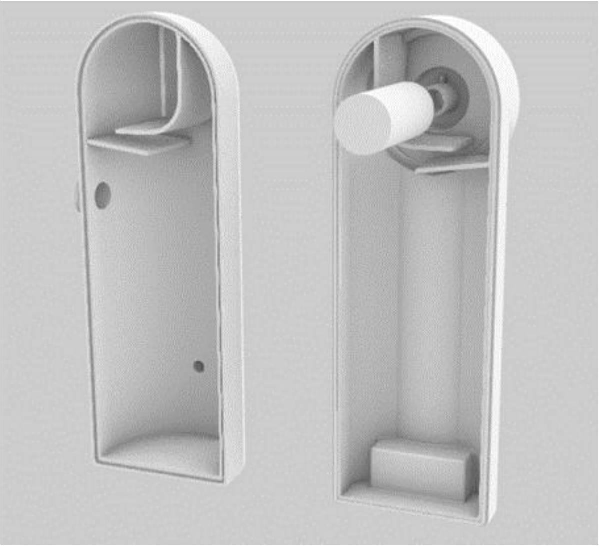


Figure 5.2.6 The structure of Laerdal click-on canister

Part H-Changes to the Unit

The little step on the bottom of the suction unit is removed to create a smooth and curved contact surface for the reusable canister. When I started the ideation, I tried to design while keeping the step, but this may lead to some undesirable situations: the canister body needs to save extra space to fit with the step, thus creating clean dead corners, which is not ideal for a reusable product that users will clean themselves.

Without the step, it will be impossible for LCSU to be compatible with the click-on canister. The consequence of this change is discussed in Chapter 7.3.3.

Figure 5.2.7 The little “step” at the bottom of the unit

Part F-Holder

The final holder design is inspired by the wire stand design from the LCSU, to adapt to different sizes of canister, Laerdal has designed various holders for LCU and LCSU.

The first iteration of the holder is a structure consisting of plastic coated wire. This material is durable, however, given its poor recyclability, the holder was redesigned to explore other material alternatives, so it can be produced in the same plastic material as the canister, which can potentially make the canister and holder as a whole easier to be recycled.

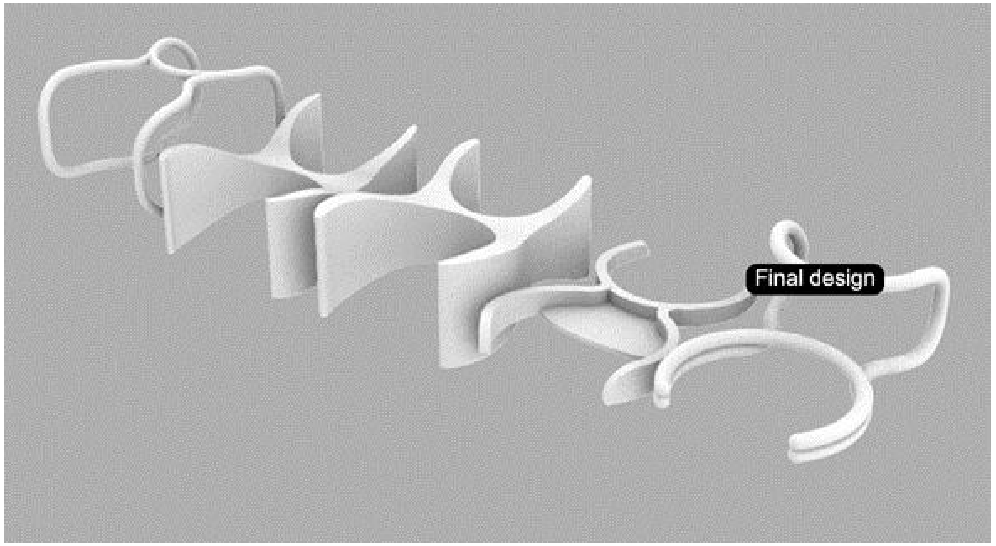


Figure 5.2.8 Iteration of holders (from left to right)

Figure 5.2.7 Wire stand (holder) for LCSU

As shown in Fig 5.2.8, to increase the structural strength of the holder, the bends are reinforced by increasing the cross-sectional area, and the areas in contact with the canister and suction unit are broadened to increase stability. At the same time, to balance the elasticity and the strength of the holder, the center part is designed to be thinner, creating a bow tie shape. I created holder prototypes using 3D printing technology, experimenting with PLA (Polylactic Acid) and SLA (Stereolithography) resin materials for the second and third from the left, I tested the shape and size with printed holders.

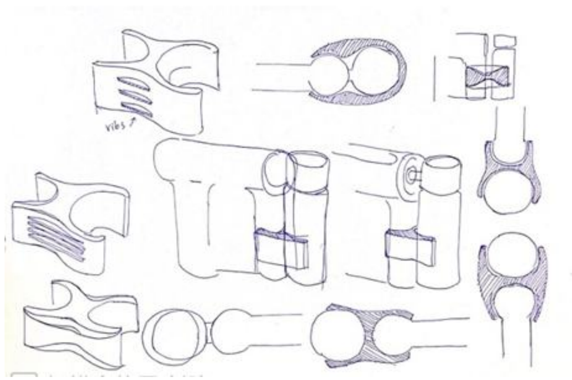


Figure 5.2.9 Sketches of holders

Conclusion

After three sets of tests, it can be concluded that the most important functions of this prototype described in Chapter 5.2.1 have been basically implemented, while another iteration round for the holder and filter structure are needed:

Protect the unit from ingress of fluids

While it was noted during experimentation that a minor amount of water leakage occurred from the filter gap, potentially seeping into the suction unit, this issue can be attributed to the imperfect fitting of the prototype filter and connector, a result of disparities inherent in 3D printing technology. However, it is anticipated that this issue will be effectively addressed by the functional rigid filter and the utilization of accurately manufactured components.

1. The canister is sealed during suction
2. The argument is explained in Chapter 5.3.2
3. The canister can be opened-up for cleaning
4. The canister can be opened-up for cleaning, and is proven in chapter 5.3.1

After detailed modifications and size adjustments to the connection dimensions, the final prototype was iterated to address the identified shortcomings. In Chapter 6, the final design with updated details is presented.

5.3 Functional Testing

In this chapter, I report three sets of testing I conducted with the printed prototypes. Iteration made based on the testing resulted in the final design.

The testing was as follows:
Cleaning test: to test if the canister is easy to clean
Sealing test: to check the airtightness of the canister
Connection test: to test if the canister is easy to attach to the LCSU

5.3.1 Cleaning Test

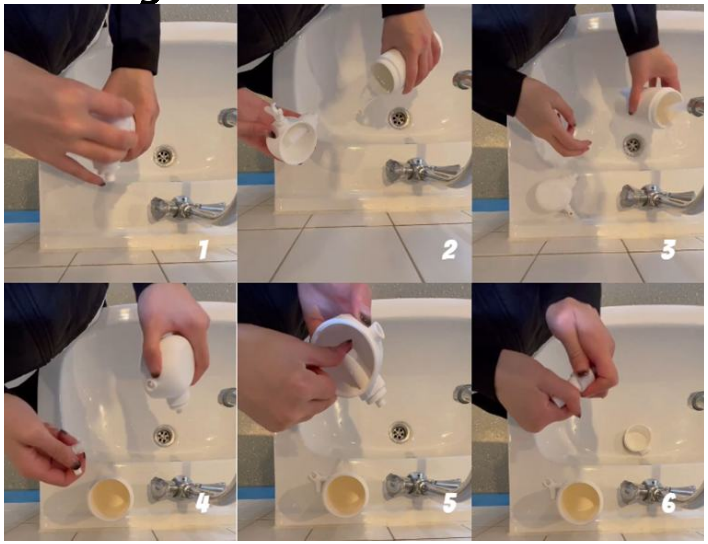


Fig 5.3.1 Testing video screenshots

Testing goal: By simulating the user's process of cleaning canister, test out the ease of cleaning of canister parts as a whole

Test process: The test is conducted at the washbasin on the ground floor of the IDE, a camera was used for recording the process.
The process is as followed:

1. Filling the canister with water and close the canister.
2. Opening the lid to pour out its contents.
3. Flushing the canister under the water pipe.
4. Disassemble all canister parts, and separate the angled connector and filter connector.
5. Thorough flushing of all disassembled parts.

Observations:

1. The filter now is too tightly inserted in the connector, it is impossible to take the filter off without touching the canister, however, the filter will be invalid if it contacts with fluids. However, in later tests, the filter drops when the canister is uneven or shaking.
2. During the cleaning process, canister parts are placed on the washbasin surface, where might be water or fluids, could also causing the filter meets fluids
3. The water flow can smoothly flush through the angled connector
4. There is a ring slot for inserting the filter on the connector, which is hard to clean thoroughly. Does the filter connector need to be cleaned every time? Since it has no direct contact with the suction content.

Takeaways

1. The connection between filter and connector needs to be improved so user won't contact the filter when taking it off,
2. The filter cannot meet with any fluids, how to protect the filter during the cleaning process?
3. The dimension of the canister can be highly compared to a water bottle, so the user is likely to clean the canister in the same way as cleaning a water bottle, for example by hand washing or putting it into the dishwasher.

