Mimic Drinking from a Straw in a Lab Environment

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DIVISION OF PRODUCT DEVELOPMENT | DEPARTMENT OF DESIGN SCIENCES
FACULTY OF ENGINEERING LTH | LUND UNIVERSITY
2021

MASTER THESIS

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Published by
Department of Design Sciences
Faculty of Engineering LTH, Lund University
P.O. Box 118, SE-221 00 Lund, Sweden

Publicerad av
Institutionen för designvetenskaper
Lunds Tekniska Högskola, Lunds universitet
Box 118, 221 00 Lund

Subject: Product Development (MMKM05), Technical Design (MMKM10)
Division: Product Development
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Abstract

In July 2021, single-use plastics will be banned from the European market, meaning that the plastic straws used with Tetra Pak's portion packs will no longer be permitted. Therefore, Tetra Pak develops new straws, and it is important to test their functionality, something that previously has been done with panel tests. However, Tetra Pak has requested to aid the development process by minimizing the need of panel tests, and it is therefore asked if it is possible to mimic the usage of a straw in a lab environment. Tetra Pak wished for the final concept to be relevant, repeatable, and efficient and for the team members to investigate in intended and foreseeable use.

A user study was planned and performed at two preschools in Lund where 25 children were each given a portion drink with a plastic straw. The children's interaction with the straws was observed and translated into stresses that the concept must be able to produce - concept needs. These were then evaluated, rated, and prioritized, depending on how often they occurred and what impact it had on the straw. Those who were given the highest rank and therefore continued with were divided into the categories *playing*, *drinking*, and *friction*, to ease the concept development. The process to the final concept was an iterative and creative one where 3D-printed prototypes were tested and evaluated. The established final concept is a modular concept that mimics the usage by exposing straws to biting, pinching, drinking, and playing stresses. It was also tested and evaluated by operators, the feedback given from these evaluations were that the concept has a lot of parts but is flexible, easy to use and has a steep learning curve. The conclusion that can be drawn is that children expose straws to a wide range of stresses, where most stresses are on the short leg of the straw. Children often drink, play, and then drink again, why the proposed concept also expose the straws in the same order. The damages caused by the concept correlate well with the damages caused by children.

Keywords: plastic straws, children's usage, mimic drinking, Tetra Pak, human stresses.

Sammanfattning

I juli 2021 kommer engångs-plastartiklar att förbjudas från den europeiska marknaden, vilket innebär att plastsugrören som används med Tetra Paks portionsförpackningar inte längre kommer tillåtas. Därmed utvecklar Tetra Pak nya sugrör och när man utvecklar dessa är det viktigt att testa deras funktionalitet, något som tidigare har gjorts med användartester. Tetra Pak har dock begärt att man underlättar utvecklingsprocessen genom att minimera behovet av användartester och det frågas därför om det är möjligt att härma användningen av sugrör i en laboratoriemiljö. Tetra Pak önskade att det slutliga konceptet skulle vara relevant, repeterbart och effektivt och att arbetsgruppen skulle undersöka påverkan från avsett och förutsett användande.

En användarstudie planerades och genomfördes vid två förskolor i lund där 25 barn fick varsin portionsdricka med ett plastsugrör. Barnens interaktion med sugrören observerades och översattes till påfrestningar som konceptet måste kunna producera – konceptbehov. Dessa var sedan utvärderade, betygsatta och prioriterade, beroende på hur ofta de inträffade och vilken påverkan det hade på sugröret. De som fick högsta rang och därmed fortsattes med delades in i kategorierna leka, dricka och friktion för att underlätta konceptutvecklingen. Processen till det slutliga konceptet var en iterativ och kreativ process där 3D-printade prototyper testades och utvärderades, dels av arbetsgruppen och dels av operatörer. Resultatet från testerna var att konceptet har många delar men är flexibelt, enkelt att använda och har en brant inlärningskurva. Det valda slutkonceptet är ett modulärt koncept som efterliknar användningen genom att utsätta sugrör för påfrestningar så som bita, klämma och dricka. Slutsatsen som kan dras är att barn utsätter sugrör för ett stort antal påfrestningar, där de flesta påfrestningarna är på sugrörets korta ben. Det är ofta att barn dricker, leker och sedan dricker igen, varför det föreslagna konceptet också utsätter sugrören i samma ordning. Skadorna på sugrören som orsakades av konceptet efterliknar väl de skador som barn orsakar på sugrör.

Nyckelord: plastsugrör, barns användande, efterlikna drickande, Tetra Pak, mänskliga påfrestningar

Acknowledgments

This Master Thesis has been performed at the Division of Product Development at Lund's University, Faculty of Engineering in collaboration with Tetra Pak. We would like to thank Tetra Pak for creating the project and giving us the opportunity to fulfill the work.

We would like to thank everyone at Tetra Pak that has provided us with help and give a special thank you to our supervisors, Philippa Salomonsson and Christel Andersson, it has been a pleasure to have you as supervisors and your support and knowledge have been of great benefit during this project.

We would also like to thank John Horvat, the teachers, and the children at his preschools for allowing us to visit them and observing when the children drank with the straws, this master thesis would not be nearly as successful without their help. Further, we would like to thank our supervisor at Lund Faculty of Engineering, Per Kristav, for your support and valuable input.

This project has been challenging, interesting, and creative, and has left us with great memories and knowledge for the future.

Lund, May 2021

Ella von Matern and Karoline Teigland

Table of contents

1 Introduction

This chapter presents the project and includes background information about the team members and Tetra Pak, a problem description, delimitations, and goals.

1.1 Background

1.1.1 **Team Background**

The team consists of Ella von Matern and Karoline Teigland, who are mastering in Mechanical Engineering at the Faculty of Engineering at Lund University. Von Matern is specializing in Product Development and Teigland in Industrial Design, the team has therefore through their education gained relevant knowledge and experience within the subject. Both team members have worked for Tetra Pak previously, von Matern since 2018 and Teigland since late 2020, and has through this gained knowledge about the company and its industry prior to their Master Thesis.

1.1.2 **Company Background**

Tetra Pak was founded 1951 in Lund, Sweden by Ruben Rausing, as a subsidiary of Åkerlund & Rausing. Tetra Pak launched a new packaging system, including machines that would fill tetrahedron-shaped cartons for milk, which was the start of a great journey [1]. Today, Tetra Pak is a specialist in complete solutions for the processing, packaging, and distribution of food products. Tetra Pak focuses on delivering sustainable, safe, and innovative products to their customers and invest in technology to meet the customers' demands. Tetra Pak's promise is to "Protect What's Good" which includes "Protect the Planet", "Protect the Food", and "Protect the People" [2].

Tetra Pak has 10 Product Development Centers, and this Master Thesis was conducted at the Centre located in Lund. The center has several departments focusing on different development matters and the Master Thesis will be conducted within the Development and Engineering Materials and Package Organization.

1.2 Problem Description

This subchapter covers information about the Single-Use Plastics Directive and the replacement of plastic straws, and through this providing a background for why this project is relevant.

1.2.1 **The Single-Use Plastics Directive**

As an action to prevent and decrease the amount of plastic litter, the European Parliament has decided to ban single-use plastics by July 3rd, 2021. In the directive, the European Parliament and the Council of the European Union define single-use plastics as:

*"*A product that is made wholly or partly from plastics and is not conceived, designed or placed on the market to accomplish, within its lifespan, multiple trips or rotations by being returned to a producer for refill or re-used for the same purpose for which it was conceived."[3].

This definition includes single-use plastic straws and due to this, Tetra Pak must replace their current plastic straws for their liquid portion packages.

1.2.2 **The Replacement of Plastic Straws**

To be comply with the Single-Use Plastics Directive, Tetra Pak has chosen to replace their plastic straws with paper straws. This replacement is a big change, for both Tetra Pak as a company but also for the whole packaging industry, and due to paper straws being a new product, for the modern time, there are limited available standards on what it should be able to withstand and how it should be used.

1.2.2.1 Current Plastic Straws

Tetra Pak has currently five types of plastic straws on the market; straight straws, sensory straws, telescopic straws, U-straws, and Z-straws, together with a large variety of packages, some of the different straws and packages can be seen in Figure 1-1. All of these straws will be banned in Europe after July 3rd but will most likely still be on the market outside of Europe [4].

Figure 1-1. Different straws and packages manufactured by Tetra Pak.

1.2.2.2 Future Straws

The replacement-material for plastic in straws is still under development and might change over time. The material that will be the most common in a couple of months might not be the most common in a couple of years but for the time being, paper is a relatively common replacement and will be focused on within this project.

1.3 Project Description and Goals

The aim with the *Mimic Drinking from a Straw in a Lab Environmen*t project is to aid the development of straws through minimizing the need of panel tests when evaluating the functionality of straws. The outcome could be a test set-up that mimics the stresses and load cases that straws are exposed to during use and the final concept must be relevant, repeatable, and efficient.

Tetra Pak wants the following questions to be answered:

- Can drinking from a straw be mimicked in a lab environment?
- Can the human interaction with the straw be fully mimicked in the lab?
- Can the eventual mimic drinking instrument produce a quantitative output?
- Can the set-up be automated, ergonomically, and easy to use for operators?

The usage of straws can be divided into three categories; Intended Use, Foreseeable Use and Un-Foreseeable Use, see Table 1-1 for description of the three categories. The objective of this project is to investigate how and to which extent these categories can be mimicked.

Table 1-1. Categories of straw use.

Term	*Definition*
Intended Use of Straws	Intended use includes removal of the straw from the package, piercing of the package (through the pre-punctured hole (PPH)), drinking, and searching for the last drops. These are the activities that straws are developed for and are the most critical for the function of the straws.
Foreseeable Use of Straws	Foreseeable use includes, among other; insertion of straw from holding on top of straw, chewing, inserting and removing from package multiple times, and pressing on corrugation.
Un-Foreseeable Use of Straws	Un-foreseeable use includes stresses that are uncommon and difficult to foresee. It could for example be rubbing the straw between one's hands. Straws are not developed to withstand these activities, but some customers might request that the straws can withstand them.

1.3.1 **Delimitations**

The project focus on U-straws, which is the most common straw, and other straw types and their specific properties will therefore not be taken into consideration. This is because the project is based and initiated by the Tetra Pak Development and Engineering Materials & Package Organization in Sweden. However, there is still the possibility that parts of the result will be useful for other straw types.

Overall, the project has delimitations such as the time schedule and economical aspects. The time period for the project is set to 20 weeks and there is a possibility that potential solutions will not be explored to the same extent within the time slot. The economic aspects are constrained by Tetra Pak and may affect prototypes and other expenses.

This project was conducted during the spring of 2021 and thus during the Covid-19 pandemic, which lead to some delimitations concerning contacts with other people and other resources. However, the team members did the best out of the situation and suspect that the resulting impacts on the project are quite small.

2 Pilot Study

The aim with the pilot study is to gain a deeper understanding of straws and the project. This includes an internal search of how Tetra Pak develops straws, a smaller evaluation of straw use, and the resulting hypotheses.

2.1 Development Steps of Straws

Test methods often play a key part during product development. They provide important input on aspects like quality, usefulness, and robustness, which can indicate the likelihood of success of the new product, including the development of new types of drinking straws.

2.1.1 **Test Methods**

Tetra Pak has multiple test methods that measure and evaluate the functionality of straws, some are applicable to both plastic and paper straws and some are only applicable to one of the straw types. The current methods measure, for example, the compression strength, the elasticity, the dent sensitivity of the straws, and the force needed for perforation of pre-punched hole by a straw [4].

The results given from the current test methods are all critical properties for straws and are needed during the development process. However, they are not on their own sufficient to verify the functionality of the straws or to confirm a pleasant user experience. Therefore, there is a need for panel tests.

2.1.2 **Panel Tests**

To get a more realistic understanding of the function of the straws and how the user uses and perceives them, Tetra Pak regularly conducts consumer studies [4]. This step is very important since it can provide Tetra Pak with information about how well the straws meet the requirements from the end users, as well as evaluate how well they withstand foreseeable and unforeseeable use.

Conducting panel tests on children is not easy and especially not in a strict environment, for example at a company site. This is due to a lot of things, including that the children are not used to the environment and might therefore act differently than if they were in a more friendly environment. The children may have stricter manners than when they are at home, leading to irrelevant results. The children may also have difficulties to evaluate the straws in a detailed and nuanced way [4].

Another difficulty that arose during the Covid-19 pandemic is the higher risk of virus infections when interacting with people that you regularly do not interact with. It is therefore not always possible to invite users to the company site to conduct panel tests.

Due to the reasons stated above, Tetra Pak needs a new way of evaluating straw robustness and functionality without the use of actual consumers. Therefore, the project *Mimic Drinking from a Straw in a Lab Environment* was initiated.

2.2 Test of Straws and Hypotheses

To gain a deeper understanding about straws and the stresses they might be exposed to, the team members conducted a straw test where they themselves tested both plastic and paper straws. The straws were tested through intended and foreseeable use, and by being exposed to different actions to try to evaluate what impact they had on the straws. These tests resulted in the hypotheses described in Table 2-1.

Table 2-1. Actions tested by team members with following hypotheses.

Action	***Hypothesis***
Removal of straw from package	Uses a too high of a force
	Pinches straw
Removal of straw from plastic wrap	Tries to open plastic wrap using corrugated part of the straw
	Bends straw
	Bites straw
Puncture of PPH	Pinches straw
	Tries to open package using straight end of straw
	Misses PPH, hits package
	Hammers to break seal
Drinking	Bites straw
	Squeezes straw between lips
	Straw is exposed to liquid during a long period
	Straw is pushed down to bottom of package and bended
	Removes and inserts straw multiple times
	Uses teeth to remove straw
Post Drinking	Plays with straw
	Tries to eat straw

From the test and the hypotheses listed above, it was expected that the solution to this problem is quite complex and might have to be divided into sub-solutions.

3 Methodology

This chapter covers the methodology used during this project, including planning of the project, and the development process.

3.1 Planning

The Master Thesis project started with an introduction together with Tetra Pak to get an understanding of the problem, the expected output, and the delimitations. A project plan and time plan were created containing the different activities that would be required within the project. These plans resulted in a Gantt-Schedule that can be seen in Appendix A.1, an updated version of the Gantt-Schedule with the actual tasks and duration times can be seen in Appendix A.2.

3.2 Development Process

The process used during this Master Thesis is based on the process in the book *Product Design and Development* by Karl T. Ulrich and Steven D. Eppinger [5]. However, to make their process more applicable to this project, small adjustments were made.

3.2.1 **Design Process by Ulrich and Eppinger**

The process described in the book *Product Design and Development* [5] consists of seven phases, see Figure 3-1.

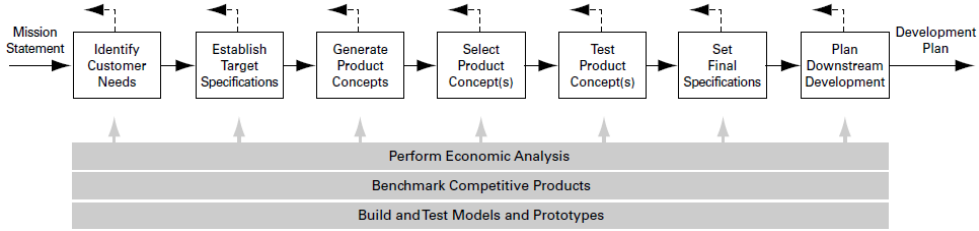

Figure 3-1. Design process by Ulrich and Eppinger [5].

The first phase, *Identifying Customer Needs*, aims to understand the customers and their needs. *Establish Target Specifications* aims to provide a description of what the product must do to be able to meet the customer needs, the target specifications are a translation of the customer needs into technical terms. The phase *Generate Product Concepts* aims to fully explore the space of concepts that could meet the needs from the customers, where the output is generally a collection of potential concepts. The next phase, *Select Product Concept*, aims to evaluate the concepts and to identify the most promising concept or concepts. *Test Product Concepts* aims to verify that the customer needs have been met. *Set Final Specifications* aims to revise the target specifications and to set the final values. The final phase, *Plan Downstream Development* aims to create a detailed development schedule for the final concept. Economic Analysis, Benchmarking and testing of prototypes are done ongoing during all the seven phases [5].

3.2.2 **Adjusted Design Process**

The process described in 3.2.1 is generic and not fully applicable on the scope and objective of this project and has therefore been adjusted. Since the expected outcome will probably be a complex product with multiple sub-systems, the process has been adjusted to better match the development process of a complex system, see Figure 3-2. In this process, the problem is decomposed into several subproblems that are solved parallel with each other.

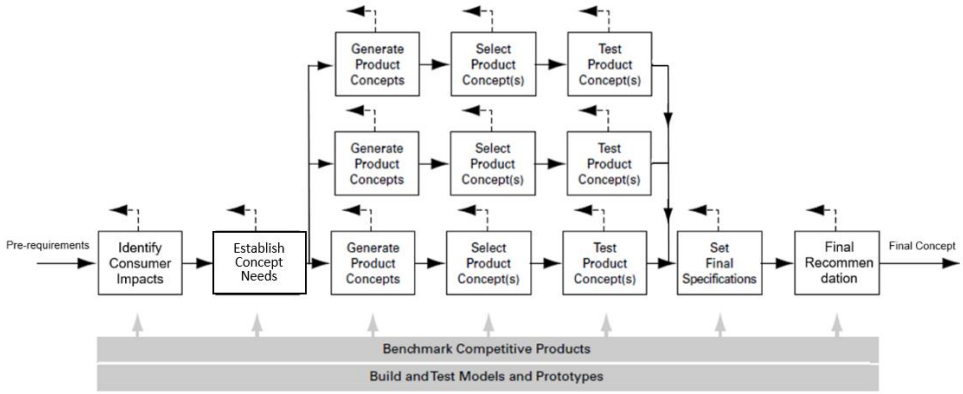

Figure 3-2. Adjusted development process by team members.