More details are given in Chapter 6.1 regarding filter usage.

Iteration:

1. The structure of filter and filter connector is updated.
2. The way to take out the inserted filter is improved with a pop-up structure, so the user doesn't need to contact the filter with finger, which is described in following chapter.

5.3.2 Sealing Test

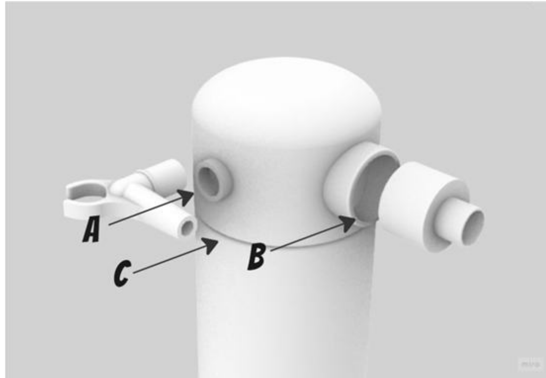


Fig 5.3.2 Three openings in the canister: A (tubing inlet), B (connector inlet), C (opening for the lid)

In this section, the canister's function of sealing will be tested. As shown in the image, the canister has three openings that need to remain sealed during use. Connection C is established using a screw structure, while opening B is sealed by a raised ring on both the connector and the lid. Opening A is inserted using the angled connector, which also features a raised ring to ensure sealing.

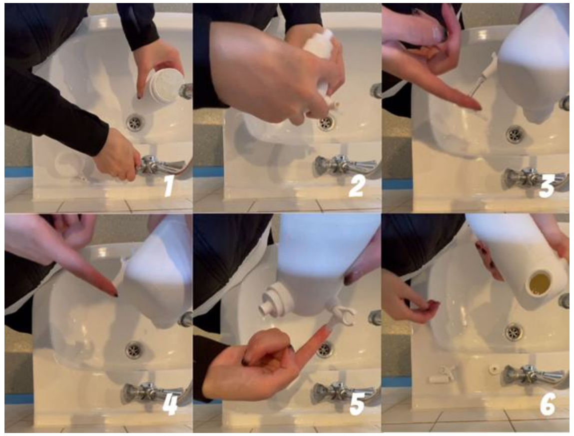


Fig 5.3.3 Testing video screenshots

Test Goal:

Test whether the three openings are well sealed by using water

Test process:

The testing procedure is conducted subsequent to the cleaning phase. Sequentially captured in video screenshots 1-6, the process unfolds as follows:

1. The canister is filled to capacity with water.
2. The canister lid is securely closed with the canister carefully with all components are properly assembled.
3. The canister is then rotated vertically, surpassing a 90-degree angle, allowing for observation of water outflow.
4. By blocking the outlet of the angled connector with a finger, any potential water leakage is recorded while rotating the canister in varying directions.
5. Rotate the canister upside down
6. Comprehensive observation of water leakage during rotation

Observation:

1. In step 3, water flow is observed solely from the angled connector.
2. In step 6, despite the screw threads, water leakage persists, attributed partly to dimensional inaccuracies in 3D printing.
3. In step 5, no water leaking is observed.
4. When the canister is horizontally positioned, water leakage from the canister lid gap is significant (see accompanying image).
5. Water leakage from the filter connector is also observed to be weaker than the water flow of observation 4.

Takeaways

1. Enhancements are necessary for the screw threads in the canister lid and canister to improve tightness.
2. Although overall sealing is imperfect, manufacturing accuracy improvements could offset this deficiency.

Fig 5.3.4 Observed water leak when horizontally hold the canister

Iteration:

1. The screw threads are updated with smaller tolerance to increase airtightness
2. The distance of screw threads is lengthened

5.3.3 Connection Test

Test Goal: Test the tightness of the connection and the ease of connection between the canister, suction unit and the holder.

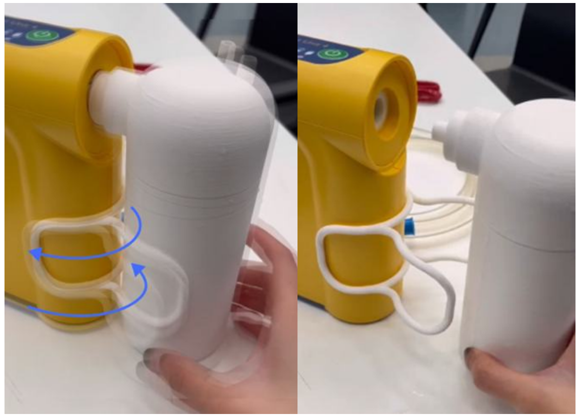


Fig 5.3.5 Image made by superimposing video screenshots (left) disconnecting the canister (right)

The stable connection between the canister and suction unit is secured by two parts: the holder, and the filter connector (inserted inside the unit)

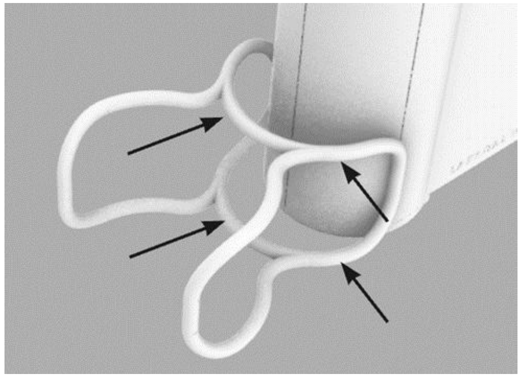


Fig 5.3.6 Holder's arc in contact with LCSU

Test Process:

1. Attach the holder to the suction unit, and then connect the canister to the suction unit properly
2. Softly shake the canister to observe movement.
3. Simultaneously observe the unit's inlet for any visible gaps.
4. Note any instability in the connection between the connector and the unit.
5. Assess the effectiveness of the holder in supporting the canister.
6. Evaluate the degree of rotation of the canister around the column of the unit, considering any discrepancies in arc size between the holder and the unit's contact (can be seen in the pictures above).
7. Disconnect the canister.

Observation:

1. Upon shaking the canister softly, movement within a 1 cm range is observed.
2. A visible gap is noted in the unit's inlet during the assessment.
3. Instability in the connection between the connector and the unit is observed.
4. The holder effectively supports the canister; however, it rotates around the column of the unit due to differences in arc size (see the blue arrow in the image).

Takeaways

1. The dimension of the holder needs to be modified as well as the connection tolerance.
2. The holder's arc in contact with suction unit needs to be broadened (as shown in Fig 5.3.6).
3. The height of canister can be adjusted to align the height of suction unit for aesthetics

Iteration:

1. The holder's arc in contact with LCSU is broadened to fit better.
2. The height of the canister is aligned with LCSU.
3. The shape of the holder is iterated, and connection tolerance is reduced, so the connection process is easier, but the connection stability is improved.

5.4 Iteration 3 Concept Finalizing

5.4.1 introduction

There are several potential improvements identified from the second iteration, including the filter parts, holder and canister transparency. With feedback from Laerdal experts (Design presentation, May 13 2024) and results from tests, I developed the third prototype. In this prototype, the focus is on addressing the canister holder and filter connection. This section follows an order based on different parts.

5.4.2 Iteration by Parts

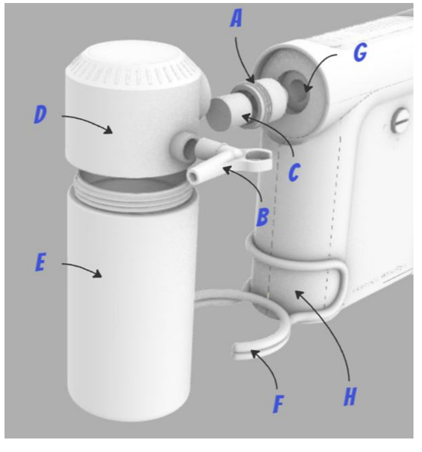


Fig 5.4.1 Testing video screenshots

Parts A&C Filter and filter connector

To address the filter connection issue mentioned in Chapter 5.2.2. and ensure the filter remains fixed in its position during use, I iterated the filter and connector, in the final design (see fig 5.4.2), the filter is securely fixed between the canister lid and the filter connector during use.

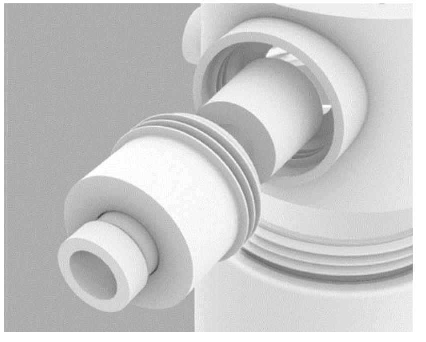


Fig 5.4.2 Final filter design

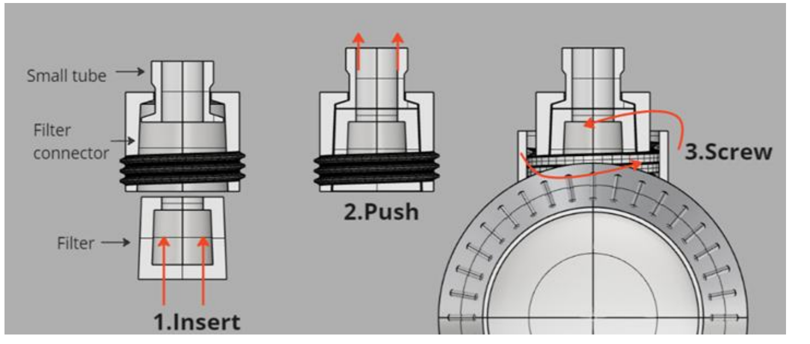


Fig 5.4.3 Mechanism of filter connector in top view

As shown in Fig 5.4.3, the filter connector consists of a small section of round tube and a filter connector. When the filter is inserted, the small round tube stretches and is inserted inside the LCSU. The small tube and filter are then fixed in place by screwing the connector into the canister lid. More details about the usage of the filter are addressed in Chapter 6.1. At the same time, the size of the filter is reduced, it is safely fixed in the filter connector during usage.

Part F-Canister holder

To address the filter connection issue mentioned in Chapter 5.2.2. and ensure the filter remains fixed in its position during use, I iterated the filter and connector, in the final design (see fig 5.4.2), the filter is securely fixed between the canister lid and the filter connector during use.

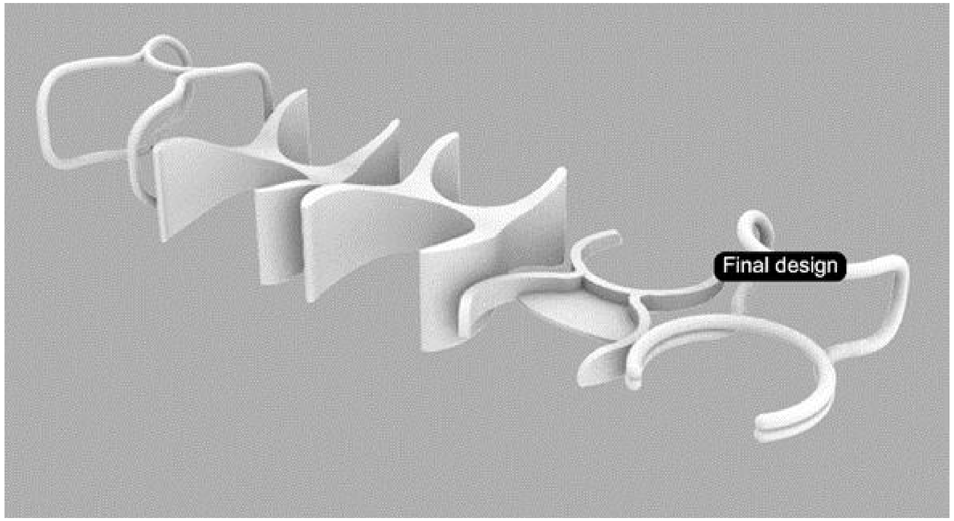


Fig 5.4.4 Canister holder iteration

Out of the priority of durability, I turned back to the metal holder, and I iterated the latest holders, the right two holders shown in fig 5.4.2d. In the final design, the user can similarly attach the canister as attaching a click-on canister: first aim the canister lid, and then click the canister body into the holder, as the "holding part" is on the bottom of LCSU, which makes the connection easier.

Parts D&E-Transparent or Not?

As discussed in Chapter 3.1.3, seeing the contents of a canister can be an unpleasant experience for many. Therefore, I explored the possibility of making the canister body translucent, allowing users to monitor the fill level without clearly seeing the contents. However, during my design sharing presentation, an expert from Laerdal highlighted an important consideration: when using the suction unit at home, it is crucial for caregivers to clearly see the contents. This is because the presence of blood or abnormally colored secretions could indicate a deterioration in the patient's health. This feedback is significant as it highlights the need for caregivers to closely monitor the patient's condition.

Considering this, I initially thought it might be better to keep the canister transparent. Nonetheless, I observed that many reusable canisters on the market are translucent. Additionally, during suction, the patient's secretions go through the transparent patient tubing (150 cm in length), providing users with an opportunity to spot irregularities before the secretions reach the canister.

To address both concerns, I decided to design the canister body with a translucent texture while keeping a transparent strip for the scale. This design allows users to monitor the fill level without exposing them to the potentially unpleasant sight of the contents. At the same time, the transparent scale strip provides a clear window for caregivers to inspect the contents, ensuring they can detect any abnormal secretions promptly.

6 Final Design

In this chapter, I introduce my final design, the Compact Reusable Canister (CRC). The CRC has five key features, which are detailed in Chapter 6.2. It is designed for easy reuse by personal users, with the use cycle explained in Chapter 6.2. Sustainability is a major focus of this design, and the CRC significantly improves sustainability compared to disposable canisters. A detailed comparison of sustainability between the CRC and disposable canisters is provided in Chapter 6.3.

6.1 Design Finalizing

6.1.1 Aesthetics Study

Figure 6.1.1 Aesthetic mood board

To align with the style of LCSU and enhance the perception of a reliable medical product, I created an aesthetic mood board (fig 6.1.1), collecting details from inspirational products. The mood board is divided into four sections: transparency, shape, color, and texture, as well as user perception.

Transparency: The canister body should have a frosted glass appearance, making it translucent, while keep the long oval "window" in clear transparency.

Color and texture: A cold-tone, single color palette will be used to emphasize its medical purpose, and the canister has a frosted texture, to minimize the visibility of potential scratches.

Shape: To enhance user-friendliness, the design will incorporate rounded edges while maintaining some straight lines to balance softness with sharpness.

User Perception: The combined elements aim to convey a perception of the product as both user-friendly and reliable.

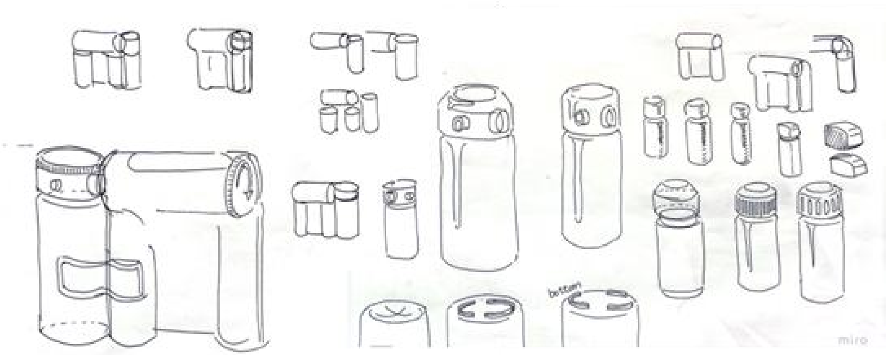


Figure 6.1.2 Aesthetics sketches

Fitting with Laerdal style

The proposed design also incorporates the same canister holder style as the LCSU, with a matching coated texture and color. The canister lid features a concave rounded shape, mirroring the sunken design of the LCSU body, which has a sunken rounded edge for clicking the canister holder into place.

Additionally, I used a fully rounded oval shape for the "window," ensuring it aligns with the user interface shape on the top of the LCSU.

Figure 6.1.3 Digital aesthetics prototype

As a result, the aesthetic prototype was decided (Figure 6.1.3). The chosen design includes a round of anti-slip texture on the edge of the canister lid, similar to the design used in the LCSU vacuum strength controller (figure 6.1.4). This raised texture increases grip, making it easier for the user to open the lid.

Figure 6.1.4 Canister lid design and LCSU vacuum strength controller

6.1.2 Materials Study

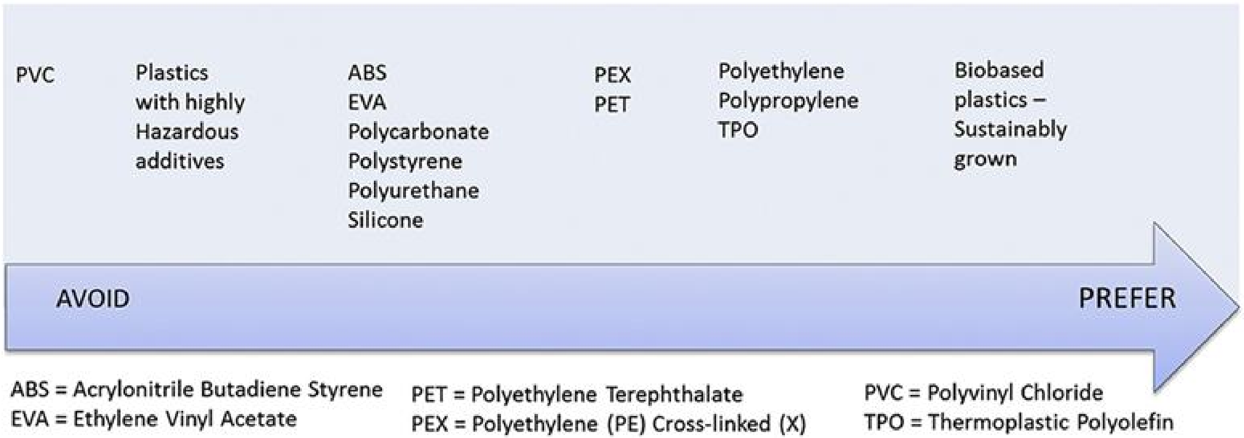


Figure 6.1.4 Environmental preference spectrum for the health-care industry(Rossi and Lent, 2006)

Components	Materials
Upper canister lid	PC
Canister body	
Connector for suctio unit	
Angled connector for tubing	
Rigid filter	PE porous plastic
Canister holder	PE coating secondary aluminum

Table 6.1.5 Material list

Based on the sustainability requirements and general requirements proposed in Chapter 4.3, I chose materials for canister based on: recyclability, sustainability, durability and transparency. This section presents how the material is set for different parts. In the material selection, I referred to the EduPack 2023, and the environmental preference spectrum brought from Rossi and Lent in 2006.