This process is often used for large-scale products where many subsystems and components interact and is used to address the different needs of each subsystem. The concept development phase includes both the development of the entire system as well as the individual development of each subsystem, the same goes for the testing phase where both the entire concept and its sub-concepts are tested and evaluated [5].

Some phases from Ulrich and Eppinger's development process were changed to better fit the purpose of this project, most of these changes are a result of that the aim is not to develop a new product to customers but to develop a concept for mimicking drinking from a straw. The first phase, *Identifying Customer Needs*, was changed to *Identifying User Impacts*, since the customer (Tetra Pak) needs had already been stated in the project description, see subchapter 1.2, and since the objective is not the development of a new straw but rather a concept that can ease the development of straws. The second phase *Establish Target Specifications* was changed to *Establish Concept Needs* since no technical specifications was needed but rather the desired actions and stresses the method could produce. The last phase, *Plan Downstream Development*, was changed to *Final Recommendation to Tetra Pak* since this was the goal with the project.

3.2.3 **Resources**

Multiple sources of information were used during this project. Internal knowledge from Tetra Pak has been used to aid the concept development process, since Tetra Pak has an extent knowledge concerning straws, current methods, and development processes. In these cases, the company supervisors and colleagues were consulted, or Tetra Pak's Intranet was searched. As of external resources, the team members used scientific literature and reports, investigated in other straw developers, and searched the internet to find answers to their questions and to gain inspiration and knowledge.

4 Additional Background

This chapter covers a brief history of straws and a description of the package and straw type used within the project.

4.1 Straw History

Different kinds of straws or straw like objects have been used by humans for centuries. However, the straws as we know them today are a younger product and were launched on the market in the late 1800s. These first straws were made of paper but were later exchanged to plastic straws due to its high durability and low cost. This transit happened during the 1960s and plastic straws have been unbeatable market leaders until now [6]. Some of the main advantages with plastic straws are their high durability and water resistance, they are not noticeably affected by neither their intended use nor their foreseeable use. Due to this high durability, there have not been a demand for testing of plastic straws and there are thus not many test methods available on straws [4].

4.2 Package and Straw Description

Figure 4-1 shows a common still drink package that is designed to be used with straws. The Figure also defines the position of PPH which is the pre-punctured hole where the straw is supposed to be puncturing through.

Figure 4-1. Package to be used with straw and definition of PPH [4].

The focus during this project will be on U-straws since these are the most common straws [4], Figure 4-2 shows the straw and its parts. Tetra Pak has multiple sizes of U-straws and all of these should be applicable in the concept to be developed. The size ranges are diameters between 4.2 mm and 5.8 mm and total straw lengths between 125 mm and 185 mm [4].

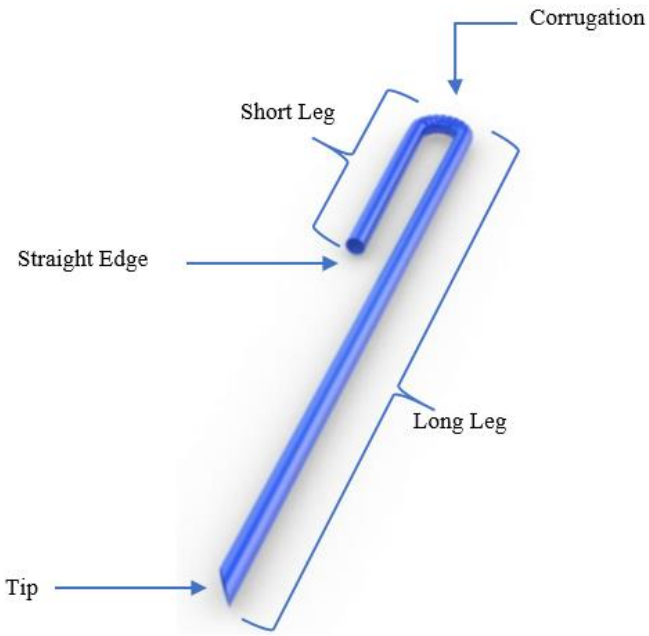

Figure 4-2. The U-Straw and its parts [4].

4.3 Differences Between Plastic and Paper Straws

Paper straws and plastic straws differ from each other in several manners, paper straws are not as durable as plastic and absorb water. Another way they differ from each other is their tendency to disintegrate, paper straws may be disintegrated in nature while plastic straws will not. However, plastic straws will not dilute in water or fall to pieces when rubbed, while paper straws might. This means paper straws cannot be used in the full extent of plastic straws.

The standard with new product updates on the market is that they are better from the functionality perspective or have some new features, this is not the situation in this particular case for straws. The transition from plastic to paper implicate a loss for the user in a functionality perspective but a profit from an environmental perspective.

The old behavior of using straws, in this case plastic straws, sets high requirements on the paper straws but a behavioral change from the user is also needed. Children may no longer be able to play with the straws as much or in the same way as before and parents may no longer be able to store their children's half-drunk package with straw in the fridge overnight.

Some users may not be as prone as others to switch their behavior, it may be factors such as age, difficulties to learn new things, or the motivation to change. The children that have used plastic straws before will most likely, the first time, interact with the paper straws in the same way as they have with plastic straws, to realize that it will not work and therefore change their behavior. The parents will also have a responsibility to teach their children how they can use the new paper straw. Children that have never drunk from a straw before will not know the old behavior of a plastic straw and therefore have a steeper learning curve for the usage of paper straws than the children and parents that are used to plastic straws [4].

However, since parents are the ones who buy the packages with straws, it is important that they are satisfied with the straws even though it is the children who in majority of the times consume the drink.

It is important to remember that plastic straws and paper straws are not the same product and that it therefore might not be possible to have the same expectations on their durability and use.

5 Identifying User Impacts

This chapter covers the different steps of the Identifying User Impacts phase. It includes an external search and an internal search at Tetra Pak to gain knowledge and inspiration to plan and conduct a proper user study for the specific purpose. It also includes the execution and results of the user study.

5.1 Planning of User Study

To be able to gather as much relevant data as possible and to perform a proper study, some external and internal search had to be completed. The external search was mainly a literature study and the internal search consisted of both interviews with Tetra Pak employees as well as reading of internal Tetra Pak documents of the subject.

5.1.1 **External Search**

To be sure that the user study would be performed correctly, a literature study was conducted. It was clear that an observation was the method that would give the most reliable data for the specific purpose, which is to see how users drink from a straw. What people say and do are often different things, why interviews can give incorrect results [7]. It can also be difficult for the user to know how she performs the activity, the perceived and the actual performance differs, leading to inaccurate answers [8, p.320].

There are different types and degrees of observations and there are many different definitions and ways to categorize them. Robson and McCartan state in *Real World Research* that there are two polar extreme types, *participant observation* and *structured observation*, and a third one, *unobtrusive observation*. The participant observation is a qualitative data gathering method where the observer seeks to become a part of the observed group. The structured observation is a quantitative method where the observer is a *pure observer* and tries to notice event sequences rather than trying to perceive what is happening. The unobtrusive method is non-participatory and non-reactive but can be either structured or unstructured [8, pp.320-321].

The observation can also be carried out in the field or in a controlled environment. Conducting the observation in a controlled environment, such as a lab, can make the user more apprehensive but makes the observation easier to replicate. There are fewer external factors that can interfere the observation, but the situation is artificial, and the results will differ from the real environment [9, p.301]. However, testing is always an artificial situation and the results from an observation in the field will be affected by the test itself [10, p.53]

It is advantageous to plan the observation in advance to get the best results: develop the observational strategy and write down the research questions you want to be answered by the study. It can also be effective to do an exploratory observation: visit the location prior to the study to get acquainted with the environment and the people [7].

The observation can be more or less structured, meaning the observer can have an observation checklist with predetermined outputs to look after or be more open minded and just take notes. A more structured observation can be beneficial since it keeps the observation more consistent, creates verifiable records, helps the observer to remember what to look for, and allows for comparison. However, a checklist and being too structured can distract the observer and critical events and deviations can be missed [7]. Being more than one observer can be helpful in several ways, it gives room for the observers to focus on different things or people, covering more data. The data may be more reliable since the observations can be compared and results will reflect different perspectives. Recording the observation with either audio, photos or video can also be helpful but makes the data analysis much more extensive and time consuming [9, pp.287-300].

The number of observations and people to observe will depend on the type of study and there is no correct answer. It can also be limited by resources such as time and money. Logically, the more accurate the estimates from the study should be, the more observations should be conducted [8, p.144].

It is important to go through the field notes and analyze the observation rather quickly after it has been conducted. This is to make sure nothing is missed or so that the observation is not confused with other observations [9, p.291].

5.1.2 **Internal Search**

5.1.2.1 Interviews with Tetra Pak Employees

Several Tetra Pak employees were consulted for advice on how to conduct the user study and to gain insight on already conducted studies at Tetra Pak. It was learned that asking children what they think of a product is difficult and that observing what they are doing is more rewarding. It was also learned that mounting a GoPro camera in front of the child is a good way to document and to capture expressions. The setup can also be beneficial since the interviewer does not have to focus on annotating at

the same time but can rather go through the material afterwards [11]. They also learnt to not take anything for granted during the observation. Children are often very inventive in their actions and might use the straws in ways that are almost impossible for adults to foresee. To get a full understanding of how children use straws, it is important to only observe, and thus not prevent the children from playing with the straws. It was also mentioned that it could be a good idea to study the straws closely after the observation to gain further knowledge of what forces the straws have been exposed to during use. It can also be beneficial to do sketches of how the packages and straws were handled, and especially if there were some handlings that was done in a less usual way [12].

In addition to giving advise concerning the observations, the Tetra Pak employees provided feedback on the preliminary plan of the study. It was also discovered that children usually consume a soft drink within 15 minutes and 2 hours and that some customers therefore ask Tetra Pak for straws that can hold for up to 2 hours in liquid [4]. It is therefore beneficial to record how long it takes for the children to finish their drinks.

5.1.2.2 Search of Tetra Pak's Intranet

To gain further understanding of how Tetra Pak usually studies children and what age groups that might be of interest, Tetra Pak's intranet was searched for earlier studies and definitions. It was found that Tetra Pak often divides children into three different age groups before they reach their teens; Babies and toddlers 0-3; kids 4-7 years; and tweens 8-12 years. Kids that are in the age group between 4-7 are growing their independence and confidence, "They want everything, and they want it now", "They're learning soft skills at an unprecedented rate: problem solving, multi-tasking and quick thinking." [13].They are in the key age for new products and belongs to the age group that mostly uses straws, which is why they were the target group for the user study.

5.1.3 **Final Plan of User Study**

After gathering information both externally and internally, it was decided that observations should be conducted to capture the usage of straws. For the observation to be as realistic as possible, it should be conducted in the field, rather than in a controlled environment. From the research and discussion with Tetra Pak it was decided that the main target group for the study is children in the age group 4-7 years old. It was also decided that it should be a structured observation, this due to interaction with the children could affect their behavior and thus also the results. The observation was planned beforehand to facilitate. For instance, a template was developed, see 5.2.1, with hypotheses and it was decided that the team members would focus on different children during the observation, this to capture as much information as possible. It was also concluded that several observations would be conducted to make the data gathering more extensive and the results more reliable.

5.2 Execution of User Study

Prior to the user study, the principal of two preschools was contacted and asked if it would be possible to conduct the study at his preschools. Fortunately for this project, the principal was positive towards the proposal and allowed the study.

The user study was executed during three days. During the first day the team members tested and evaluated the study plan, and the actual study was performed during the following two days. The intention with the first day was to get acquainted with the study template and to look for eventual needed improvements, both of the study itself and the template.

5.2.1 **The Study Template**

As mentioned earlier, the Study Template was created to assist during the observations. The template was divided into four different sections with hypotheses, “Opening of the plastic wrap”, “Puncturing PPH”, “Drinking”, and “Afterwards”. Each section contained multiple predicted actions. There was also a three-step scale for the impact on the straw beside each hypothesis, these were “Barely noticeable”, “Little”, and “Big”. It was up to each observer to decide where on the scale to draw the line for when a hypothesis occurred. However, it was discussed beforehand, and the study templates would be compared afterwards to see that the valuation had been rather similar. The template also had a free space where the team members could write or sketch other findings. The template can be seen in Appendix B.

5.2.2 **Day One**

The test observation was performed at the café *Espresso House* at Stortorget, Lund. Since drinking from single-use packages and straws is quite unusual in public spaces, it was decided to observe other behavior such as drinking from a cup, talking and similar. Even though it was different behaviors observed, the team got acquainted with being observers and to annotate. IPads were used to annotate, and it was decided that Teigland would use the same method for the actual study but von Matern would use physical paper and pen. The Study Template with the scale felt like a good technique and would therefore be used for the actual study as well.

5.2.3 **Day Two**

Day two was the first study day. During this day, the team members went to *Plommonet Preschool*, Lund, and met two groups of five children each. The children were aged three to five years old.

The team members were invited inside the preschool and greeted both the children and the teachers. The teachers had told the children that two students would visit the preschool during their afternoon snack time, but nothing about the study or its purpose. Figure 5-1 shows the still drinks provided to the children and teachers. The provided still drinks had plastic straws since the aim with the study was to mimic the general use of straws.

Figure 5-1. The still drinks provided to the children.

Except the presence of the team members and that the children were given still drinks instead of water and milk, the study environment and the procedure of the afternoon snack time was just as an ordinary day at the preschool.

The two groups ate one after the other in the same room and during each observation, the two team members sat approximately two meters from the table and observed two respectively three children each. See Figure 5-2 for visual description of the study set-up.

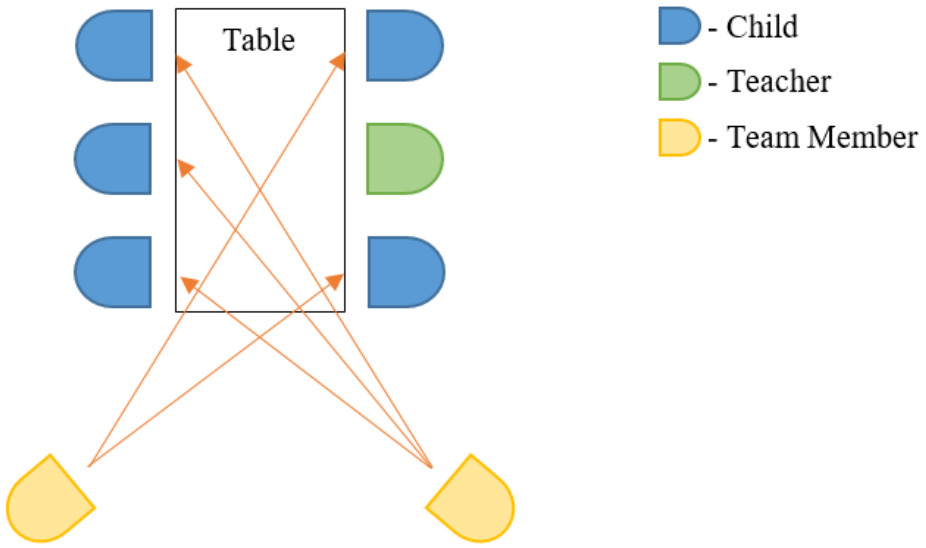

Figure 5-2. Day one, study set-up.

It was planned to not interact with neither the children nor the teacher during the observation. This was the case during the entire study except for once when one of the children asked the team why they were there, and one team member answered that they were there to learn about the afternoon snack time.

Each sitting took approximately 30 minutes and all children finished their still drink. At the end of the day, the results from the study template and the study itself were summarized.

5.2.4 **Day Three**

The same general procedure as described in 5.2.3 was followed, but at *Arken Preschool*, Lund, and concerning 15 children all aged 5 years. Just as for the day before, the intention was to not interact with the children but as opposed to day two they failed with this. The children asked different questions, most not concerning the study, and the team members answered. However, when asked what they did there, the team members answered that they were there to learn about the afternoon snack time, just like the day before.

Unlike day two, the packages and straws were collected after the snack time, with the intention to being able to analyze the straws further.

The children were divided into two groups that ate at the same time but in different rooms, one team member observed each group. Within this section of the report, these two groups will be referred to as Group A and Group B.

Group A consisted of seven children and the team member stood approximately two meters from the table to observe. The team member moved from side to side to be able to see better, see Figure 5-3. Group A had their packages and straws removed from them directly after being finished with the still drink.

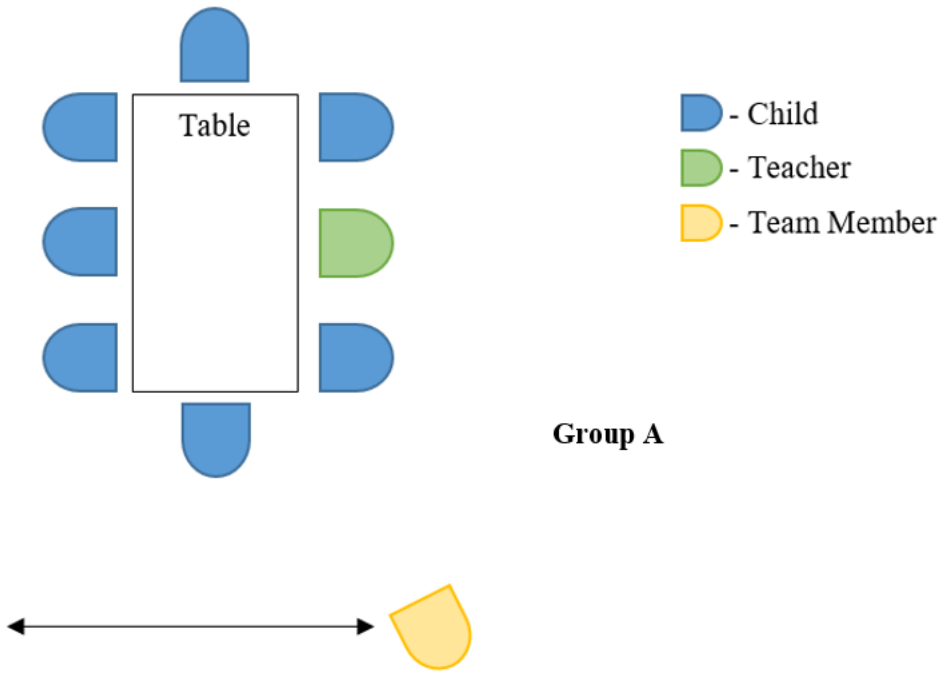

Figure 5-3. Study set-up for group A.