There are at least three materials involved in this product, and they are for: the filter, canister parts.

Rigid filter

The rigid filter is constructed from sintered polyethylene (PE) material. Through the sintering process, the material becomes porous, a feature that has been utilized in click-on canisters for years. In this design, the filter is reusable as long as it remains dry. The original filter material is white, which makes it difficult to determine if it is wet. To address this issue, a layer of Bromophenol Blue is coated on the surface of the canister filter. Bromophenol Blue, commonly used in baby diapers, changes color when it comes into contact with fluids due to a change in pH. This color change allows users to easily identify when the filter is wet and needs to be replaced.

Note: Bromophenol Blue is not suggested use for private purposes (household). Food, drink and animal feeding stuffs. It may be irritating to the mucous membranes and upper respiratory tract, and can be harmful by skin absorption. However, it is still widely used as witness indicators. More tests are needed in the future to verify the feasibility of this filter design.

Canister holder

The original holder for the LCSU was made with PVC-coated aluminum. However, PVC is not an ideal option for sustainability. As an alternative, I propose using polyethylene (PE), which is more sustainable and can achieve a soft texture. This texture allows for adequate tolerance in the connection with the canister.

Canister parts (angled connector, filter connector, canister lid, canister body)

The canister parts are manufactured from low-viscosity polycarbonate (PC), which is easier for injection molding. To mitigate scratches on the canister surface, the canister body is designed with a frosted texture to enhance durability and maintain its appearance.

Figure 6.2.2 Connected CRC and canister holder

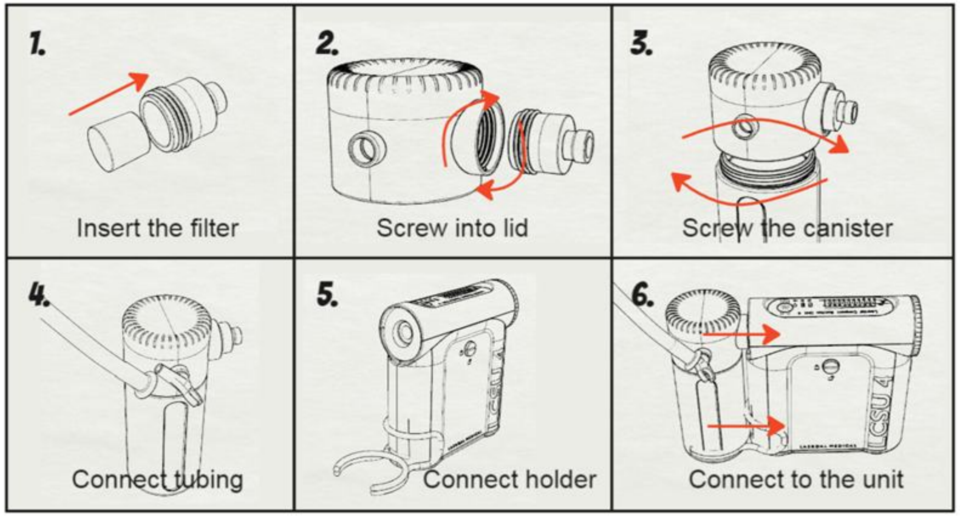


Figure 6.2.3 Connecting steps of the Compact Reusable Canister

Easy to Clean

The CRC is designed for easy cleaning. Users can clean it with daily cleaning sponge, and it is dishwasher-safe, user instruction is given to guide user about the cleaning process. To create an easy cleaning process, the design avoids dead corners and features rounded edges, making it easier to rinse and flush thoroughly.

Easy to Set up:

The Compact Reusable Canister is designed for user-friendly setup. The setup process involves six steps (see Figure 6.2.2):

1. Insert the filter.
2. Screw the filter connector into the canister lid.
3. Screw on the canister lid.
4. Connect the user tubing.
5. Attach the canister holder to the LCSU.
6. Connect the canister.

6.2 Design Proposal

The Compact Reusable Canister is easy to use for personal users, this section introduce the five features that makes CRC an ideal option for personal users.

Compact

The Compact Reusable Canister is designed to be easily portable, fitting comfortably in a bag or the LCSU carry case (fig 6.1a). It has similar dimensions to the Click-on canister: 7.6 cm x 12 cm x 18 cm (when assembled with the holder) compared to 7.2 cm x 12 cm x 19.2 cm (Click-on canister). Its size, comparable to a water bottle, allows users to conveniently carry it in the side pocket of a backpack. When using the LCSU outdoors, the suction unit and canister can remain in the carry case, ensuring smooth and secure operation.

Figure 6.2.1 Current LCSU Carry Case

Sustainable

The CRC improves sustainability. Compared to the disposable Click-on canister, the Compact Reusable Canister reduces carbon emissions by at least 70% if reused 100 times, the details are expanded in LCA chapter 6.3. Detailed sustainability comparisons are available in Chapter 6.2.3. Additionally, the canister is designed for easy recycling. Except for the filter, all parts of the canister are made from the same material, allowing it to be recycled as a whole.

Durable

The CRC is robust and reusable, featuring thick walls and impact resistance. Its frosted surface minimizes visible scratches, ensuring it maintains a clean appearance over multiple uses.

Design requirements Completeness

In this section, I compared the design requirements that were fulfilled in the final design. Some of these requirements are difficult to verify at this stage, such as finding real users to assess whether the design appears reliable. Therefore, I have marked the requirements that are clearly met with a green "Complete."

Soft requirements

1. Can be cleaned in 15 minutes by a user without a medical background**(Needs further user verification)**
2. The canister will not create unpleasant sounds**(Needs further user verification)**
3. The canister is visually reliable and user-friendly**(Needs further user verification)**
4. Canister design should take into account wheelchair usage. **(complete)**
5. The design should be compatible with standard tubing from other suppliers**(complete)**
6. Use environment friendly/recycled materials**(complete)**
7. Reduce the materials used on canister
8. Design the usage process for involving less energy and source**(Needs further verification)**

Hard requirements

1. The canister is portable, can be easily carried with **(complete)**
2. All parts can be assembled and disassembled in 1 minute **(Needs further user verification)**
3. No tubing needed between canister and machine**(complete)**
4. The canister can be opened-up for cleaning**(complete)**
5. Use guidance and suggestions should be provided and tailored for personal users**(complete)**
6. Provide guide on the replacement and recycle of canister parts**(complete)**
7. Accessibility for personal users should be prioritized in the design**(complete)**
8. Reusable canister can be reused for more than 100 times**(Needs further user verification)**
9. The canister has a larger capacity than 300ml**(complete)**
10. robust, safe from falling at 80cm**(Needs further verification)**
11. The canister is sealed with content, fluids-proof mechanism/ structure for the suction unit**(complete)**
12. A tubing parker/holder for the canister**(complete)**
13. The proposed design should be capable to be produced by Laerdal and assemble with LCSU, and at the same time available for separate selling**(complete)**
14. The proposed design should align with Laerdal's sustainability goal**(complete)**
15. Use quantitative analysis tool to assess the environmental impact**(complete)**

6.3 Life Cycle Assessment

This section presents a sustainability comparison between the Compact Reusable Canister and the Laerdal Click-on Canister, focusing on four key aspects: manufacturing and materials, transportation, usage, and end-of-life. Section 6.3.2 explains the scenarios used for calculation, detailing the best and worst-case scenarios. At the end, I discussed the results and give conclusions. The limitations of this study are discussed in Chapter 7.4.5.

6.3.1 Introduction and Assessment Scope

The fast-track LCA is a simplified tool for estimating the environmental impacts of products, this study is conducted with several data resources.

This LCA specifically compares the CO2 equivalent emissions of the Laerdal Click-on Canister and the CRC. Note that patient tubing is not included in this assessment. The CO2 emissions are calculated across four sections: manufacturing and materials, transportation, usage, and end-of-life. Due to a lack of relevant information, other processes are not included, which may result in some inaccuracies. However, this study aims to provide an early-stage sustainability estimation of the two products.

For each product, both best-case and worst-case scenarios are considered. In the best-case scenario, the product is managed in an environmentally friendly manner. In the worst-case scenario, users have lower environmental awareness and tend to use more energy and water during usage. The calculation is based on the CRC will be reused for 100 times.

The carbon emissions calculations are based on the Greenhouse Gas Reporting from the UK government. The IDEMAT 2024 database (Eco Costs Value, 2024), short for Industrial Design & Engineering Materials database, along with other databases, is used for this study. Detailed calculations can be found in the appendix, section LCA Calculation.

6.3.2 LCA Settings

Manufacture and materials

The calculation of manufacturing carbon emissions includes materials and manufacturing processes.

The processes considered are injection molding for polycarbonate (PC) and aluminium extrusion. The sintering process for the rigid filter is excluded due to a lack of relevant data. The Click-on canister body is assembled by gluing two parts: the front cap and the rear cap. Both the gluing process and the polyethylene (PE) coating process for the Compact Reusable Canister (CRC) holder are not considered.

As shown in Table 6.3.2a, the Click-on canister has a weight of 160 grams, including the angled connector and the rigid filter. The rigid filter, calculated based on its volume in the 3D file and the density of porous PE, weighs 2.7 grams. Together, the angled connector and filter constitute only 2.6% of the canister's total weight. Consequently, for the purposes of calculations, the Click-on canister is considered to be made entirely of 160 grams of PC, as the impact of the other two materials on the overall environmental results is relatively small.

Part	Material	Weight
Front cap for Click-on Canister	PC Kotex K-30	155.8g
Rear cap for Click-on Canister	PC Kotex K-30	
Rigid filter	PE porous plastic	2.7g
Angled connector	PP	1.5g

Table 6.3.1 Materials list for Laerdal click-on canister

Components	Materials	Weight
Upper canister lid	PC	46.4g
Canister body		131.5g
Connector for suctio unit		8.1g
Angled connector for tubing		2.8g
Rigid filter*100	PE porous plastic	210g
Rigid filter*30	PE porous plastic	62g
Canister holder	PE coating secondary aluminum	43.1g

Table 6.3.2 Materials list for Compact Reusable Canister

For the CRC, the bill of materials is listed in Table 6.3.2. The rigid filter is unlikely to become wet during use, as it is securely fixed within the filter connector. Assuming careful use by the user, it is estimated that 30 filters would be needed for 100 uses. In the worst-case scenario. Where the user replaces the filter every time the canister is used, 100 filters would be required.

Transportation

The Click-on canisters are produced in Suzhou City, China. Some click-on canisters are sold separately, while others are packaged with the LCSU and then shipped to Stavanger. For transportation calculations, I assume all canisters are produced, packed, and shipped from Suzhou City to Stavanger via container ship (see Fig 6.3.2a).

Figure 6.3.3 Shipping route from Suzhou to Stavanger

It is important to note that packaging is not considered in the transportation process. The Click-on canister and the CRC are very similar in size: 7.2 cm x 12 cm x 19.2 cm and 7.6 cm x 12 cm x 18 cm, respectively (assuming the reusable canister is assembled with the holder), and canisters are comparably light-weighted products, thus the carbon emissions from the transportation are also scaling down for the reusable canister as 100 to 1.

Usage-CRC best and worst conditions

In the best usage condition, I assumed that users use a more efficient toilet to flush and use less warm water to rinse the canister during cleaning. The user only rinses the canister with warm water once, consuming the same amount of water as its capacity: 430ml. Additionally, they use less cold pipe water for rinsing and flushing. I assume the user would use 4L of pipe water in the flushing process, which, in my test, is sufficient to flush all canister parts and also wash the cleaning sponge and rag.

For the worst condition, I assumed the user uses an average toilet and more warm water. I set the user to rinse the canister with warm water three times, and all flushing water (4l) is also warm.

Usage Click-on canister

No carbon emission is generated in the usage process for the click-on canister.

Usage-CRC Dishwasher

In the dishwasher scenario, I assume per wash the user will wash 4 CRCs, so a total of 25 dishwasher washes is calculated. For the energy consumption and water consumption, I referred to a study on the sustainability of dishwasher usage (Venkatesh, 2022).

End of life-CRC best and worst conditions

For the best case, the user would recycle the canister and holder. The PE rigid filter will go to the municipal waste process. Due to the little weight of the total material (under 300 grams), I ignore the carbon emissions in for the best condition. For the worst case, all parts, including 100 filters, canister parts, and holder, will go through the municipal waste incineration process, and carbon emissions are generated in the process.

End of life-Click-on canister

The used click-on canisters are discarded containing secretions, which cannot be emptied out due to the design, making them extremely difficult to recycle. In the power plant plastics are shredded, cleaned and dried before incineration. However, the process requires extra energy to clean out the slimy contents, which is not accounted for due to the lack of relevant data. As a result, the carbon emissions from burning these materials will likely be higher than those suggested for burning 100% PC.

6.3.3 Results

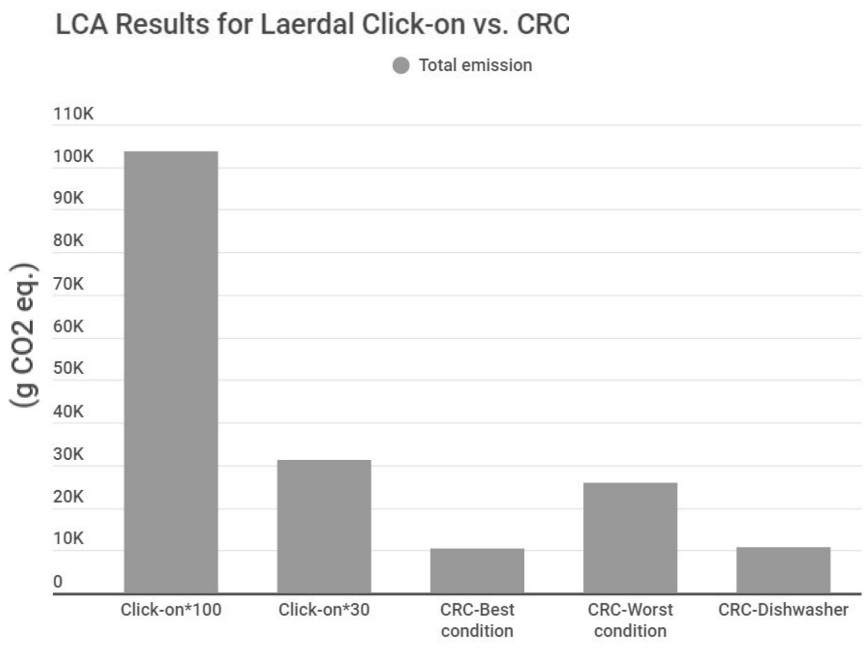


Chart 6.3.4 LCA results for Laerdal click-on canister and CRC

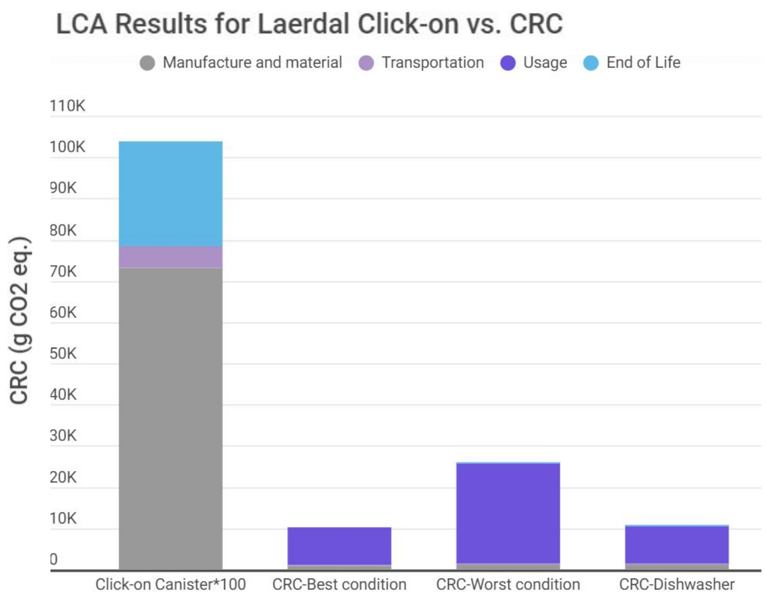


Chart 6.3.5 LCA results for Laerdal click-on and CRC by four section

After calculating the overall carbon emissions (Chart 6.3.4), it is evident that, even in the worst-case scenario, the CRC reduces carbon emissions by at least 75% if reused 100 times. The CRC remains more sustainable even with 30 uses. In the best-case scenario, the carbon emissions are almost equivalent to those of using a dishwasher, which is an efficient method for cleaning the canister.

The overall results across four aspects (Chart 6.3.5) indicate that for the click-on canister, the majority of carbon emissions stem from manufacturing and materials, with the second-highest emissions occurring at the end of life. For the CRC, the highest carbon emissions arise during the usage process. Warm water consumes the most energy in this process; thus, users can save a significant amount of energy by opting for cold water or a dishwasher.

6.3.4 Conclusion

Takeaways:

1. This LCA compares the environmental impacts of Laerdal click-on canister and the proposed reusable canister.
2. The LCA calculation includes CO2 equivalent from four process: manufacture and materials, transportation, usage and end of life.
3. Patient tubing is not included in this study.
4. Best condition and worst condition calculation is given in this study.
5. The calculation is based on the CRC will be reused for 100 times.

The majority of carbon emissions of click-on canister coming from the manufacture section. Additionally, the disposal of canisters containing secretions poses challenges for waste incineration processes. Using reusable canisters, emissions from manufacturing can be significantly reduced. Initially, I had concerns about whether the cleaning process for reusable canisters might offset their sustainability benefits compared to disposables. However, it became evident that reusable canisters not only minimize plastic usage but also more sustainable in the disposal and transportation processes.