Group B consisted of eight children and the team member stood at approximately one meter away from the table, see Figure 5-4. Group B had their packages and straws during the entire snack time and had therefore more time to play with them.

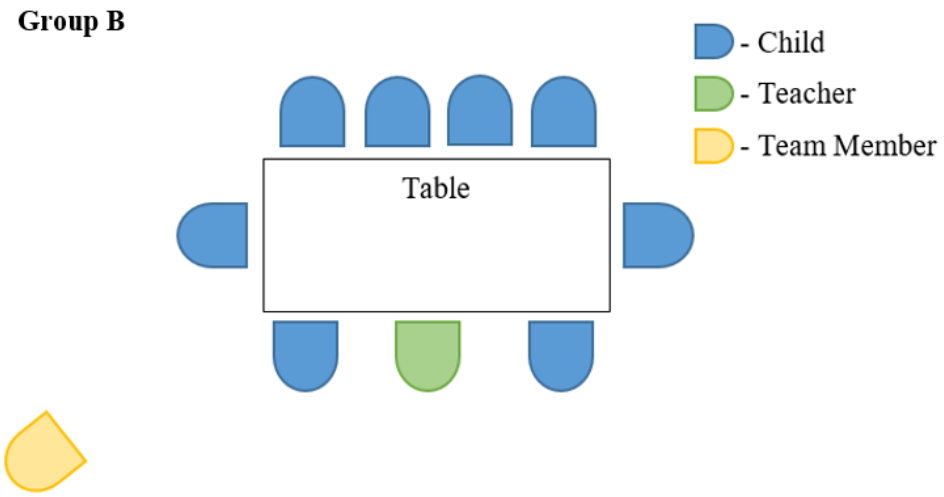

Figure 5-4. Study set-up for group B.

The snack time took approximately 30 minutes and all children except one finished their still drink, just as during the day before. At the end of the third and final study day, all results were summarized and the damages on the straws were investigated.

5.3 Previously Performed Straw Studies at Tetra Pak

A study on 27 children aged 4 to 12 was conducted in Lund, 2019. The focus was to test three different paper straws and analyze how the children handle and insert the straws, and to get an understanding of how they experienced the different straws. Each child was filmed with a GoPro camera and interviewed by Bengt Ask. The children were accompanied by a parent and sat in a room at Tetra Pak together with Ask and an observer. The questions asked were if they usually drank from packages with straws, what they thought it felt like to put the straw into the package, and what it felt like to drink from the straw. The children answered with words as well as pointing on a smiley matching the feeling the best, see Figure 5-5.

Figure 5-5. Smiley scale for evaluating straws.

The study was conducted in a controlled environment where the interviewer told the child what to do, meaning *intended use* of the straw was the only use-phase tested [14].

The documented films were watched to observe how the children handled the straws and drank. The results were annotated and compared with the results from the user studies at the preschools.

In addition to the study in Lund, an open discussion between four mothers about children's usual interaction with U-straws was performed in Italy, 2019, and the data from this discussion was received [15].

5.4 Results from User Study and Previous Studies

5.4.1 **Results from Study Template**

Below are the results from the user study from day two and day three. The study templates have been merged into one, see Table 5-1, to make it easier to interpret. The values shown in the columns are the number of situations when the children did the different actions with the specific impact level.

Table 5-1. Merged results from the study template.

Action	***Barely noticeable***	***Little***	***Big***
Opening			
Pinching hard on straw	3	7	0
Removes from plastic wrap on a deviating manner	3	3	1
Bends/Bites on straw	2	6	1
Puncturing PPH			
Squeezes (on straw)	3	6	1
Pushes down straw the wrong way	1	0	0
Misses the hole/hammers with straw	0	1	0
Drinking			
Bites/squeezes between lips	16	18	11
Bends in the bottom	2	2	0
Scrapes straw up and down in PPH	14	9	4
After			
Plays	12	16	2
Pushes down the whole straw in package	8		

5.4.2 **Playing with Straw**

Playing with the straw was done in different ways where some actions were done more frequently than others. Blowing into the straw, while having it inside the package as well as outside, occurred frequently. Several children flipped the straw and drank from the other end, while others bent the straw with their hands. Other actions were spraying drink on each other, spinning the straw around in the PPH to make it bigger, putting the straw on the table and pounding on it, pulling with a big force to stretch out the straw, bent the straw by the corrugation, bent the straw around the package, and shot out the straw from the package by pressing on the package.

5.4.3 **Other Observations**

It was observed that most of the children had about one centimeter of the straw in their mouth while drinking, however it also occurred that children had the whole short leg, until the corrugation, in their mouth. A lot of children had their hands on the straw and close to their mouth while they were drinking but holding it gently and it was also usual to pinch the straw on the corrugation. The straw was typically

inserted so that the corrugation was by the PPH on the package. It was common to drink, play with the straw and package, and then drink again. A lot of the children drank under a long period of time, to then take a break.

5.4.4 **Visual Results of Used Straws from Day Three**

The straws were collected after the observations from day three, to provide visual results of how the straws were impacted by the children. From Group A, there was one straw that was impacted considerably, see Figure 5-6 and there were two straws that had very little damage, see Figure 5-7. From Group B, where the children kept their drinks during the whole snack time, the straws were comparably much more affected than the ones from Group A. There were three straws that were heavily damaged, see Figure 5-8, one that was significantly damaged, see Figure 5-9, and four that were barely impacted, see Figure 5-10.

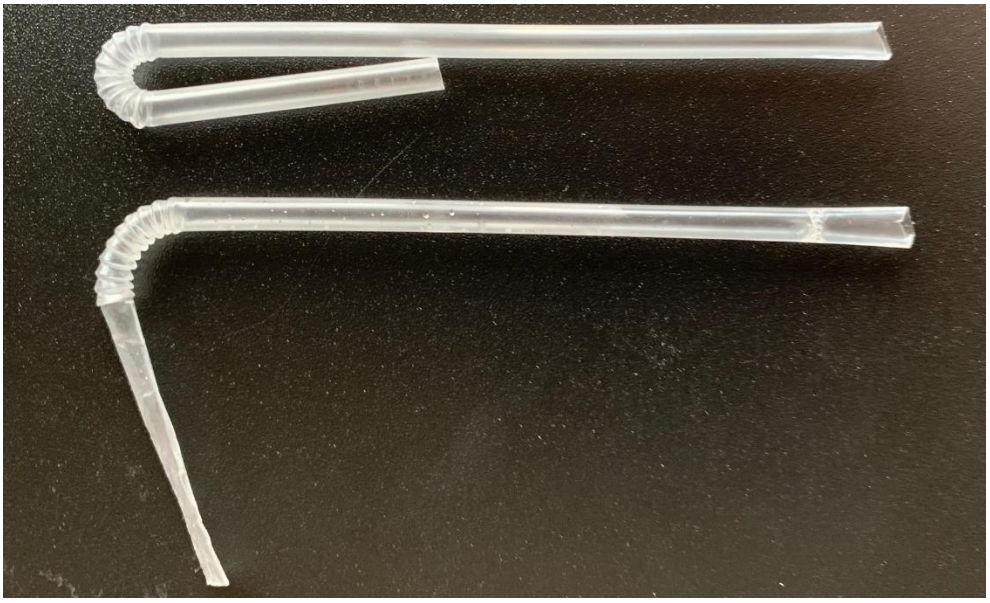

Figure 5-6. Straw from Group A, considerably impacted compared to new straw.

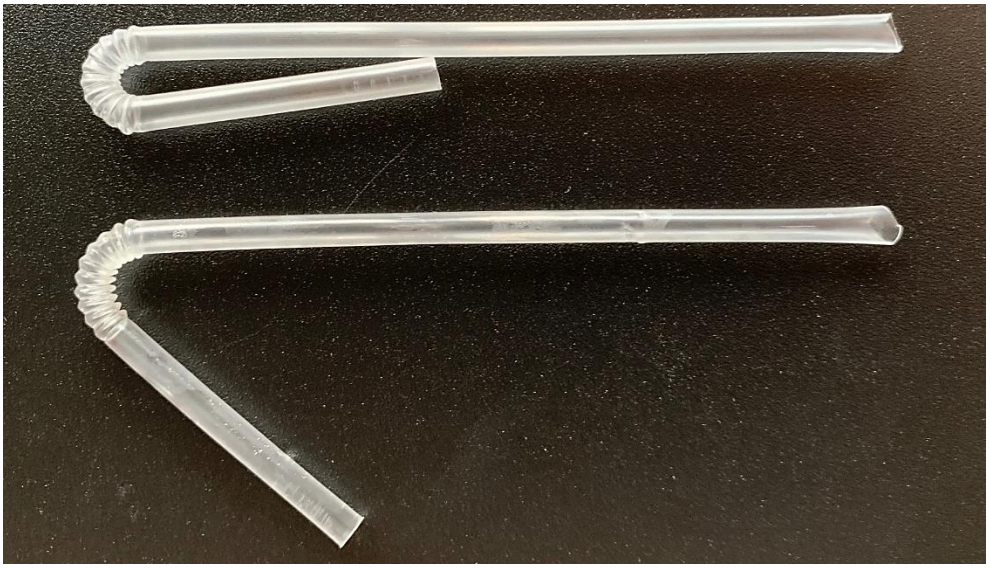

Figure 5-7. Straws from Group A – barely impacted compared to new straw.

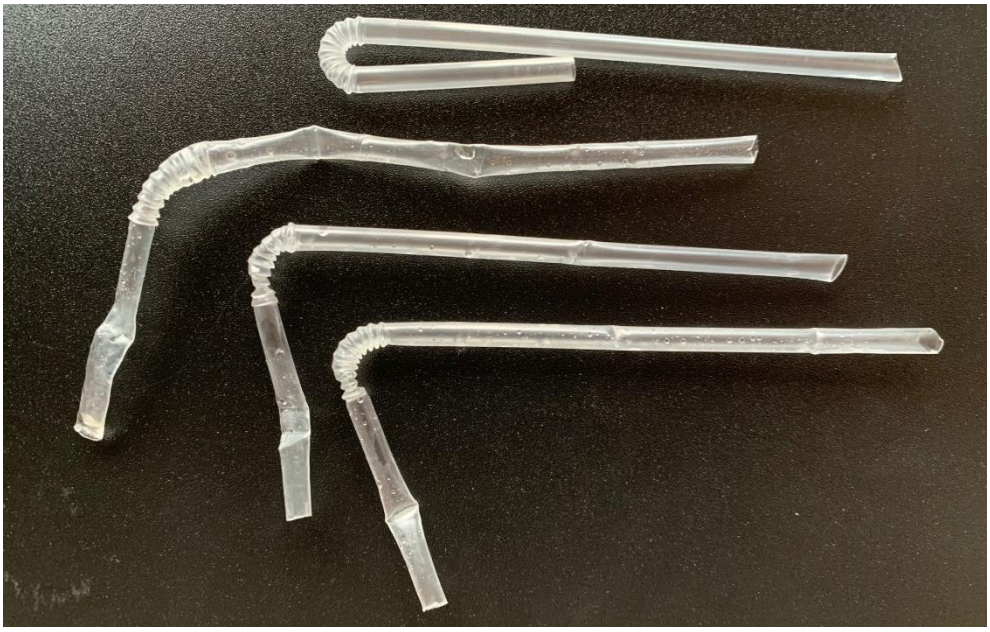

Figure 5-8. Straws from Group B – heavily damaged compared to new straw.

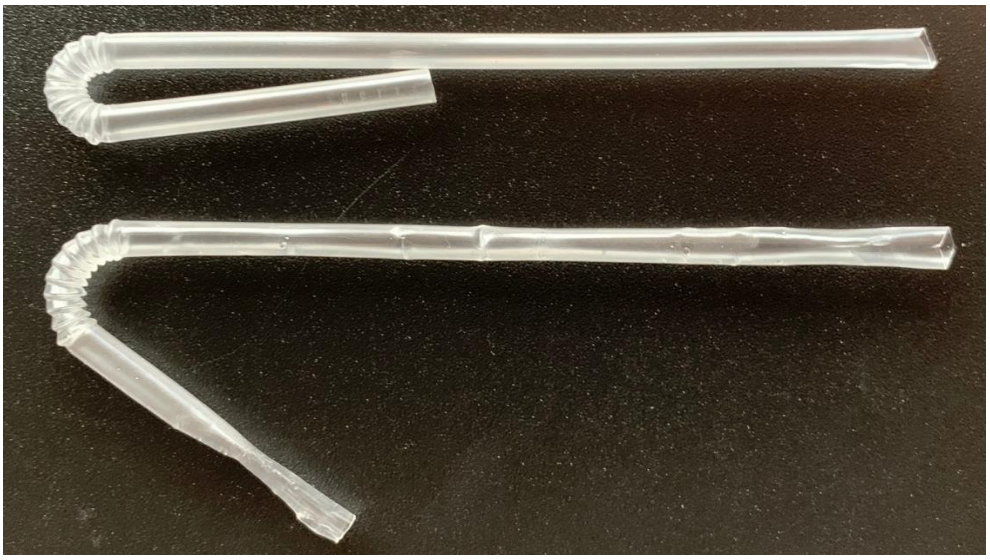

Figure 5-9. Straw from Group B – significantly damaged compared to new straw.

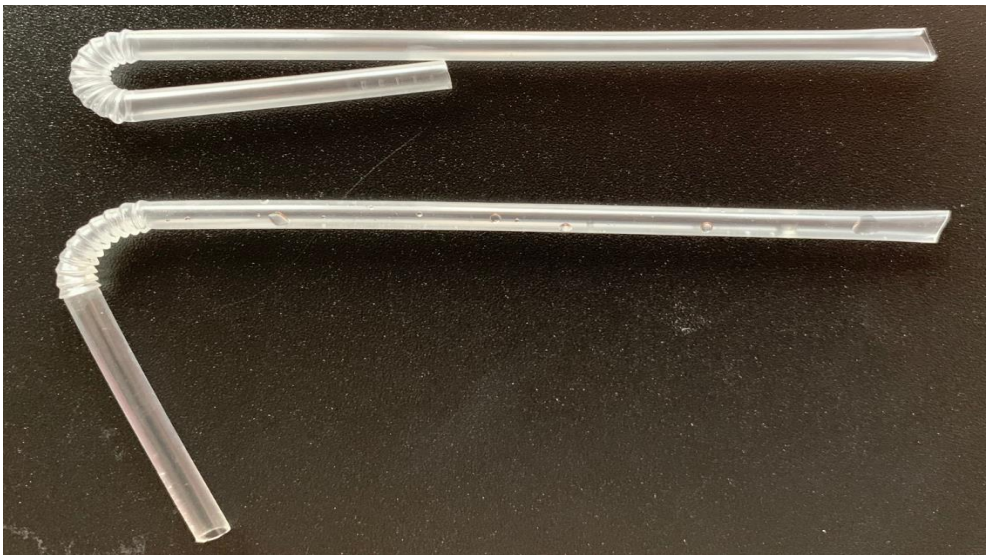

Figure 5-10. Straw from group B – barely damaged compared to new straw.

All in all, almost all children played with the straws, but the intensity of the playing actions increased when they had finished their drink, and this is also when the greatest impacts on the straws occurred. Since the drink is finished by this point, the straws' ability to withstand intended use decreases, even though it would be preferable that the straws could withstand intended use throughout the action it is most critical prior to the drink being finished. The damages shown in Figure 5-8 are thus more extreme than the straws must be able to withstand.

5.4.5 **Results Provided from Previous Studies at Tetra Pak**

The results from observing the videos can be seen in Table 5-2.

Table 5-2. Results from observing movies of study performed at Tetra Pak.

During puncturing of PPH	Holding high up on long leg	Holding in the middle of long leg	Holding far down on long leg
Number of children:	9	8	7
Drinking, amount of straw in mouth	Little	Alot	
Number of children:	19	1	

Table 5-3 shows a summary of the load cases and situations found from the previously done studies at Tetra Pak, that is, the movies and the discussion.

Table 5-3. Load cases and situations from previously done studies at Tetra Pak.

Action	***Findings***
Straw Insertion, puncturing of PPH	Holding on long leg, far away from PPH. Holding on middle of long leg. Pushing on top of straw, on corrugation. Pushing the whole straw, including the corrugated part, into the package.
Drinking	Inserting straw only a few millimeters into package. Inserting the straw until the straight edge and touching the top panel with lips. Inserting until corrugation.
Other	Playing with straw by rotating it around PPH. Bending straw before inserting. Playing by moving/touching the straw, both inside and outside of package. Biting the straw. Inserting and removing the straw several times. Pulling and pushing the corrugation. Press/damage the straw before/while inserting into package. Straw removed and inserted in the opposite direction.