In conclusion, adopting CRC enhances sustainability primarily by reducing plastic consumption. With sustainability and environmental awareness in usage, users can potentially cut carbon emissions by up to 90%.

7 Recommendations and Limitations

In this chapter, I discuss potential future steps to complete the proposed design. Given the 8-month project duration, some details were left for further verification and iteration, such as the filter. I also address the limitations within the project scope and my design, which could be valuable for future development.

7.1 Recommendation for Laerdal

Broaden the design scope

The proposed design primarily targets personal use, which limits its user base compared to other canister products that serve broader applications, including professional medical settings such as ambulances and hospitals. Although this design could benefit LCSU personal users, it may not align with Laerdal's business goals, as this user group is not a priority for the company. In the future research, it would be interesting to explore the possibility of adapting and applying the proposed design to the field of EMS.

Conduct User Interview

I recommend that Laerdal continue engaging with personal users in the future. Although Laerdal has attempted to establish connections with users through the distribution sales team in the Netherlands, I believe there are additional strategies to reach individual users. For instance, Laerdal could contact local distributors and nursing homes directly.

Additionally, encouraging customers to provide feedback and submit contact forms via the Laerdal website could serve as another valuable source of user insights.

Provide a Specialized User Guide for Personal Users

Both the LCSU and the LSU are used by a certain number of personal home users. However, the user manuals for these units are written with the assumption that users have a medical background.

To improve the usability for personal users, I recommend that Laerdal provide a simplified illustrated guide specifically designed for personal use. This guide can be included on the packaging or directly on the product, clearly marked with "For Personal Usage." This differentiation will help that users can easily identify and follow the appropriate user guide.

7.2 Limitations

7.2.1 Reusability in Personal Usage

In addition, the risk of unintended use by personal users should also be considered. In the proposed design, the rigid filter should be replaced after contact with fluids, as an invalid filter may lead to ineffective filtration of bacteria and viruses.

The PE porous filter is coated with Bromophenol Blue to indicate whether it is wet. No filter prototype has been made to verify the design. The feasibility of manufacturing a rigid filter with a Bromophenol Blue-coated surface should be discussed in the future as mentioned in Chapter 6.1.2. Additionally, the airflow rate of the new filter should be tested.

The future study should also discuss the service life of the proposed design. The proposed design is intended to be reused for more than 100 days (100 use cycles), which is a conservative estimation. Products made from polycarbonate (PC), such as water bottles, typically have a service life longer than 100 days (Granta Edupack, 2023). The suggested service life of a medical product is usually provided by the manufacturer after extensive testing, making it difficult to estimate or simulate in this project. Future tests should focus on the airtightness and robustness of the canister after multiple uses.

7.2.2 Limited Study Methods on the User Group

This project lacks first-hand information from personal users of medical suction products. No valid direct connection was established with them, potentially leading to some unreasonable design details in the concept.

During this project, both Laerdal's sales team in the Netherlands and I tried to reach personal users. However, this user group is situated at the far end of the canister product sales chain, making it challenging for companies to contact them through the multiple layers of the distribution chain. For future research, I recommend building connections with these users through medical professionals and organizations and conducting real user tests.

7.2.3 Product Compatibility

In the proposed design, the compatibility of the LCSU is affected by removing the small step on the bottom of the unit. This change directly results in the Laerdal Click-on canister no longer being attachable to the LCSU, as the little step is necessary for its attachment. However, the 800ml disposable canister is not affected by this modification and can still be used with the altered LCSU.

This change has little impact on users, as the proposed design covers almost all functions and usage contexts of the click-on canister.

7.2.4 Regulations and Medical Compliance

I gave less priority to meeting medical regulations in this project. As discussed in Chapter 1.4, medical regulations are crucial in the development of medical products. A new product must undergo extensive testing before it can be marketed. This medical compliance process can take years, which is beyond the scope and timeline of this graduation project.

The proposed design, serving as an early-stage exploration, does not comply with canister product regulations and standards. This lack of compliance may result in some design elements, such as filter structure and “clear window” being invalidated and requiring attention and adaptation in future development. Additionally, there is a complex issue: while the concept is intended for personal users (non-professionals), it must also meet medical standards applicable to canisters designed for medical professionals as long as it is a medical device. This requirement could present medical compliance challenges when bringing the potential future product to market.

7.2.5 Life Cycle Assessment

To obtain quantitative results regarding the sustainability of the proposed concept, I conducted a simplified LCA. In Chapter 6.3, I discussed the positive outcomes under various calculation scenarios. However, there are several limitations in the LCA that need to be addressed and verified in the future with more accurate data.

7.2.5 Life Cycle Assessment

To obtain quantitative results regarding the sustainability of the proposed concept, I conducted a simplified LCA. In Chapter 6.3, I discussed the positive outcomes under various calculation scenarios. However, there are several limitations in the LCA that need to be addressed and verified in the future with more accurate data.

Main limitation:

This LCA considers and calculates only carbon emissions. Other greenhouse gases, water and soil pollutants, detergent consumption, resource consumption, and waste are not included, which may affect other impact parameters.

1. Manufacturing and Shipping Assumptions: I assumed that both the proposed design and the Laerdal click-on canister are manufactured in Suzhou City, China, and then shipped to Stavanger, Norway via container ship. Due to a lack of detailed information, I omitted the carbon emissions produced during subsequent distribution and sales processes. Future studies should specify the distribution chains and product delivery.
2. Carbon Emission Proportions in Shipment: I assumed that the two products generate carbon emissions in proportion to their mass (1:100), given that they have the same volume but differ in weight. In future calculations, more details should be confirmed, such as the products' volume with packaging and accurate weights. Carbon emissions from packaging were not calculated due to insufficient information.
3. Material Transportation: I did not consider the transportation of production materials in the calculations. The distance from material suppliers to the manufacturing factory was not accounted for. For example: If the polycarbonate (PC) materials for the two products are sourced from different suppliers, the carbon emissions generated during this process need to be recalculated with details.
4. Reuse Process Emissions: Only carbon emissions from water consumption were considered in the reuse process. Detergents and disinfectants were not specified due to limited information obtained from two recorded interviews regarding the cleaning and disinfection process. Any scenarios I assumed would be inaccurate. More investigation is needed in future studies on personal usage.
5. Filter Consumption: The rigid filter in the proposed design is considered a medical consumable and can be purchased separately. No carbon emissions from the filter are calculated in this assessment. Users would need to have multiple filters available at home. Future research should extend to include the manufacturing, shipment, and sale of the filter to provide a more comprehensive evaluation.
6. Dishwasher Energy Consumption: In the dishwasher scenario, only the electricity and water consumption generated by the dishwasher are calculated. However, research indicates that users in certain regions often pre-wash dishes manually before loading them into the dishwasher (Venkatesh, 2022e). If we consider the additional water used for pre-washing, the total carbon emissions will increase.

8 Reflection

Time management

One of the most significant challenges I faced during this project was managing my time, especially as I moved into the later stages. In the beginning, I felt confident in my ability to stay on track, but as the project progressed, I encountered unexpected difficulties that disrupted my schedule. There was a period when I felt overwhelmed, as if I had lost control of my time, which made it difficult to stay focused and productive. What I learned from this is setting proper goals and leave certain space for delaying.

Plan, mean to be broken?

At the beginning of this project, I was ambitious, thinking about graduating in May, creating the entire summer vacation, and going to my dream island, everything was so bright and shinning, I did well for the first two months, but when I start the report writing, things didn't go as planned.

As time went on, I found it increasingly difficult to keep up with the small weekly goals I had set for myself. The report writing didn't progress as I had hoped, and the meticulously crafted Gantt Chart I had created became less and less useful. Eventually, I stopped checking it altogether, as it was clear I wasn't sticking to the original plan.

"You should never make a plan at the beginning for the whole project, because that's the moment you know least about everything" I couldn't agree more with this when I learned it from an Agile course. Flexibility is required in a several-month project, and space should be saved for the unknown future. However, I also recognize that in a six-month project, some level of early planning is necessary to provide direction and structure.