5.4.6 **Reflection of User Study**

Overall, the user study gave a lot of useful information and insights to continue with, however, there are some factors to take into consideration while analyzing the results. As stated earlier it is an advantage to get acquainted with the place and people one is about to observe. However, this was not possible because of the Covid-19 pandemic. Face masks were worn while conducting the observation, which may have attracted the attention of the children even more than if no face masks had been used. This could have affected how the children acted, something that is difficult to investigate.

The children had drunk from straws before and during the first observation it did not seem like a big deal that they received soft drinks, but during the last day of observations, it was discovered that the children normally do not get the sort of drinks that was distributed during the observation. This resulted in a lot of excitement among the children. This may have affected their behavior, however, children normally get the type of drinks when they are on field trips or on birthday parties, where excitement occurs [4].

The team members might have observed and assessed behavior differently, meaning the results could have differed if only one member had conducted the observations. The scale used in the study template may have been perceived differently because of human bias, which is impossible to avoid.

The observations were done on children between the age of three and five, where a lot of the five-year old's were close to six. There were girls and boys in all the observations as well as spread between ethnic backgrounds. However, the children had probably similar social economic backgrounds since they went to the same preschools and thus probably lived in the same neighborhoods. What background a child has may affect how the child behaves and interacts with the straw and package. However no difference in behavior among these groups were observed.

The straws that were used in the observations were plastic straws, even though the requested final concept will test other material of straws as well. The goal with the user study was to see how children interact with straws in general. However, if straws of other material had been used instead, the behavior as well as forces on the straw may have been different. If straws of another material had been used, the children would most certainly not be used to them, which itself may affect the results. The conclusion was therefore that performing the test with plastic straws was the preferred approach.

It was common that the children imitated each other and played with the straws in similar ways. Some actions that children normally do may therefore not have played out. However, 25 children were studied in total and specific behavior and actions

could be observed and seen as general. All of the children but one finished their drinks within the snack time which was set out to be 30 minutes. The information gathered from the observations, in addition to the previously done studies at Tetra Pak, was enough to progress with the concept development. No further observations or research felt necessary to conduct.

5.5 Conclusion of Identifying User Impact

The identification of user impacts was fortunate, and a great amount of information about the usage of straws was gained. The study template was beneficial during the observations and provided a solid ground for the following evaluation process. 25 children were observed during the study and even though this number is not very high, the team members felt comfortable with the results and that they had covered the majority of the most frequently occurred stresses on straws. The children showed both intended, foreseeable, and unforeseeable use of the straws and the project could therefore continue without any further user studies.

One of the most important understandings that was gained from the user study was that children often drink, play, and then drink again with the straws. The user study also showed that the greatest impacts on the straws were on the short leg, which the children usually had in their mouth, exposing it to both saliva and concise forces.

6 Establishing Concept Needs

This chapter covers the translation of raw data from the previous chapter into stresses that the concept must be able to produce – the concept needs. These concept needs are then evaluated, rated, and prioritized to ease the subsequent work.

6.1 Interpreting Raw data

The actions that occurred during the observations at the user studies and that have been discovered from previously done studies, were translated into concept needs to ease the process of the idea and concept generation. These concept needs are stresses that the test method is wished to produce, most of them consist of exposing the straws to certain forces or transporting liquid through the straws. Table 6-1 shows examples and the full list of the concept needs can be seen in Appendix C.

Table 6-1. Cut-out from full list of Concept Needs

User Action	***Concept Need*** *- Concept has to be able to produce*
OPENING	
Pinching hard on straw	**Dry straw** - Expose straw to a force
Removes from plastic wrap on a deviating manner	**Dry straw** - Expose corrugation to a force
Bends/Bites on straw	**Dry straw** - Expose straw to sharp concise forces - Bend straw
PUNCTURE PPH	**Dry straw** - Expose tip of the straw to a force
Holding high up on the straw	**Dry straw** - Bend straw
[illegible]	[illegible]

6.2 Evaluation of Concept Actions and Concept Needs

To somehow organize and prioritize the user actions and concept needs, an evaluation has been done. Table 6-2 below shows the final evaluation of the found user actions, the actions that resulted in the same concept need were merged into one. The actions have also been grouped together when their concept needs were alike. There was a small focus on paper straws during this step instead of plastic straws and straws in general, the reason for this was that paper was the most likely first replacement material for plastic in straws and that it thus had a relevancy for this project. The actions have then been further evaluated on a scale from one star (*) to three stars (***) as a sign of their level of predicted impact on paper straws. Actions with one star has a low predicted impact on paper straws while actions with three stars have a large predicted impact on paper straws. The level of impact has been determined by the team members and are mainly based on how severe the damages on paper straws would be if exposed to the user action. For example, sharp concise forces from bites have a high level of impact since paper is not an elastic material and a paper straw will probably not spring back to shape as a plastic straw does. Sharp concise forces have therefore three stars while transportation of water has only one.

The concept needs have also been evaluated on their relative importance for this project. This evaluation had a scale from 1 to 5, where needs with a low number of relative importance are less important than needs with a high number. The relative importance is a compile of the impact the action had on the straw and its frequency during the user study. It is for example much more important to expose straws to a mimicked biting action when the straw is wet compared to when the straw is dry. This is since it is both quite difficult to bite on the straw without making it wet and since wet paper has inferior strength properties compared to dry paper. The decisions about the level of relative importance for each need are based on consensus between the team members and Tetra Pak and relies on their experience within the subject.

The user actions have also been divided into the categories of use that they belong to, where *I* stand for *Intended Use*, *F* for *Foreseeable Use* and *U* for *Un-Foreseeable Use*. The user actions that belong to the *Intended Use* category are all rated 5 on the relative importance scale since it is fundamental for the straws to be able to withstand these stresses.

Table 6-2. Evaluated and grouped concept needs. Cut out version, for full version see Appendix D.

Category of Use (I/F/U)	***Need Number***	***User Action***	***Concept Need*** *Concept has to:*	***Predicted Impact on Paper Straw***	***Relative Importance***
F	1	Pinching on dry straw	*Dry:* Expose straw to a force	*	3
F	2	Removes from plastic wrap on a deviating manner	*Dry:* Expose corrugation to a force	*	3
F	3	Bends/Bites on dry straw	*Dry:* Expose straw to sharp concise forces	**	3
U	4	Bends/Bites on dry straw	*Dry:* Bend straw	**	2
I	5	Puncturing PPH	Dry: Expose tip of the straw to a force (z-direction)	**	***5***
F	6	Holding high up on the straw	*Dry:* Mimic fingers high up on long leg of straw	*	2
U	7	Pushes down straw	*Dry:* Expose straight end of the	*	2

The concept needs with relative importance level 5 and 4 were prioritized within this project and can be seen in Table 6-3. It was planned to continue with the following needs in a decreasing order if there would be time to do so.

Table 6-3. Most relative concept needs.

Need Number	*User Action*	*Concept Need*	*Relative Importance*
5	Puncturing PPH*	Dry: Expose tip of the straw with a force (z-direction)	5
9	**Compressing straw**	**Wet: Expose straw to compression (x- and y-direction)**	5
14	**Drinking**	**Wet: Transport liquid**	5
15	**Bending straw**	**Wet: Produce bending motion**	5
17	**Biting straw**	**Wet: Mimic biting action on straw and produce concise forces**	5
11	**Produce friction**	**Wet: Produce friction along sides of the straw**	4
16	**Pulling and pushing straw**	**Wet: Produce pulling and pushing motion**	4

(*) This action was de-prioritized due to already existing test methods but will be investigated further if time allows.

In addition to the concept needs seen in Table 6-2, which are the result from the user study, the project also had some internal needs given from Tetra Pak. These needs are further discussed in 1.3 and includes that the final concept must be user friendly, ergonomic, efficient, able to measure multiple straws at once, provide accurate results, et cetera.

7 Translating the User Actions into Mechanical Stresses

Since the scope of this project is relative complex with multiple sub-problems, the stresses are divided into categories to ease the concept development process. This chapter begins with benchmarking and patent search and continues with the categories being defined and investigated. Multiple concepts are designed and evaluated, and the final concept is chosen at the end of the chapter.

7.1 Benchmarking and Patent Search

Benchmarking and patent search were conducted to gather inspiration and knowledge about what the final concept might look like and to determine if there already were any existing similar products on the market. The Google Search Engine was used to find standards and competitive paper straw companies. Some of the companies were contacted and asked how they test their straws, and it was established that many companies expose the straws to liquid to evaluate how well they can withstand it and that some companies had additional lab tests. However, what type of lab tests could not be established due to immaterial rights.

Patents were searched for on Google Patent Search Engine. Words and phrases used to find patents were among others: “paper straw”, “straw test method”, “mimic drinking from straw”, “bending test”, “biting test”, “drinking straw test”, “folding test”, “quality control”, and “evaluating paper straw”.

Overall, there seem to be very little done on the subject, which strengthen the reason for the project. There was however one patent relevant for the subject which covered a test method for evaluating life expectancy for plastic straws through stimulating biting stresses on straws [16]. In addition to this, some other patents that provided inspiration on how to mechanically perform for example a bending test [17] or test the folding endurance in paper [18] was found, these patents were more general and not necessarily developed for straws but were still useful.

7.2 Concept Generation

The concept generation process consisted of multiple iterative steps. The first steps were to generate many concept ideas and then later to evaluate and further develop the most promising ideas. The aim was to generate ideas that covered the different concept needs in an as large extent and realistic way as possible.

7.2.1 **Idea Generation**

The first step of the idea generation process was to separate and further define the different stresses to ease the concept generation. These stresses were (a) Drinking (b) Bending, (c) Biting, (d) Friction, (e) Bending of Corrugation, (f) Pinching, and (g) Pulling and Pushing. The next step was to sketch on possible solutions, this was done individually to increase the number of solutions investigated and to not influence each other. The results from this sketch session can be seen in Appendix E. After the first sketch session, the team evaluated the different ideas and decided which to go forward with and which to leave. This decision was based on the feasibility of the idea and the predicted level of resemblance to reality of the resulting stresses. See Figure 7-1 for the classification tree of the first concept ideas.

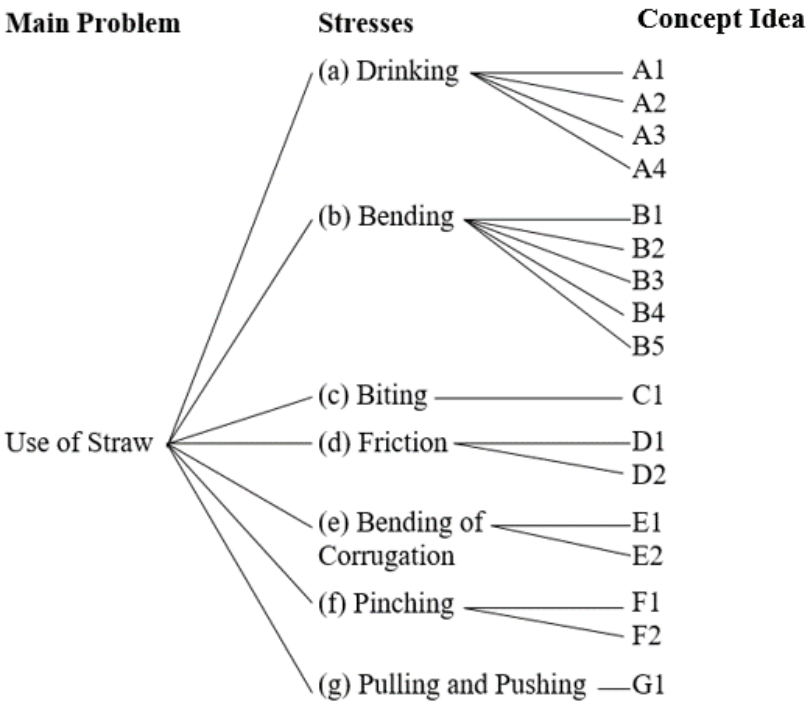

Figure 7-1. Classification tree, version one. A1 to A4 represent the four different concept ideas that were generated for mimicking of the drinking action, the same goes for the rest of the stresses and their resulting concept ideas.

The following step was to evaluate which concept ideas that could be combined to make the concept generation process and the final concept more efficient. A table with the resulting combinations can be seen in Appendix F.

7.2.2 **Combining Concepts**

The next step of the development process was to further develop and sketch the combined concepts. To make the sketching process less time consuming, the combinations were divided between the team members to further develop and evaluate. This process resulted in 13 concepts, where the majority covered multiple concept needs, an example of one of these concepts can be seen in Figure 7-2 that show concept 4 which is a combination of concept idea B3, C1, E1, and F2. An updated version of the classification tree can be seen in Figure 7-3 and the sketches of the combined concepts can be seen in Appendix G.

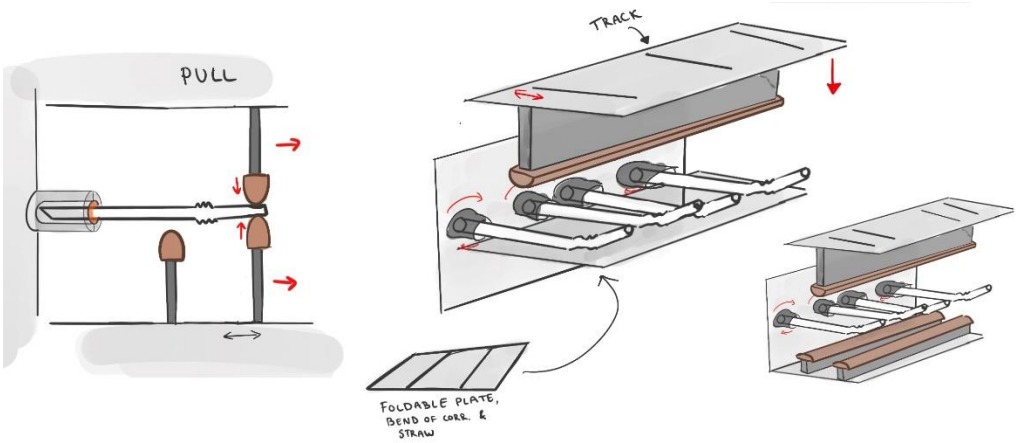

Figure 7-2. Example of a combined concept – here Concept 4; a combination of concept idea B3, C1, E1, and F2.

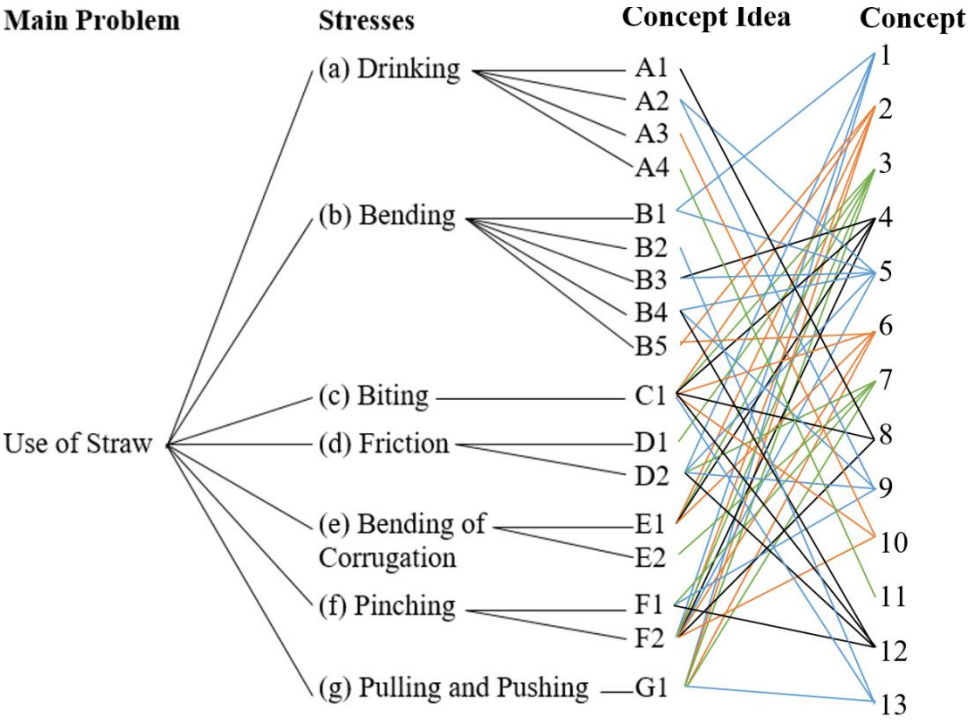

Figure 7-3. Classification tree, version two. As the blue line indicate, concept 1 is a combination of concept idea B1, D2, F2, and G1.

A screening matrix was used to decide which concepts to continue with and which to abandon. The screening matrix is seen in Table 7-1 below. Concept one was used as a reference concept and the other concepts were evaluated if they were predicted

to perform better (1), worse (-1), or the same (0) as the reference concept concerning different criteria. If the concept has been rated with “0” or ”-1” followed by an extra minus sign (0- or -1-) it means that the concept cannot perform the action to cause the stress, this concerns the last seven criteria. The sum of these ratings results in a total score for the concept.

Table 7-1. Concept screening matrix.

Concept	**1 Ref**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Level of Similarity to reality	0	1	0	1	0	0	1	1	0	1	0	0	0
Ease of Manufacturing for team	0	-1	0	1	1	-1	-1	1	1	1	1	1	1
Ease of Use	0	0	-1	1	1	0	-1	1	1	1	1	1	-1
Bending	0	1	0	1	0	1	-1	0	0	-1-	-1-	0	1
Biting	0	1	1	1	1	1	-1-	1	-1-	1	-1-	1	1
Drinking/Pumping	0-	0-	1	1	0-	0-	0-	1	0	1	1	0	0-
Friction	0	1	0	0	1	0-	1	0	1	-1-	-1-	1	0-
Bending of Corrugation	0	1	0	1	0	1	1	1	0	1	1	1	1
Pinching/ compression	0	1	-1	1	0	1	1	1	1	1	-1-	0	-1-
Pulling and Pushing	0	1	-1-	0	-1-	1	1	0-	-1-	-1-	-1-	-1-	1
Total Score	0	6	-1	8	3	4	1	7	2	4	-1	4	3
Rank	8	**3**	9	**1**	5	4	7	**2**	6	4	9	5	5
Continue?	N	**Y**	N	**Y**	N	N	N	**Y**	N	N	N	N	N

From Table 7-1, the three concepts that got the highest scores were all supposed to be continued with, however it was decided to continue with concept 6 instead of concept 4. This decision was based on that concept 2 and concept 4 were alike and that continuing with concept 6 would lead to a broader investigation of the concept spectra. Concept 2 was prioritized over concept 4 since it was believed that concept 4 would request a big stand and thus be less space efficient. Concept 8 was the only chosen concept that covered drinking, and it was therefore decided to continue with concept 10 as well. This concept selection led to the following classification tree, see Figure 7-4.

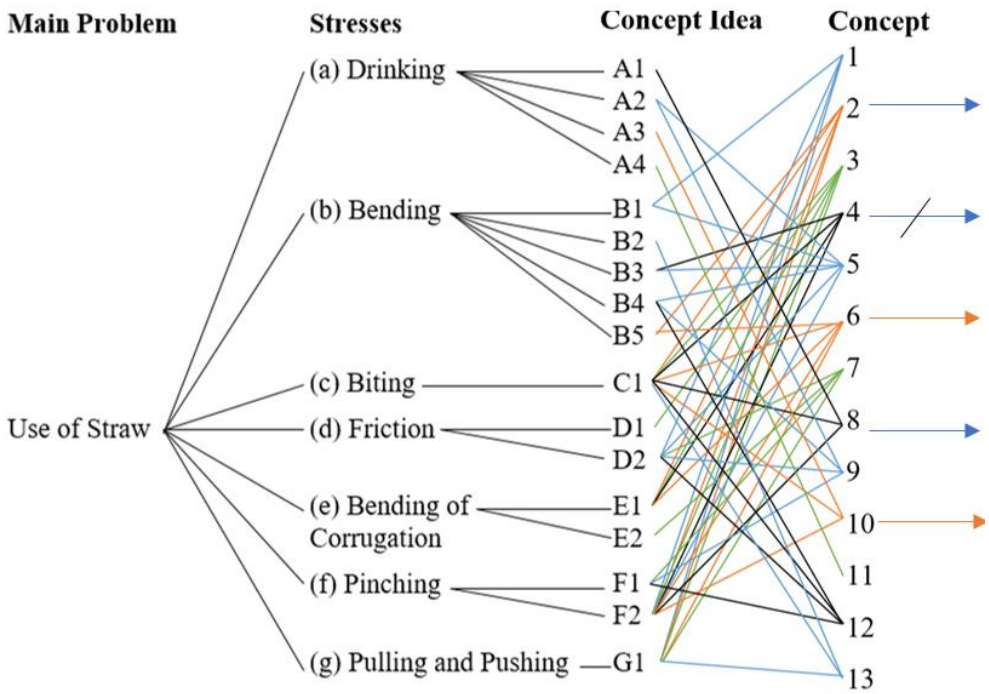

Figure 7-4. Classification tree, version three. The blue arrows represent the three concepts that scored the highest from the screening matrix and the orange arrows represent the two concepts that were chosen to continue with as well. The crossed-out arrow represents the concept that was decided to discontinue with, despite its high score.

Figure 7-5 to Figure 7-8 show early sketches of the concepts that were chosen to further develop. Concept 2 works in that way that the straws are fixated between two plates where the top plate is movable and the one that locks the straws, the plates pinch the straws' long leg. Once fixated, two new parts expose the straws to the actions, for example bending, biting, and friction. The heads on these parts are exchangeable, making it possible to perform the different actions, see the bubble in Figure 7-5.

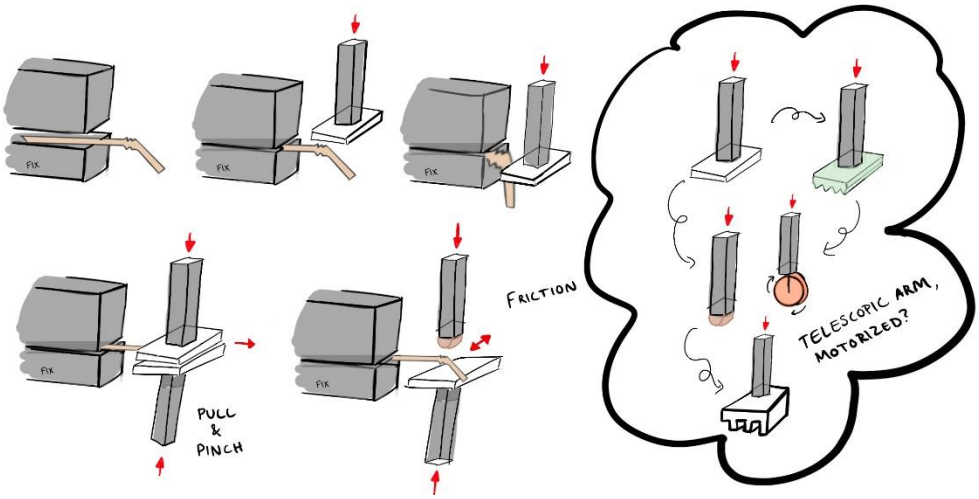

Figure 7-5. Early sketches of concept 2.

Concept 6 works in that way that the straws' long legs are fixated in a straw holder. Two plates on either side of the straw holder pinch the straws and can move in the horizontal and vertical plane. The plates have arms with rails, making it possible to move the plates.

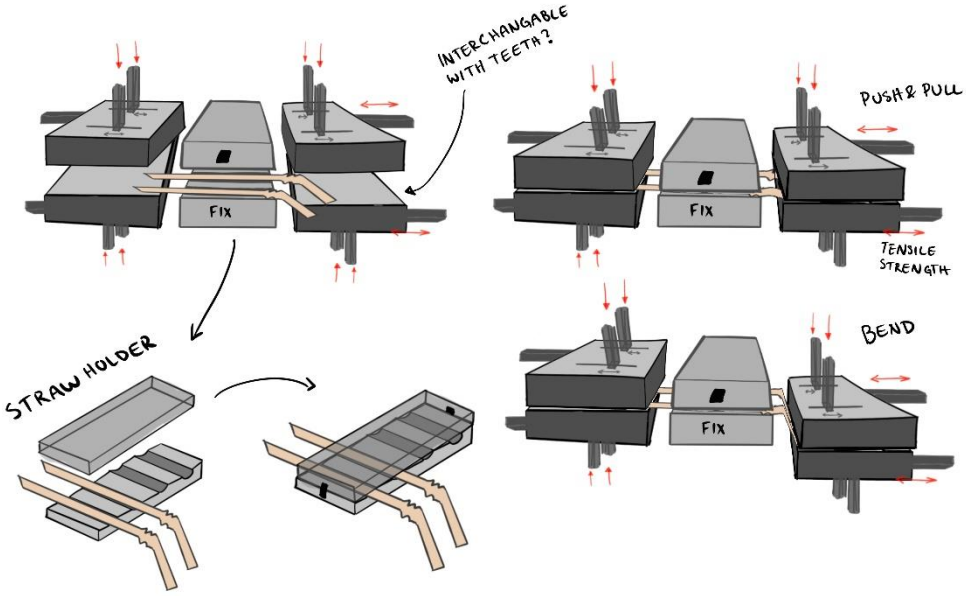

Figure 7-6. Early sketches of concept 6.

In concept 8, the straws are put in a water container with eight dividers so that each straw has the correct amount of water. The short leg is pinched in a clamp that has a damp material, e.g., a cloth that resembles the human lips. The clamp is connected to eight pipes that lead to a pump. The pump can then pump water through the

straws, resembling the drinking motion. The pinching clamp is then replaced with a clamp with teeth that can resemble the biting motion. The top part of the clamp is also movable to resemble the grinding motion.

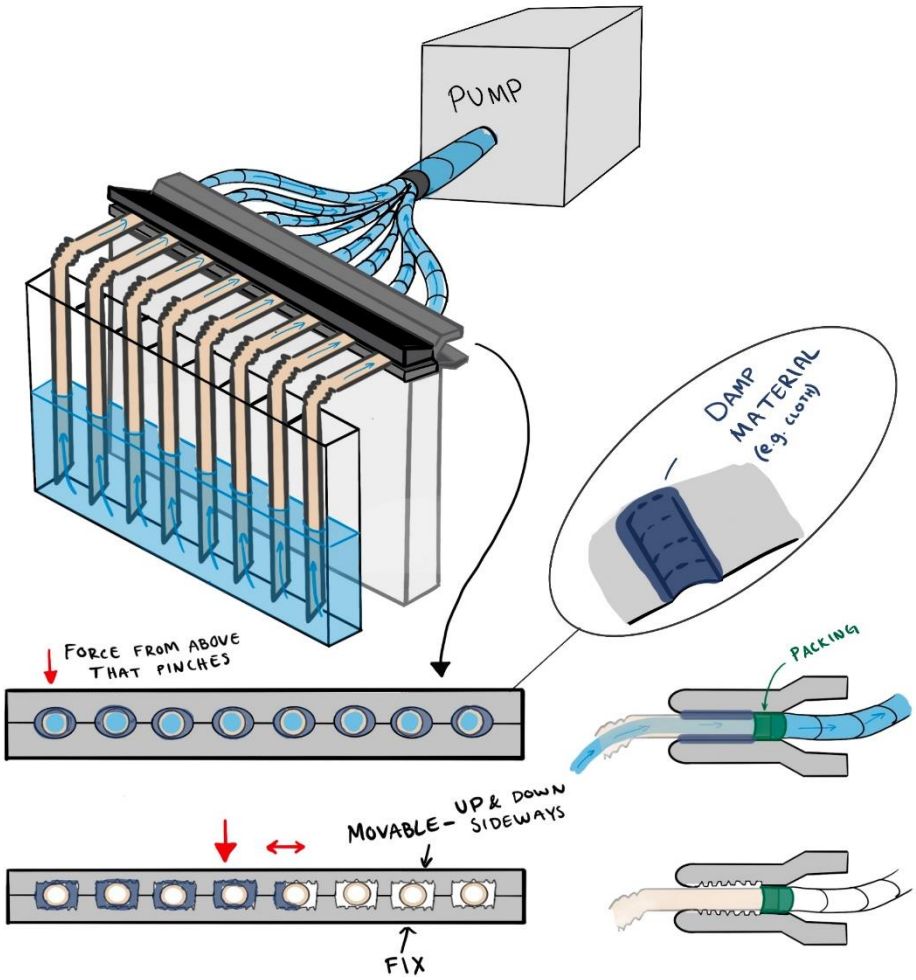

Figure 7-7. Early sketches of concept 8.

Concept 10 is similar to concept 8 but there is no pump to transport the liquid, instead, the straws are lowered almost completely into the water and a clamp is fastened on the straws. The straws are then lifted so that only the long leg is exposed to water on the outside, but the whole straw is exposed to water on the inside. There are also two different clamps, one for pinching and one for biting. The clamps can rest on the stand.

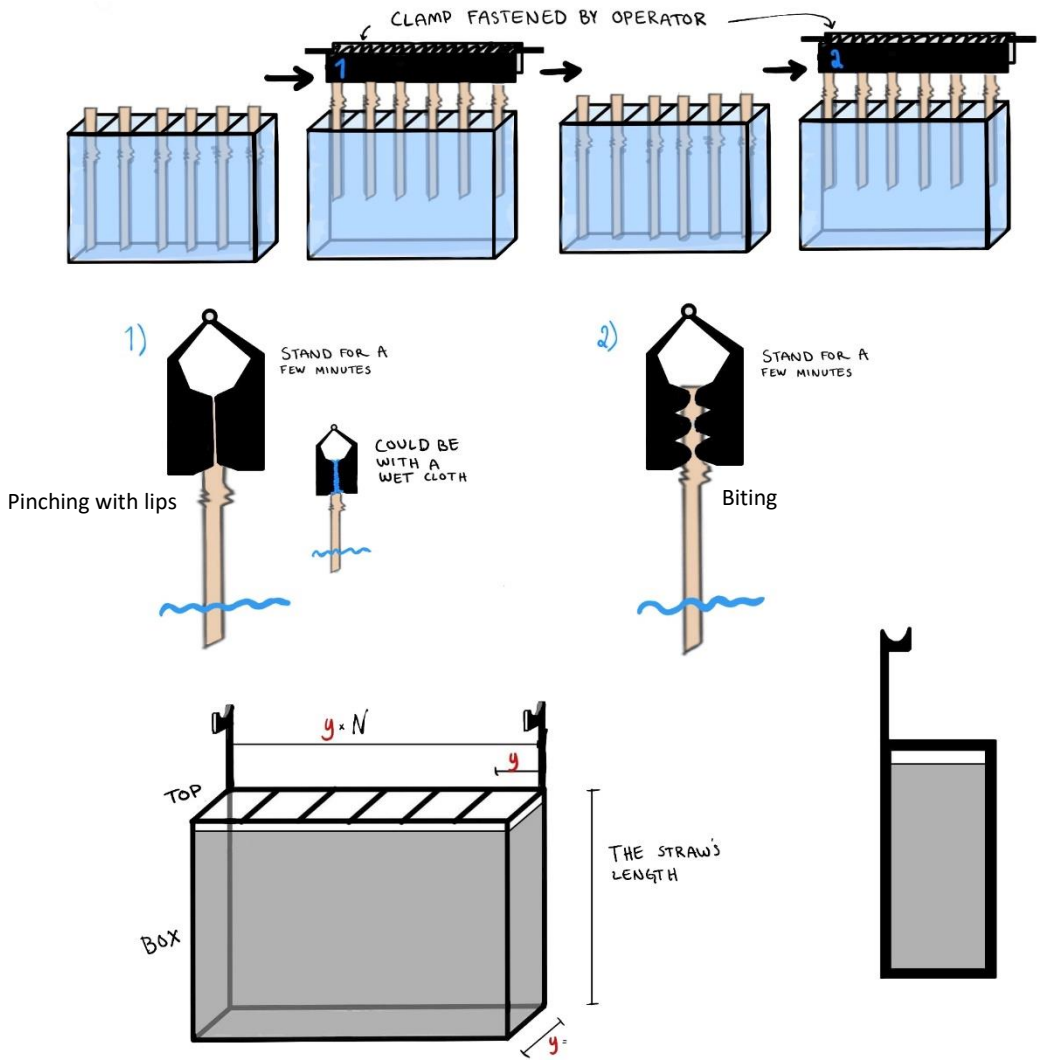

Figure 7-8. Early sketches of concept 10.

7.3 Established Concepts

It was discovered that the selected concepts from the concept screening phase could be divided into categories depending on which kind of stresses they caused on the straws and when the stresses most frequently occurred. This division aimed to ease the continued development process by allowing focus on one category of stresses at

a time. Some problem with combining the friction action with the other actions in an efficient and realistic way had been experienced and the action was therefore separated to its own category. This resulted in the categories playing, drinking, and friction, see Table 7-2 below. In addition to this separation, the concepts were also renamed to ease the understanding.

Table 7-2. Established categories with different actions and concepts that fit into the categories.

Categories	***Activities***	***Old Concept Names***	***New Concept Names***
Playing	Bending Bending of corrugation Pinching Pulling & pushing	Concept 2	P1
		Concept 6	P2
			P3*
Drinking	Exposure to liquid Biting Pinching with lips	Concept 8	D1
		Concept 10	D2
Friction	Inserting straw through PPH multiple times		F1 F2

(*) There were multiple ideas about concept 6 and it was decided to divide it into two for further development, these are concept P2 and P3.

Below follows figures and detailed descriptions of the different concepts. All concepts were to be designed to be applicable for the whole span of straw sizes currently used at Tetra Pak and for ten straws at a time.

7.3.1 **Playing**

The following concepts focus on bending, bending of corrugation, pinching, and pulling and pushing of the straw. They are all dependent of an external force, this force will most likely be applied through the use of some kind of universal tester, like an Instron, Zwick or similar, and will from here on be referred to as *The Universal Tester*. All three concepts use tools for “fingers” and these fingers should be designed to resemble actual children fingers.

7.3.1.1 Concept P1

The top part is attached to a machine that can apply a controlled force and a vertical moving motion, *The Universal Tester,* and the bottom part is a sled connected to the

upper part by a string that goes through a wheel. The straws are fixed in a portable straw holder, and when the top goes down and meets the bottom part the straws are pinched between the imitated fingers. Once this has happened the top moves up with the help of the machine, making the string pull the sled to the right which changes the position of the lower fingers. The top part then moves down, and the straws are bent against the bottom part instead of being pinched, Figure 7-9 demonstrates this action.

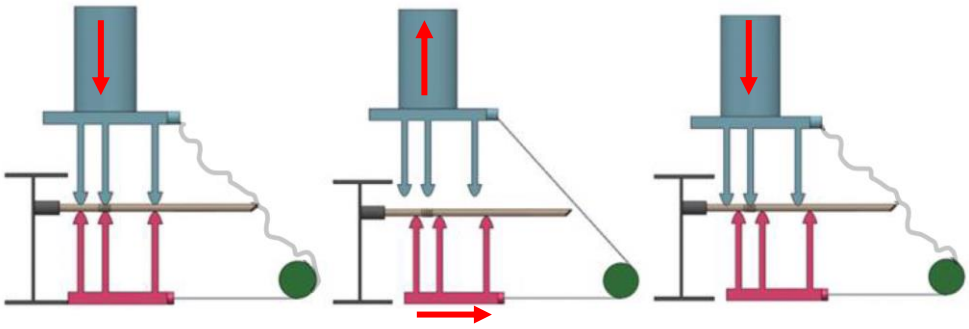

Figure 7-9. Side view of concept P1, shows the different positions of the parts.