**For my readers who reach here, thank you,
it took me 2 years and 7933kms to present this to you.**

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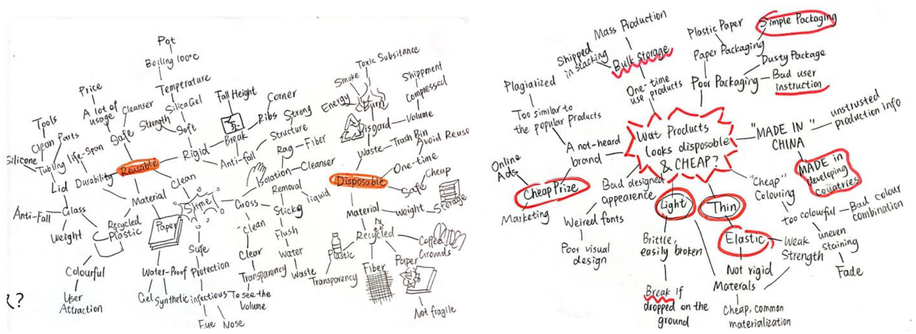
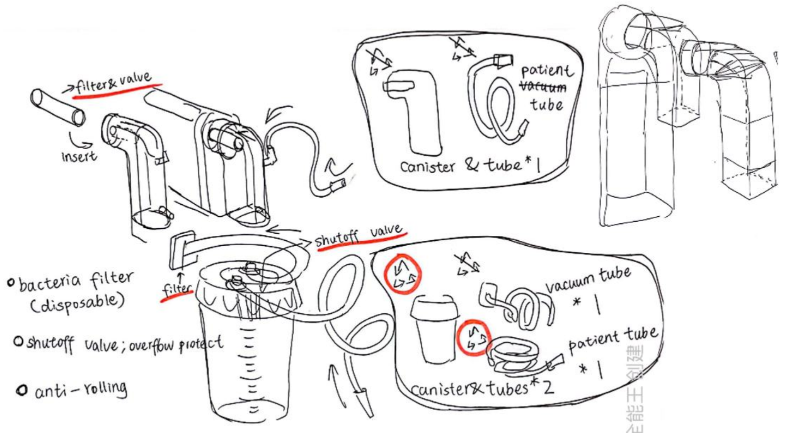
Appendix-ideation

Brainstorming

To kickstart the ideation process, I initiated a brainstorming session aimed at exploring diverse solutions. Through this session, with two keywords "reusable" and "disposable", I gathered numerous keywords and phrases, some of which initially seemed unrelated, but sparked my inspiration for further exploration.





A the same time, I sketched out Laerdal's reusable canister and click-on canister based on my memory, this helped me to keep basic design criteria in mind, so in the following ideation phase, my creativity and wild thoughts will be exercised within certain limits.

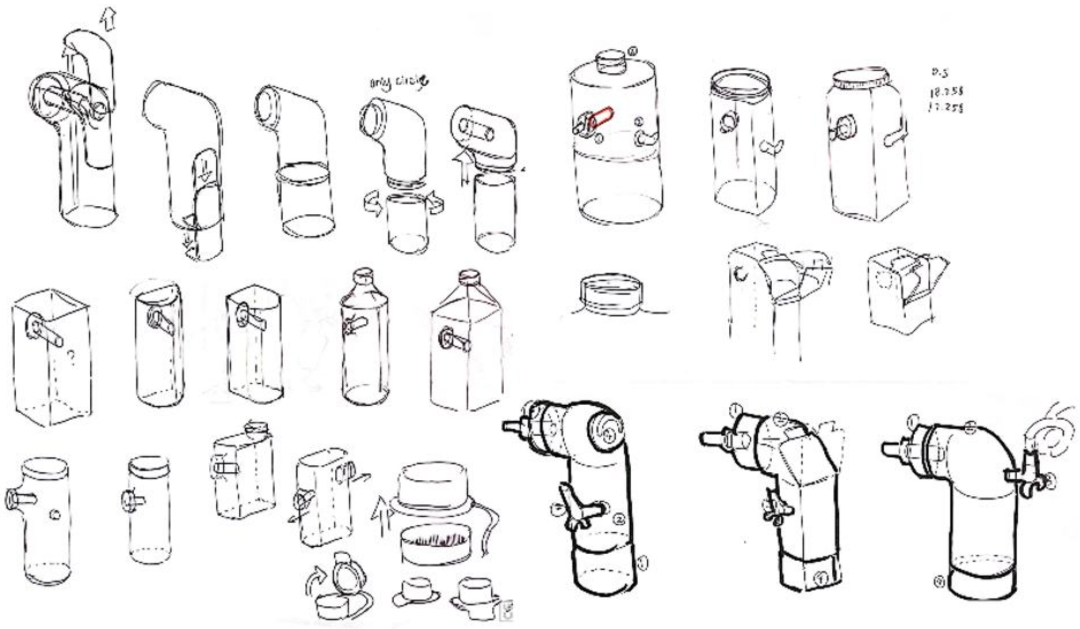
Ideation Process

With the requirements from Chapter 4.3 in mind, and priority to those hard requirements, I began my ideation process. I initiated my creative process by sketching different container designs and then adding openings to them.

To be able to open up for cleaning and has a replaceable filter (Hard requirements, Chapter 4.3), the canister should at least have these following openings:

1. Opening for connecting the suction unit
2. Opening for patient tubing
3. Opening for pouring our contents
4. Opening for inserting the filter.

Appendix-ideation



After several rounds of ideation, I combine some openings together. I proposed two key questions to guide the generation of the canister concept.

1. How to open and close the canister?
2. How to save space for the filter?

The figure on the left shows a part of my ideation sketches, where I focused on the shapes of the canister (left middle row) while exploring the locations of different openings (the three in the lower right corner). In the early-stage sketches, I also explored different forms of the canister filter and the methods for replacing the filter. More details of my design process and design choices are explained in Chapter 5.2.2.

Appendix: Expert interview list

Introduction

- The goal of my project, and my 2 approaches
- Laerdal reusable canisters and disposable canisters

Suction Unit:

- Under what condition would you use the Suction Unit?
- And how about during the surgery?
- How often is the suction unit used? Every surgery?
- Where would you use the suction unit besides patients?
- Has there been any cross-infection due to the suction unit?

Canisters:

- How long have you been using the same Serres semi-disposable canister?
- What do you think is good about the Serres canister?
- What do you think is bad about the Serres canister?
- Can you show me how you use the Serres canister and discard it?
- Where will the used canister bags go in the disposal process?
- How infectious/dangerous are the used canisters?
- Will you clean the big bucket after each use?
- Has there been any leakage or bag breakage?
- What canisters did you use before Serres? Did you find any problems with those ones?
- What do you think if one day the canisters are replaced with reusable ones? Meaning it has to be cleaned after use.

General:

- Who is deciding which suction unit you use in the hospital?
- What do you think of sustainability in medical consumable products?
- Do you think there is a trend that medical users are transferring from one-time products to more sustainable solutions (with longer product life spans)?
- What do you think is blocking users from choosing more sustainable products?

Questions List

- Have you ever talked to any european users?
- Do you think there will be a big difference between EU and US users? pre-in-home local guidelines
- Why users don't buy reusable one instead? access bemis is the onlt one, do they have this option? regulatory issues 1999
- where do they purchase canisters? distrubu
- I notice there is reusable option on Laerdal website, is that the only way user can but it? do you also send the reusable ones to distributor?
- I noticed that the price of Reusable canister could be different according to region, why is this?
- How often does Laerdal recommend replacing the reusable canister?
- the users didn't mention how often do they clean the canisters, how often do you think they will do that?
- I assume more personal users choose LSU than LCSU, is this correct?
- Is LSU more durable than LCSU?
- How would you define the target group of reusable canisters?

Appendix-LCA Calculation

Scenarios	Title	Amount of energy/resource	Carbon emissions (Kg CO2 eq.)
Click-on canister	PC injection molding	160g*100	18.67kg
	PC material	160g*100	54.4kg
CRC	Aluminum extrusion	43.1g	0.03kg
	PC injection molding	188.8g	0.22kg
	PC material	188.8g	0.64kg
	PE material	2.1*100	0.38kg
	PE material	2.1*30	0.11kg

Table 1. manufacture and materials

Scenarios	Title	Amount of energy/resource	Carbon emissions (Kg CO2 eq.)
CRC transportation	Container ship-Suzhou to Stavanger	20185km	0.05kg
Click-on canister	Container ship-Suzhou to Stavanger	20185km	5.21kg

Table 2. Transportation

Scenarios	Title	Amount of energy/resource	Carbon emissions (Kg CO2 eq.)
CRC best condition	Pipe water consumption-toilet	3l*100	3.18kg
	Pipe water consumption-cleaning	4l*100	4.26kg
	Warm water	0.43l*100	1.38kg
CRC worst condition	Pipe water consumption-toilet	6l*100	6.36kg
	Pipe water consumption-cleaning	0	0
	Warm water	(4l+0.43l*3)*100	18.0kg
CRC dishwasher	Pipe water consumption-toilet	6l*25	1.59kg
	Dishwasher Wate consumption	10.34L *25	2.74kg
	Dishwasher energy consumption	0.942 kWh*25	4.87kg
Click-on canister	None	0	0

Table 3. Usage

Scenarios	Title	Amount of energy/resource	Carbon emissions (Kg CO2 eq.)
CRC best condition	Recycle	0	0
CRC worst condition	Municipal waste incineration-PC	188.8g	0.3kg
	Municipal waste incineration-PE	210g	0.24kg
Click-on canister	Municipal waste incineration-PC	16kg	25.46kg

Table 4. End of life

Appendix-LCA Calculation

Calculation for heating warm water

1. **Calculate the energy required to heat the water**:
   - The specific heat capacity of water is 4.18 J/g°C.
   - We need to know the mass of water being heated.
   - The temperature change (ΔT) is 60°C - 20°C = 40°C.
2. **Determine the energy usage of the heater**:
   - Convert the energy required from joules to kilowatt-hours (kWh).
   - Take into account the efficiency of the heater.
3. **Calculate the carbon emissions**:
   - Find the carbon intensity of the electricity used (typically measured in kg CO2 per kWh).