To complete the pulling and pushing exposure the straws are rotated 90 degrees and the top part, that is connected to the machine, is replaced with a new part that holds the straws in place. The machine then goes up and down to replicate the push and pull motion, see Figure 7-10.

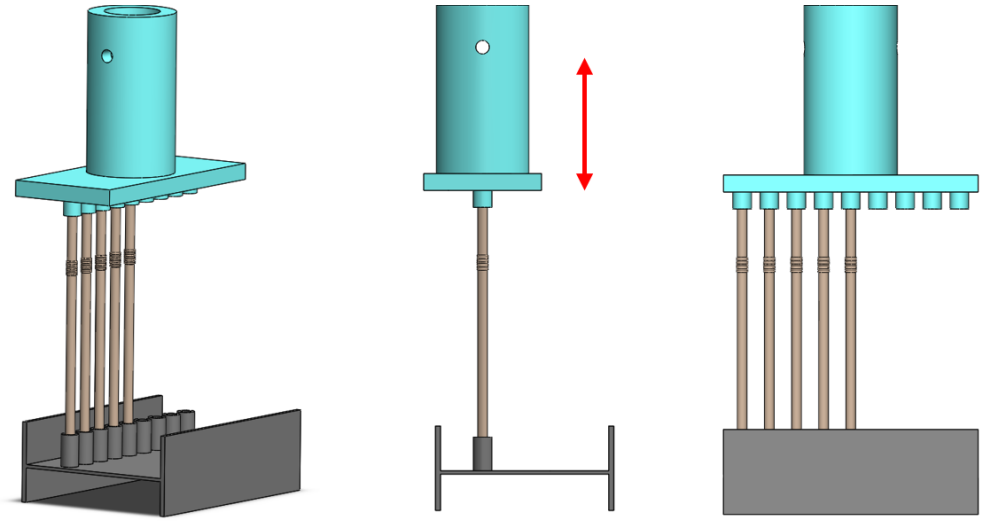

Figure 7-10. Concept P1, set up for performing pushing and pulling motion.

7.3.1.2 Concept P2

The top part is connected to *The Universal Tester* and the straws are pinched in a straw holder to keep in place. The machine goes down and presses on the clamps, causing them to open. The machine releases and the clamps shut, causing the straws to bend. The machine opens the clamps again and the clamps are moved outwards by the operator rotating the wheels placed on the bottom part. The machine then releases and the clamps pinch on the straws on a different position. The bottom part of the clamp is switchable so that different actions can be performed. The green part, A, can perform a more aggressive bending action than the pink part, B, and the blue parts can create a pinching and a pushing & pulling action. By fixating the clamp in a certain position so that a small force is applied upon the straws, a friction motion can be created by moving the clamp side to side. See Figure 7-11 for concept with different parts and actions performed.

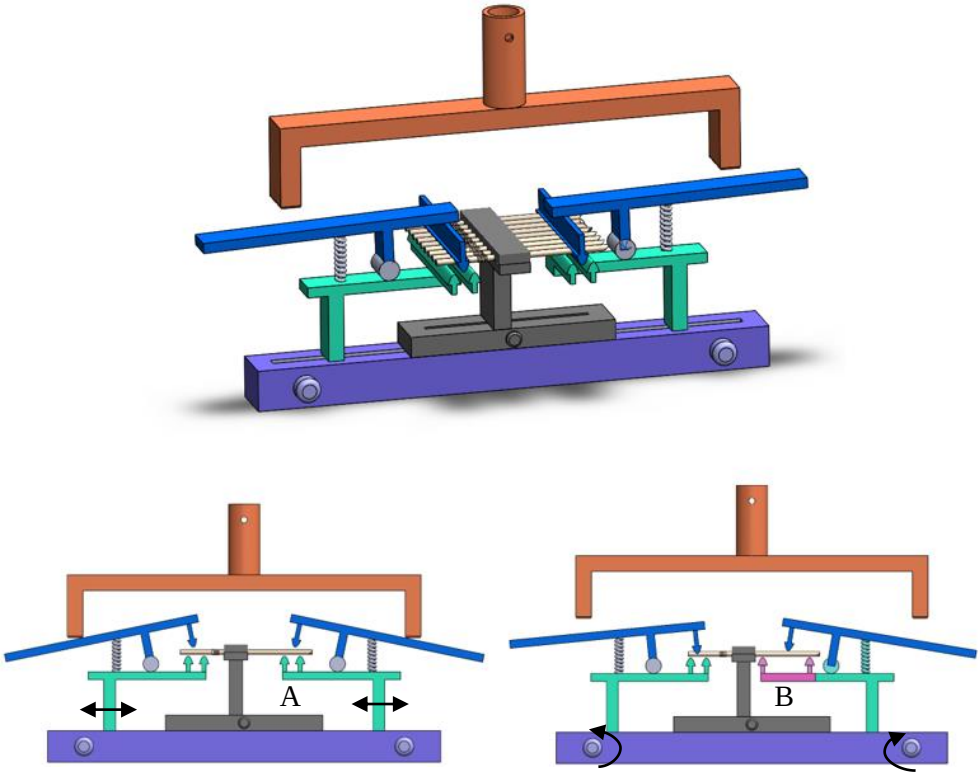

Figure 7-11 Concept P2 in open and closed position. The bottom part of the clamp has different add-ons to perform different tests, marked A and B.

7.3.1.3 Concept P3

Concept P3 has a top part that is connected to *The Universal Tester*. The straws are fixed in a straw holder that can be moved horizontally by rotating the wheel on the bottom part. The top part moves down, and the straws are bent by the pink arms

pushing on them. The pink arms can be moved sideways to hit the straws on different positions. To perform bending of corrugation and three-point bending, the blue parts can be moved on the bottom part. These can also be mounted next to each other so that a friction test can be performed by having the pink arms move back and forth to rub the straws. Figure 7-12 shows concept P3 in different positions.

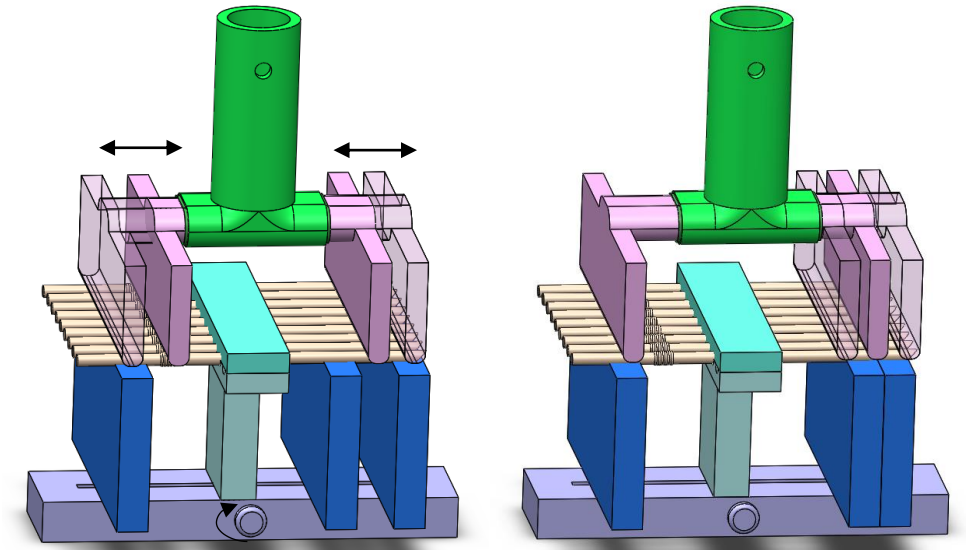

Figure 7-12 Concept P3 in different positions with slidable parts.

7.3.2 **Drinking, Biting, and Pinching with Lips**

The following two concepts focus on the drinking, biting, and pinching with lips actions. The stresses from biting and pinching with lips are centered to the short leg of the straw since this is where the actions occur most frequently. Both concepts use clamps that are applied to the straws manually by the operator.

7.3.2.1 Concept D1

This concept has two exchangeable clamps, each performing either the biting action or the pinching with lips action. Figure 7-13 shows the clamp in both open and closed position, with straws and liquid container. The long legs are inserted into the container, which is filled with liquid, and the clamps are attached to the short leg successively.

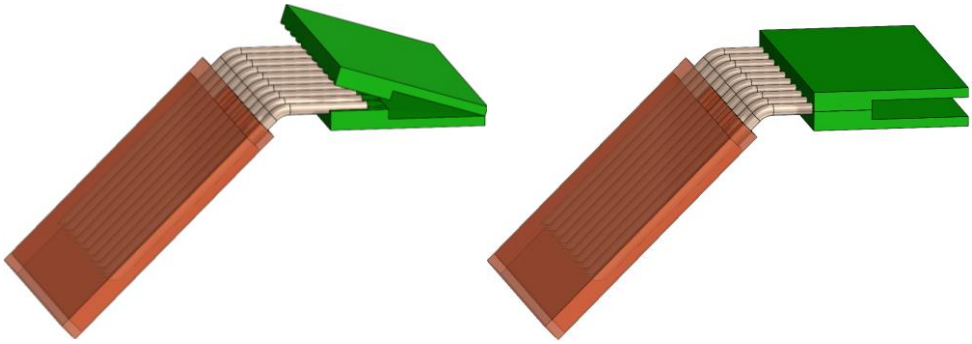

Figure 7-13. Concept D1 in open and closed position with straws.

Figure 7-14 shows one side of the two clamps. The pinching clamp will be connected to a pump that can transport liquid through the straws, this is to mimic the actual drinking. Figure 7-15 shows a close-up on the teeth used during biting, the dimensions of the teeth are according to a standard for safety constrains regarding children's toys [19].

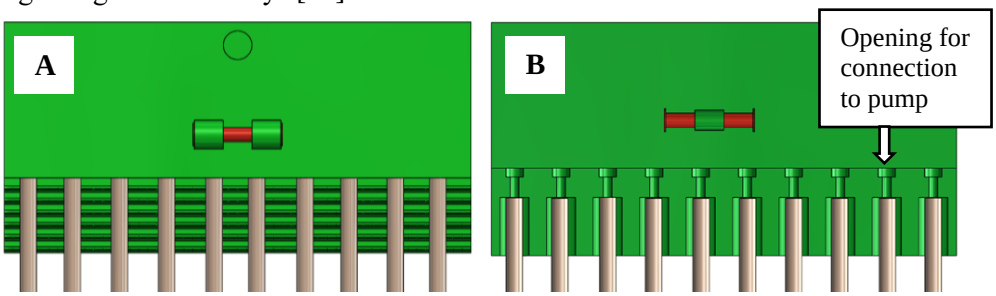

Figure 7-14. A - Biting clamp, and B – Pinching clamp for concept D1 with eight straws in place.

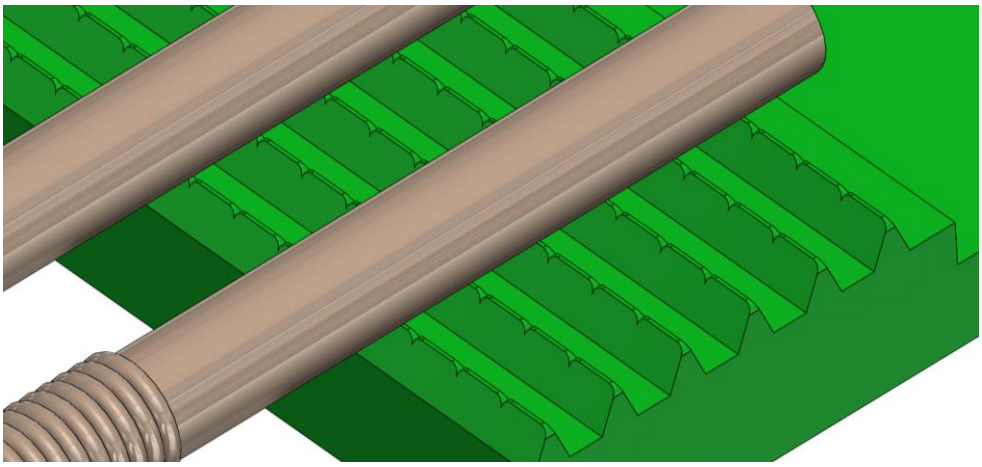

Figure 7-15. Close-up on teeth for concept D1.

7.3.2.2 Concept D2

Just as concept D1, concept D2 has two exchangeable clamps. The biting clamp is identical to the biting clamp used for concept D1, but the pinching clamp is slightly modified since no pump will be connected to the clamp, see Figure 7-16 for the difference of the pinching clamps.

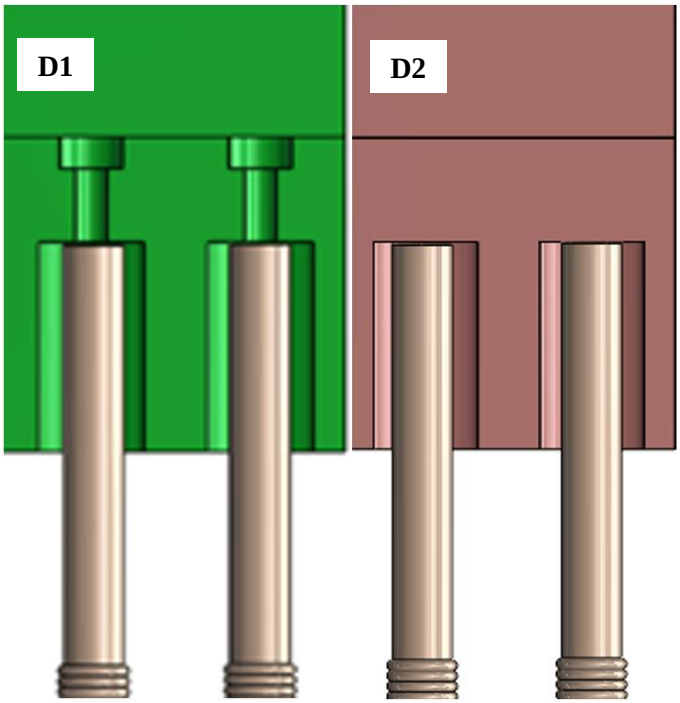

Figure 7-16. Close-up of the pinching clamps for concept D1 and D2.

Within this concept, the straws are fully inserted to a container with liquid, a clamp is attached to the short leg and the straw is then halfway removed from the liquid. This motion will allow liquid to fill the whole inside of the straw and keep it there by closing one end and thus causing a negative pressure. Figure 7-17 shows the three steps of concept D2; straw fully inserted to liquid, attach clamp, and removal of short leg from liquid.

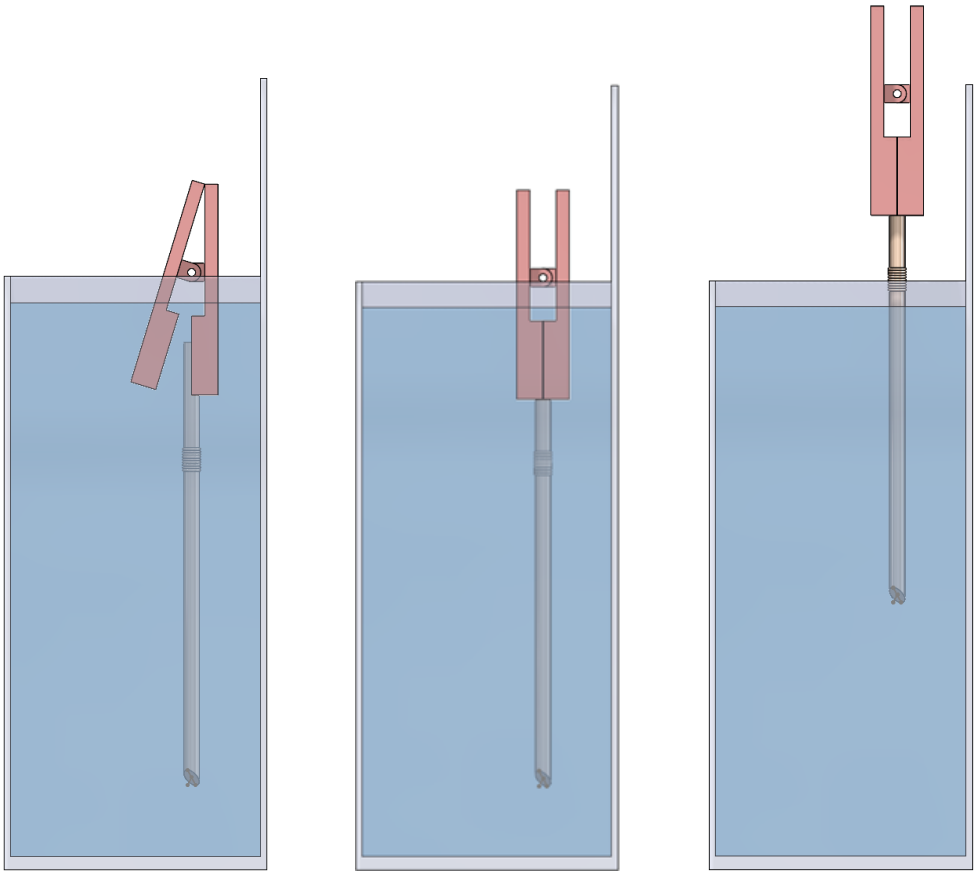

Figure 7-17. The three steps of concept D2; straw fully inserted to liquid, attach clamp, and removal of short leg from liquid.

7.3.3 **Friction**

Since there had been some problems to combine the friction stress with the other stresses in a concept, they decided to develop two concepts that only focus on friction, these two are called F1 and F2.

7.3.3.1 Concept F1

This concept is designed to act as a pendulum and uses gravity to cause friction and is based on an already existing product for friction testing [20]. The straws are placed on its designated place and the pendulum is released from its holder, falls towards the straws, and causes friction when in contact with the straws. The tip of the pendulum should be in a material that provides the same friction as the PPH would. The pendulum holder can be moved to be able to cause friction on different sized straws. Figure 7-18 shows concept F1 in action with two different straw sizes.

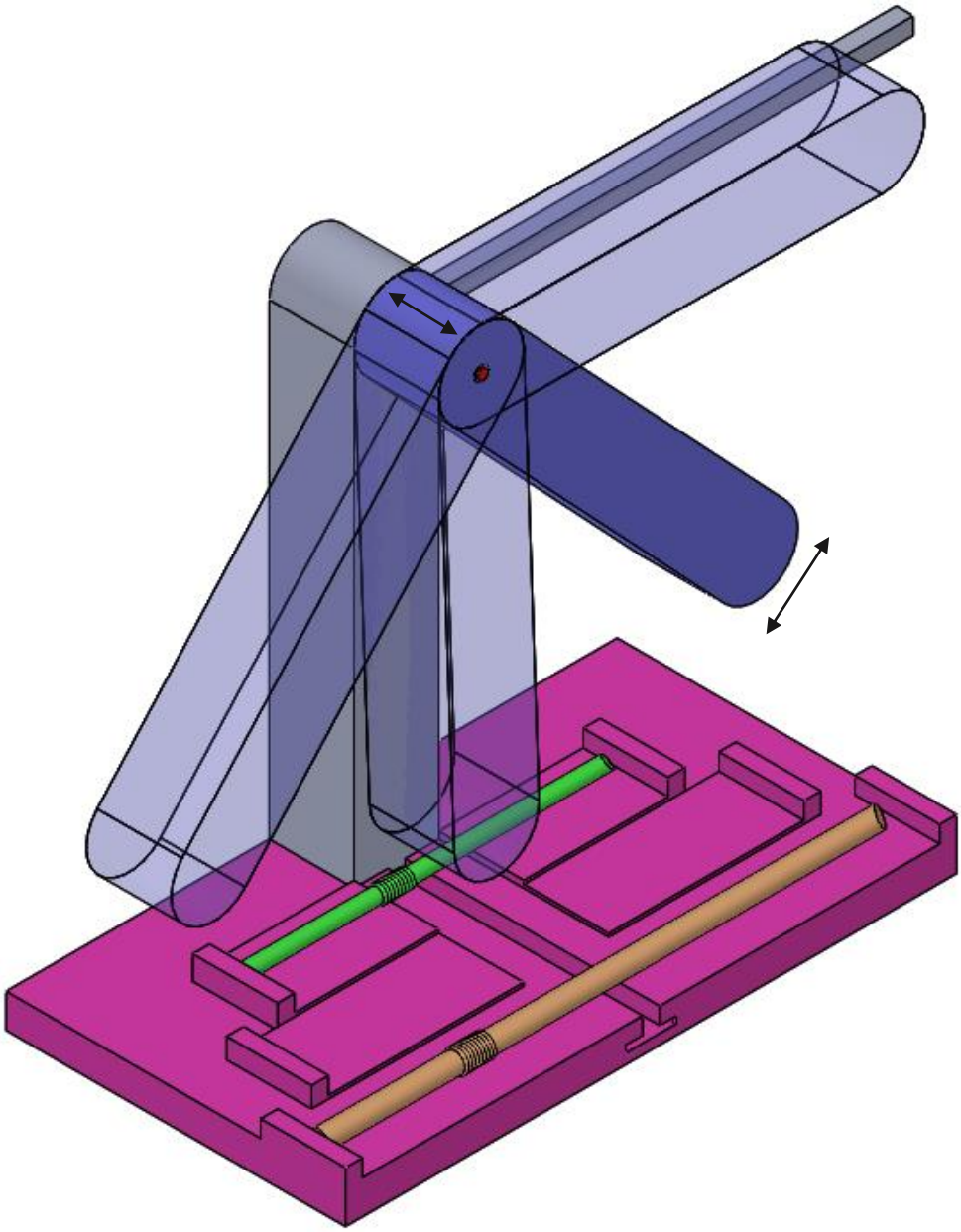

Figure 7-18. Concept F1 with pendulum in action.

7.3.3.2 Concept F2

This is a simple but effective concept; the straws are put on a plate and a "friction comb" is moved across the straws to cause friction. It is possible to cause friction on a small part of the straw or on the whole straw. Figure 7-19 shows the concept.

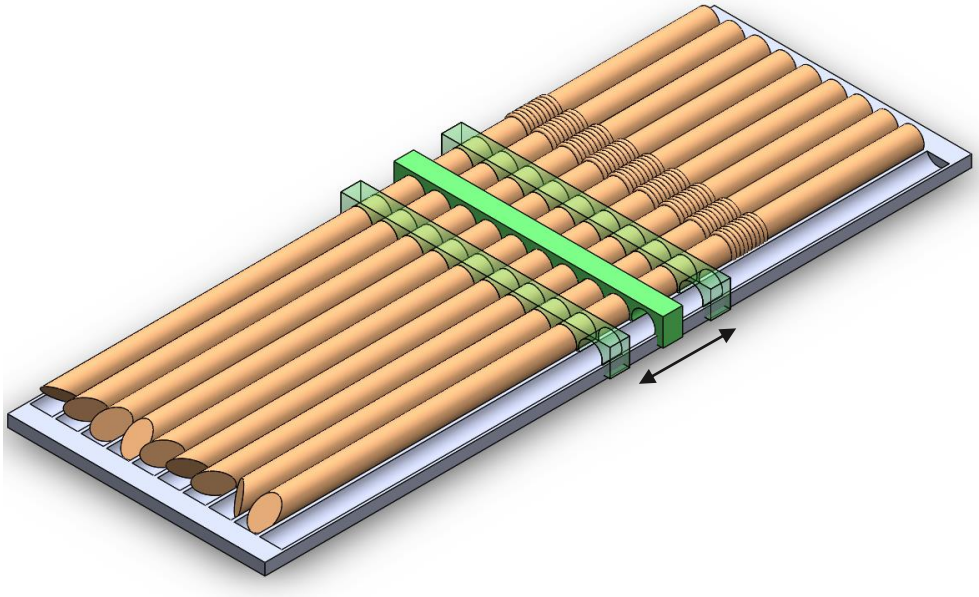

Figure 7-19. Concept F2 with slidable friction comb.

7.3.4 **Evaluation of Concepts**

To be able to fully evaluate the level of resemblance to reality between the different concepts, three smaller evaluation studies were conducted, one for each concept category. These studies were conducted on paper straws and due to immaterial rights and since the straws were not yet on the market at the publishing time of this report, the pictures and the results have been censored.

7.3.4.1 Evaluation of Playing Concepts

Simple prototypes were manufactured to evaluate how well the three playing concepts would be able to mimic the impacts from the actual playing that was done during the user study.

The straws were exposed to a drinking action prior to the test, this was because most of the children from the user study played after drinking. The straws were put in a glass of water and a team member took approximately 10 sips from it. One concept was tested at a time and the impacts on each straw was evaluated after each test. Table 7-3 shows the different actions performed during the test.

Table 7-3. Different actions to mimic playing.

Evaluated Concept	***Action Description***
Concept P1	A thread is pulling a sled to change its position. The first position exposes the straw to pinching on three points, the second position exposes the straw to bending of both the straw and the corrugation. See Figure 7-20.
Concept P2	The straw is put between two plates with pins to replicate fingers. The pins expose the straw to two kinds of bending, one with the pins close together for an extremer bending and one with the pins further apart for a gentler bending. See Figure 7-21.
Concept P3	Same set-up as for Concept P2 but with the addition of a friction function where the straw is held still between two pins and a plate with a rough surface is dragged along the long leg. *Since the main difference between this test and the test of Concept P2 is the friction function and since different friction concepts are evaluated in 7.3.4.3, pictures of Concept P3 is moved to that subchapter.*

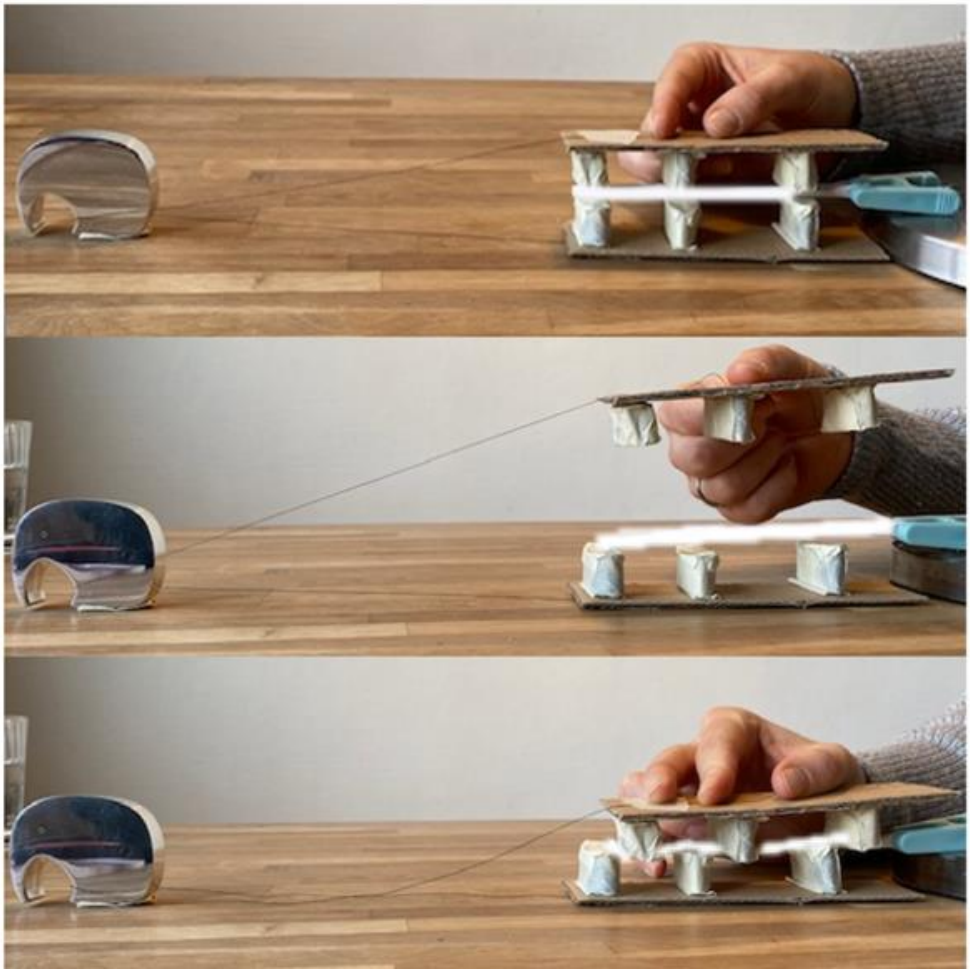

Figure 7-20. Step one, two and three for testing of concept P1.

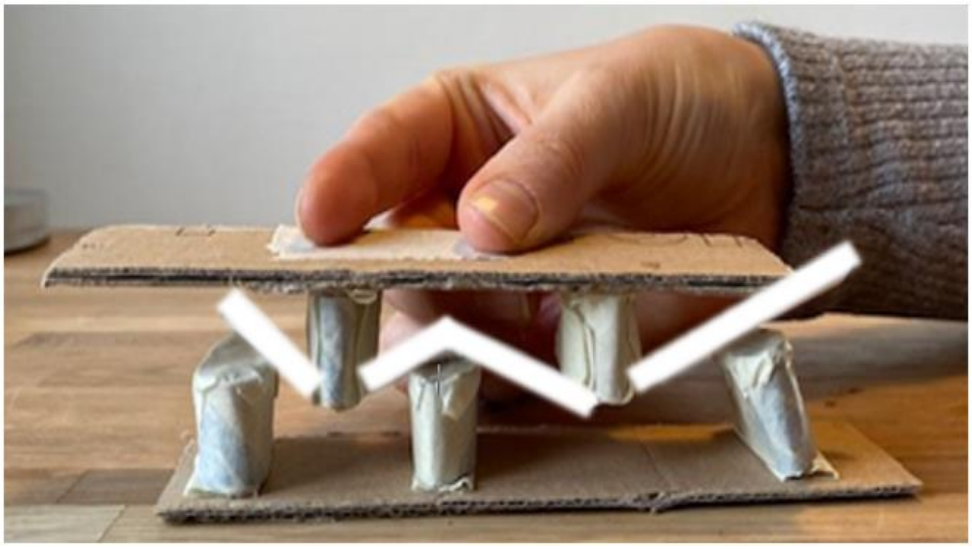

Figure 7-21. Testing of concept P2, bending of straw.

The impacts caused by the different concepts were compared to the impacts observed during the user study. All three concepts had promising impacts that resembled the impacts caused by children playing.

The result from the test were fortunate and by further developing the shape and size of the pins used to cause impacts, it is most likely that the impacts can be made even more alike the actual impacts.

7.3.4.2 Evaluation of Drinking Concepts

Within this study the drinking action was mimicked in three different ways and compared to an actual drinking action. See Table 7-4 for description of the different actions.

Table 7-4. Different actions to mimic drinking

Evaluated Concept/Action	***Action Description***
Reference Straw 1: *Actual drinking, to be used as a reference*	Long leg in water, one team member takes two sips (approximately 15 ml) of water once every minute during the first 15 minutes.
Test Straw 2: *Straw fully covered with water*	The current method to expose straws to liquid during tests at Tetra Pak. The whole straw is placed in a glass with water.
Test Straw 3: *Test of concept D2*	The straw is first fully inserted into the water to allow the whole inside to be in contact with water. A clamp with a damp cloth is then applied to the short end to "close" the straw and the straw is then removed halfway from the water; this allows the whole inside of the straw to still be in contact with water and the outside of the long leg.
Test Straw 4: *Test of concept D1*	The straws' long leg is in water, a damp cloth and funnel are connected to the short leg. 15 ml of water is poured into the funnel, and thus into the straw, once every minute during the first 15 minutes.

The straws were evaluated after 5 minutes, 15 minutes, 1 hour and 2 hours through a compression test and a bending test. The compression test was conducted on three different positions on the straws and the bending test was conducted at one position, see Figure 7-22 for the different positions. Figure 7-23 shows the procedure for the bending test. Each position was compressed or bended twice per time period, the perceived force needed to fully compress and bend the test straws were evaluated and this force was compared to the reference straw. See Appendix H for a more precise description of the test procedure.

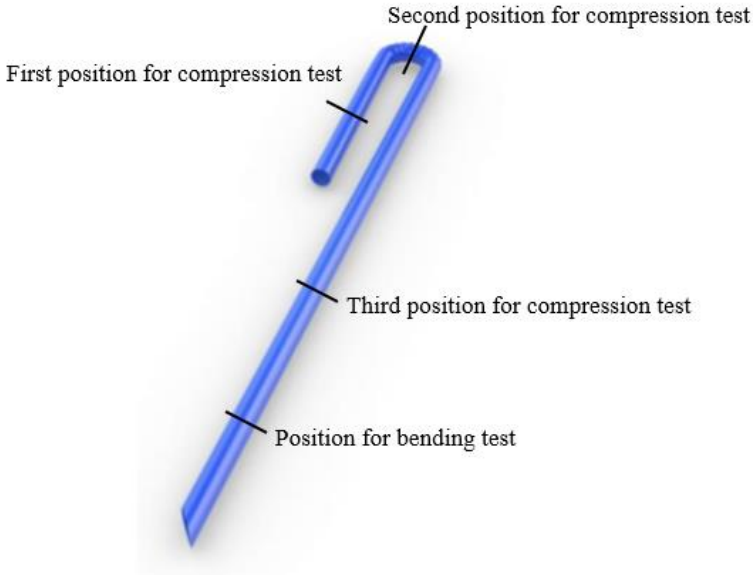

Figure 7-22. Positions for tests.

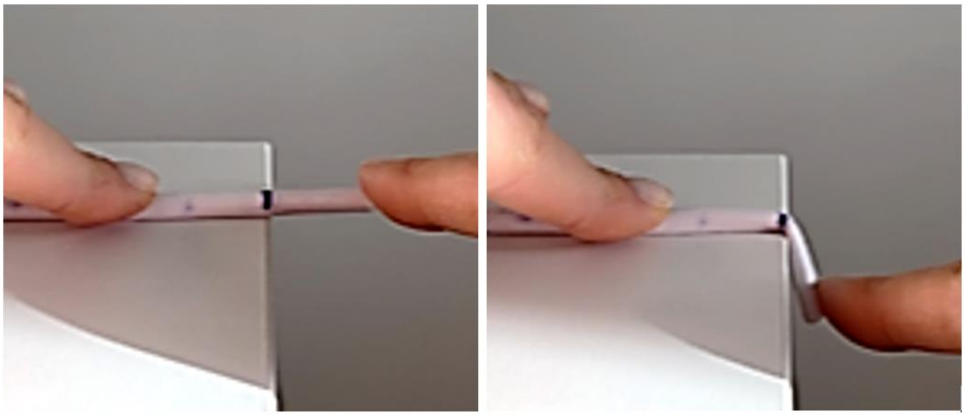

Figure 7-23. Procedure for bending test.