So, heating 130 liters of water from 20°C to 60°C with an average house heater would result in approximately 3.02(heating energy consumption)+ 1.38kg(water) = 4.4kg of CO2 emissions.

Step 1: Calculate the Energy Required to Heat the Water

Assume we are heating 100 liters of water (100,000 grams).

$$Q = mc\Delta T$$

Where:

- Q = energy required (in joules)
- m = mass of water (in grams)
- c = specific heat capacity of water (4.18 J/g°C)
- ΔT = temperature change (40°C)

$$Q = 100,000\,\text{g} \times 4.18\,\text{J/g}^\circ\text{C} \times 40\,^\circ\text{C}$$
$$Q = 16,720,000\,\text{J}$$

Step 2: Convert Energy to kWh

$$1\,\text{kWh} = 3,600,000\,\text{J}$$

$$\text{Energy in kWh} = \frac{16,720,000\,\text{J}}{3,600,000\,\text{J/kWh}}$$
$$\text{Energy in kWh} \approx 4.64\,\text{kWh}$$

Step 3: Account for Heater Efficiency

Assume the heater is 90% efficient.

$$\text{Energy used} = \frac{\text{Energy required}}{\text{Efficiency}}$$
$$\text{Energy used} = \frac{4.64\,\text{kWh}}{0.90}$$
$$\text{Energy used} \approx 5.16\,\text{kWh}$$

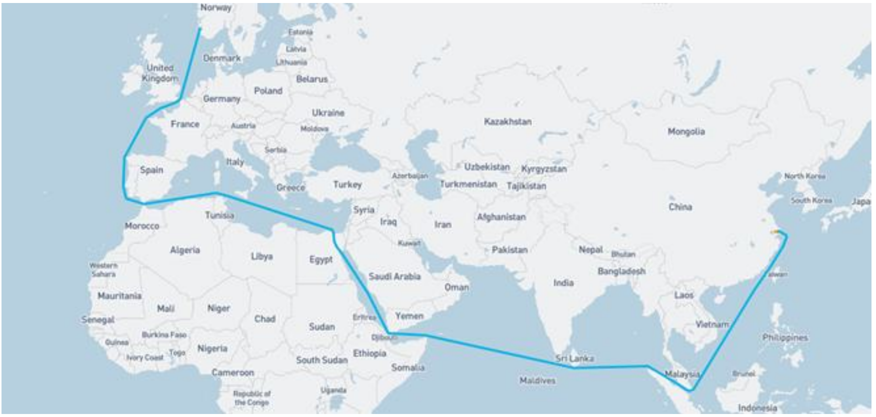
Step 4: Calculate Carbon Emissions

The carbon intensity of electricity varies by region. For example, the average carbon intensity in the US is about 0.45 kg CO2 per kWh.

$$\text{Carbon emissions} = \text{Energy used} \times \text{Carbon intensity}$$
$$\text{Carbon emissions} = 5.16\,\text{kWh} \times 0.45\,\text{kg CO2/kWh}$$
$$\text{Carbon emissions} \approx 2.32\,\text{kg CO2}$$

Appendix-LCA Calculation

Calculation for Transportation



Sea Ship transport service			
Distance (km)	**Transport**	**Origin**	**Destination**
114.6	Truck	[cn] SUZHOU	[cn] Shanghai
20 185.3	Sea ship	[cn] Shanghai	[no] Stavanger
Total distance : 20 299.9 km			

Appendix-project brief

Personal Project Brief – IDE Master Graduation Project

Name student Linman He **Student number** 5,732,514

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Redesign a canisters set to improve the sustainability of Suction Unit Products for Lærdal Medical

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

The Laerdal Suction Unit (LSU) is a medical device designed to extract secretion—such as mucus, vomit, blood, saliva, serum etc.—from a patient. These suction machines are commonly used in Emergency Medical Services (EMS) and ongoing patient care within hospitals. They are crucial in medical contexts for clearing patients' upper airways.

The design target of this project is a medical consumable product for the suction unit, canisters. Medical canisters function as secretion fluid collection containers, working alongside suction units and tubing. Healthcare professionals will conduct the suction in different medical contexts. After suction for one patient, the canister and tubings need replacement with a new (cleaned) one.

This graduation project will focus on improving the sustainability of canisters and their tubings used for both the LSU and the Laerdal Compact Suction Unit (LCSU). Laerdal Medical, the collaborator in this project, aims to achieve a 70% reduction in carbon emissions by 2030. Addressing disposability in medical products is crucial for enhancing sustainability, given the plastic waste generated and the resulting environmental impact. This initiative benefits both users and the enterprise. Medical workers are also important stakeholders in this project, studying their preferences and behaviors helps me envision how to improve the sustainability of different canisters, and the acceptability of sustainalble solution.

Currently, a substantial proportion of users opt for disposable canisters due to the nature of Emergency Medical Service usage and cross contamination. Also, considering the cost of cleaning and reprocessing, retaining the disposable option is reasonable. Used canisters are processed as medical waste in the medical waste disposal department or outsourced to a disposal company. Among existing solutions, a reusable canister requires cleaning and disinfection after each use, typically managed by the hospital's disinfection department. However, its user acceptance lags behind other alternatives. Improving the user-friendliness of reusable solutions could enhance the overall sustainability of canister products.

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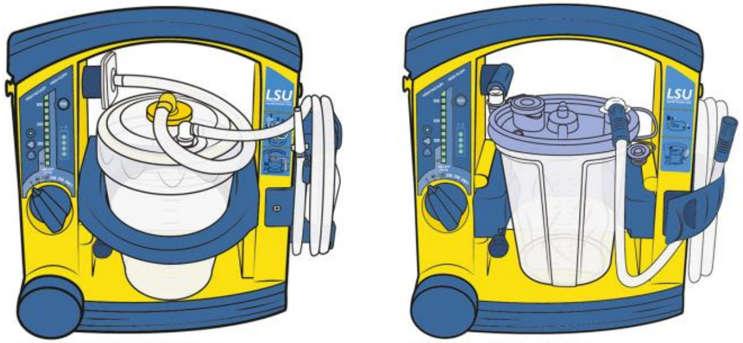
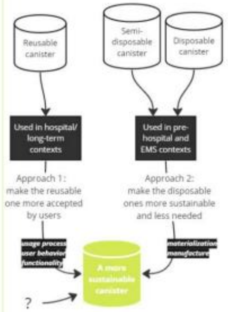


LSU Reusable Cat.no 78 00 00 LSU Serres Cat.no 78 00 30

image / figure 1 Laerdal Suction Unit with different canisters



Canister					
Unit	LCSU		LSU		
Reusability	Disposable (Laerdal design)	Disposable	Semi-disposable (Serres)	Disposable (Bemis)	Reusable (Laerdal design)
Capacity	300ml	800ml	1000ml	1200ml	1000ml

image / figure 2 Possible approaches for a more sustainable canister; current canisters

Appendix-project brief

Personal Project Brief – IDE Master Graduation Project

TUDelft

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

When selling suction units, Laerdal Medical offers users various canister options (Fig.2), which are classified into reusable, semi-disposable, and disposable types, totaling five variations, with two of the canisters sourced externally. Both the LSU and LCSU suction unit canisters fall under the design scope.
Disposable canisters, a prevalent medical consumable, generate substantial plastic waste. The healthcare industry, contributing 4.4% (Karliner et al., 2020b) of global CO_2 emissions, significantly impacts the environment. Although eliminating disposable canisters isn't currently feasible, they are frequently used in situations requiring rapid treatment of multiple patients, often discarded despite little secretion volume of one-time use. Understanding users' behavior and thinking behind is important for addressing this problem. I aim to define the scenarios that necessitate the use of disposables, at the same time converting as many one-time-use scenarios as possible into reusable solutions, this requires me as a designer in-depth study of medical context users, including their behaviors, preferences, pains&gains of one solution.
Laerdal developed the reusable canister, which is less commonly chosen and often used in long-term medical care contexts, requiring additional effort in cleaning and disinfection. This project involves conducting a user and contextual study to understand the barriers preventing users from opting for the reusable solution before adapting the design to improve its desirability among users.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Redesign the disposable canisters set and increase the user acceptability of reusable canister to improve the sustainability of consumable Suction Unit Products for Lærdal Medical

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

The project follows a four-stage process: research, design, design validation, and wrap-up. To ensure organized progress with visible information, I'll create Gantt charts for the overall timeline and use Kanban during the process. These tools support structured work while accommodating dynamic changes.
This project will begin with extensive user and context research, to define the most valuable user group for this project to learn from. Learning the users' perspectives is essential for the later design process, especially for the users who work in the first line, I plan to conduct several interviews with them.After that, I will gain a clear and in-depth product understanding, so I can propose my design vision. Also, a stakeholders list will be mapped out in the early stage. Before the concept development, a design research conslusion will be created as a sum-up.
At the ideation stage, I will map out possible directions for concept development in the brainstorming. Throughout the design phase, collaboration with sustainability and material experts will enhance the solution. Prototyping will be a key part of iterating concepts, I will try to involve users and experts in this period. Finally, I'll conduct a simplified LCA to assess the sustainability and environmental impact of the proposed design. This will help me to evaluate the proposed concept last. At the end of this project, I will conclude the whole process in a design report and present my design in the final presentation.