The test resulted in a deeper understanding of the different drinking concepts; the results have been censored from this report, but the main findings can be seen in Table 7-5.

Table 7-5. Main findings of testing the three different drinking concepts

Main findings of testing drinking concepts
All four concepts were rated the same for “compression on long leg” and “bending”.
The original method affects the straws more than actual drinking and has thus a low level of resemblance to reality. Short leg and corrugation are exposed to too much water.
Concept D1 has a medium level of resemblance to reality; however, this can probably be corrected by using a less wet cloth since the cloth used in this test exposed short leg to a lot of water. This concept is similar to reality since water is poured through the straw.
Concept D2 has a high level of resemblance to reality. The clamp did however cause big impact on the straw, which can be beneficial if the clamp is designed in such a way that the impact resembles the biting action.

As described above, both concept D1 and D2 had promising results and should be continued with. The original method where the straws are inserted fully into water is not recommended since it has a low level of resemblance to reality.

7.3.4.3 Evaluation of Friction Concepts

The aim with this study was to evaluate the two different friction concepts and the friction function in Concept P3. Just as in the evaluation of playing concepts and for the same reason, the straws used in this test were exposed to a drinking action prior to the test. Table 7-6 states the different actions used within this test.

Table 7-6. Different actions to produce friction.

Evaluated Concept	***Action Description***
Concept F1	Since the idea of this concept arose in an existing instrument for friction testing [20], this concept is only tested through the manufacturing of a simple prototype to evaluate how easy it would be to build a friction pendulum. See Figure 7-24.
Concept F2	A straw was attached to a plate and exposed to another plate with a rough surface which was dragged back and forth along the straw. See Figure 7-25 for friction tool.
Friction Function of Concept P3	The straw is held still between two pins and a plate with a rough surface is dragged along the long leg.

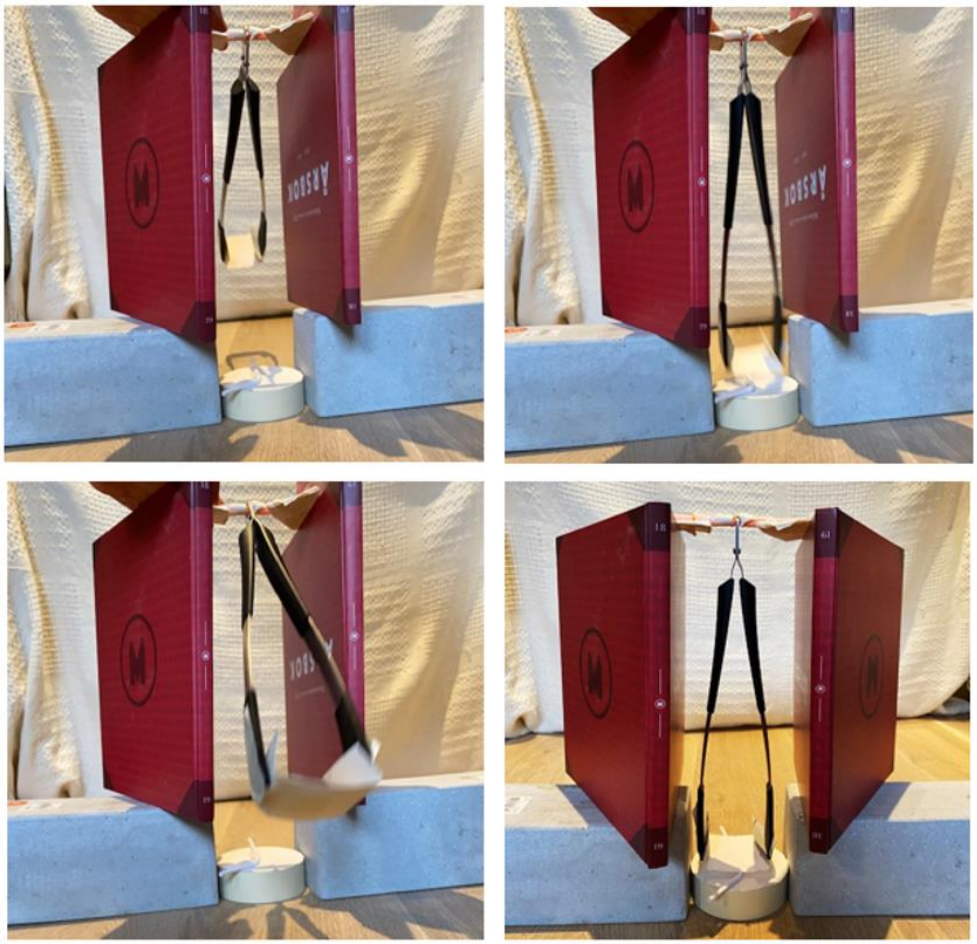

Figure 7-24. Prototype of concept F1.

Figure 7-25. Prototype of concept F2.

The team members had no problem testing the concepts and were confident that it would be feasible to manufacture a concept that would expose straws to friction and that the level of friction would be easy to alternate.

7.3.4.4 Reflection

The results of the three evaluations confirm that the full scope is covered, and enough concepts had been developed for the project to be fortunate. All three concept categories produced realistic stresses on the straws and it was believed that they could be further developed in such a way that the outcome would look like the damages produced by the children.

7.4 First Concept Selection

Once the concepts had been evaluated the next step was to select which concepts to further develop and which to leave behind. The selection was based on a concept scoring and a discussion with Tetra Pak.

7.4.1 **Concept Scoring Made by Team Members**

To ease the first concept selection and to decide which concepts to develop further, a concept scoring was performed. This concept scoring was based on the concept selection method Ulrich & Eppinger suggest in *Product Design and Development* [5]. The concepts were scored against different concept properties that were weighted differently, depending on their importance. The properties and their weight numbers were decided, where the properties with high importance received a high number, while the ones with lower importance received a low number. For example, “ease of use” of the concept was considered to be more important than the automation level of it, why “ease of use” received 17.5 and “level of automation” 7.5. The total weight scores of all concept properties sum up to 100.

The concepts were rated on a scale from 1 to 5 points depending on how well they fulfilled the different concept properties, where 5 declares that the concept fulfills the property very well and 1 that the concept does not fulfill the property at all. This applied to all the concept properties except “action performed” where a rating of 1 to 7 was used instead since there were 7 actions in total. A concept received 1 point for each action it could perform, the actions being bending, biting, bending of corrugation, friction, drinking, pinching, and pulling & pushing. For example, concept D1 can perform biting, pinching, and drinking, why it received 3 points.

Each concept then received a weighted score for each property that was calculated by multiplying the weight of the property with the rating of the concept. The total score for each concept was summed and the concept with the highest score within each category (*playing, drinking, and friction*) were the ones suggested to continue on with. The concept scoring matrix can be seen in Table 7-7.

Table 7-7. Concept Scoring 1.

Concepts		**Playing**						**Drinking**				**Friction**			
		P1		**P2**		**P3**		**D1**		**D2**		**F1**		**F2**	
Concept Property	***Weight***	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Operator Dependency	**25**														
- Level of Automation	7.5	4	30	3	22.5	4	30	4	30	3	22.5	2	15	4	30
- Ease of Use	17.5	4	70	2	35	4	70	4	70	3	52.5	4	70	5	87.5
Level of Similarity to reality*	**30**	3	90	3	90	3	90	5	150	4	120	4	120	4	120
Ease of Manufacturing for team	**25**														
- No Need of Coding (cost)	10	5	50	5	50	3	30	5	50	5	50	5	50	5	50
- Complex Mechanics	10	4	40	3	30	2	20	4	40	4	40	5	50	4	40
- Number of Parts	5	4	20	2	10	2	10	3	15	4	20	5	25	4	20
Actions Performed (Biting, drinking, friction, bending of corrugation, pinching, pulling & pushing, and bending)	**20**	4	80	5	100	4	80	3	60	3	60	1	20	1	20
Total Score	100	**380**		337.5		330		**388**		365		350		**367.5**	
Develop	N/A	**Yes**		No		No		**Yes**		No		No		**Yes**	

(*) The scoring of level of similarity to reality was based on the results from the performed concept tests, see subchapter 7.3.4.

The concepts and the scoring matrix were later presented to the supervisors at Tetra Pak for the final decision to be made.

7.4.2 **Concept Discussion with Tetra Pak**

The seven different concepts were presented to the supervisors at Tetra Pak and the pros and cons, based on the concept scoring, with each concept were discussed. Guidance and feedback were received and resulted in development of a new concept and an adjustment to an existing concept.

It was decided to discontinue with the pulling and pushing action since it does not affect the plastic straws in a large extent and since it probably will not be possible to do with paper as a material since it is not as elastic and flexible as polymers. Deselecting the possibility to mimic this type of playing also made it possible to focus on other more relevant load cases.

It was established that drinking concept D1 was the one to go forward with and that concept F2 was the best alternative for the friction test. However, Tetra Pak wished for a more flexible version of Concept P1, which lead to an updated version of the concept where the "fingers" can be moved, see Figure 7-26, and suggested that Concept P3 was not in need of programming and the level of automation that had been predicted. This resulted in a new concept scoring for the category *playing*, see Table 7-8.

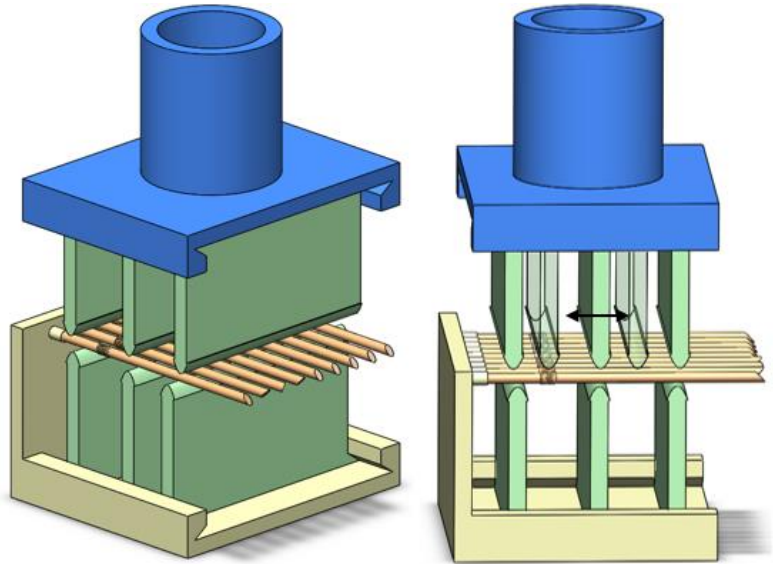

Figure 7-26. Updated version of Concept P1 in different positions.

To show the differences between the updated and original version, the original version of concept P1 can be seen in Figure 7-27. The main idea is still the same, but some small modifications have been done.

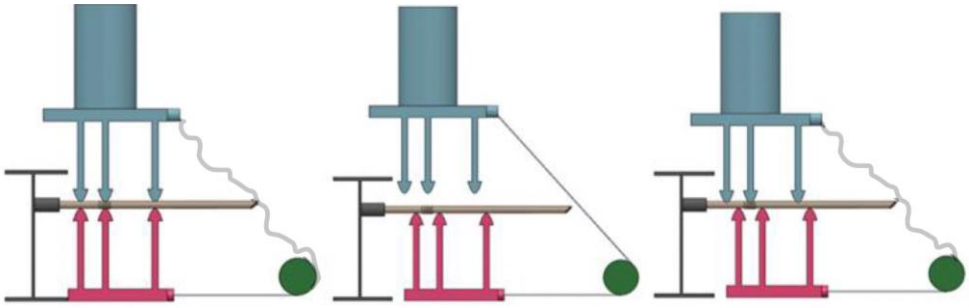

Figure 7-27. Original version of Concept P1.

Table 7-8. Concept Scoring 2. New scoring with updated version of P1 and adjusted P3. The ratings that have changed for P3 are underlined.

Concepts		**Playing**							
		P1		**Updated P1**		**P2**		**P3**	
Concept Property	***Weight***	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Operator Dependency	**25**								
- Level of Automation	7.5	4	30	3	22.5	3	22.5	3	22.5
- Ease of Use	17.5	4	70	3	52.5	2	35	3	52.5
Level of Similarity to reality	**30**	3	90	4	120	3	90	4	120
Ease of Manufacturing for team	**25**								
- No Need of Coding (cost)	10	5	50	5	50	5	50	5	50
- Complex Mechanics	10	4	40	5	50	3	30	3	30
- Number of Parts	5	4	20	4	20	2	10	2	10
Actions Performed	**20**	3	60	3	60	4	80	4	80
Total Score	100	360		**375**		317.5		365	
Develop	N/A	No		**Yes**		No		No	

It was decided unitedly together with Tetra Pak that the updated version of concept P1 was the one to further develop in the *playing* category, and D1 in the *drinking*

category. Additionally, during the discussion with Tetra Pak, it was discovered that concept F2 could be merged with the updated version of concept P1, see Figure 7-28 in subchapter 7.5.

7.5 Further Development of Concepts

The subchapters below describe the further development of the concepts that were done. One concept category at a time was initially focused on and planned to later evaluate how well they worked together in the full test procedure. It was decided to start with the drinking concept since it was categorized as intended use and therefore the most important one. The plan was to have multiple smaller iterations and two larger iterations with tests within each category, however, after the first large iteration of the drinking concept they decided to merge the three concepts into one universal concept. The concept development process can therefore be divided into two phases, one before and one after the merge of concepts.

During the second phase of the development process, more detailed prototypes of the concepts was designed, and additive manufacturing was used to build them. The prototypes were then evaluated on if the impact they had on plastic straws were alike the impacts caused by the preschool children. This was an iterative process where the evaluated concepts were further developed multiple times to extend the level of resemblance to reality. Figure 7-28 shows a description of how the concept categories were merged with each other and their loops.

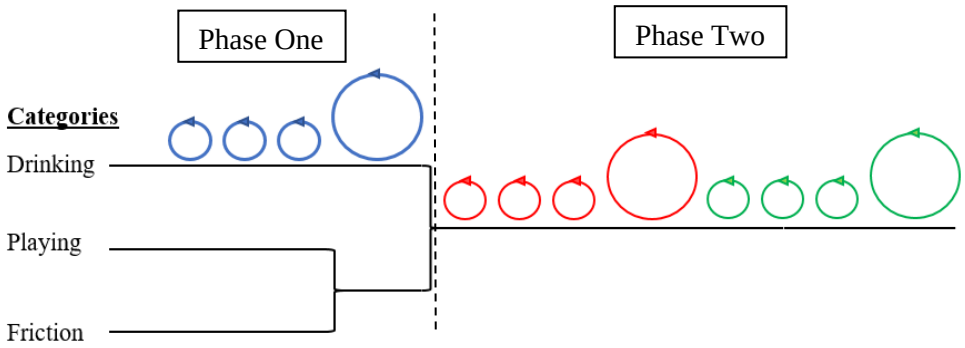

Figure 7-28. How and when the concept categories merged and their loops, the loops are represented by one color each.

This process concerns the development of a prototype, further development concerning the choice of material and manufacturing methods will be continued on by Tetra Pak.

7.5.1 **Phase One of Development Process**

The drinking concept consists of three parts: a pinching clamp, a biting clamp and a straw holder that connects the straws to a pump. One of these parts were focused on at a time but the remaining parts were kept in mind during each process to make their interaction with each other as good as possible. Figure 7-29 shows an overview of the drinking concept idea.

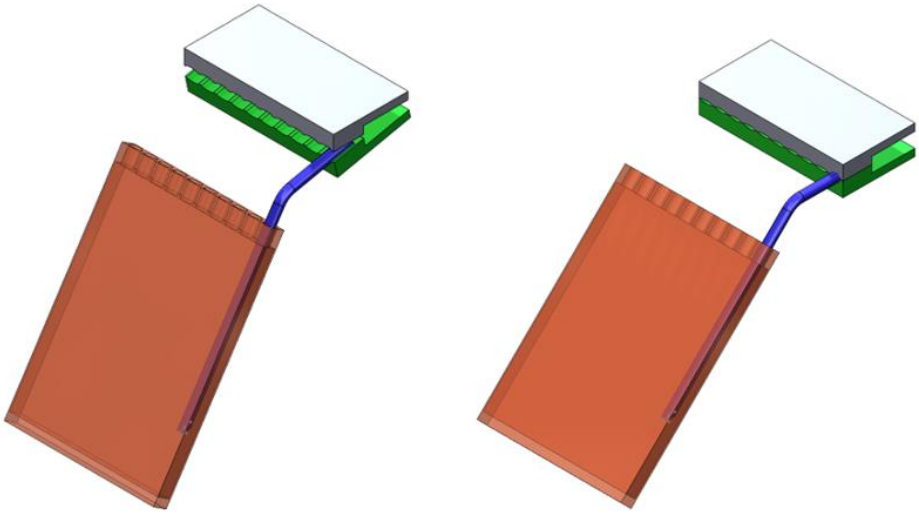

Figure 7-29. Overview of drinking concept idea.

A pump from Tetra Pak had been received and the first step was to get acquainted with the pump and to manufacture a setup that would allow the pump to transport liquid through straws. The pump was an Integra DOSE-IT P910 which is a peristaltic pump, Figure 7-30 shows the pump and its tubes.

Figure 7-30. Integra DOSE IT P910 pump.

To transport an equal amount of liquid through the straws, the distances between the straws and the pump had to be the same for all straws. A variety in distance would lead to a variety in air pressure in the straws and thus that different amount of liquid would be transported through the straws, depending on how close the straw is to the pump. To simplify this setup, it was decided to decrease the number of straws from 10 to 8. Figure 7-31 shows the connections between the eight tubes, one from each straw, to the joint tube that will be connected to the pump.

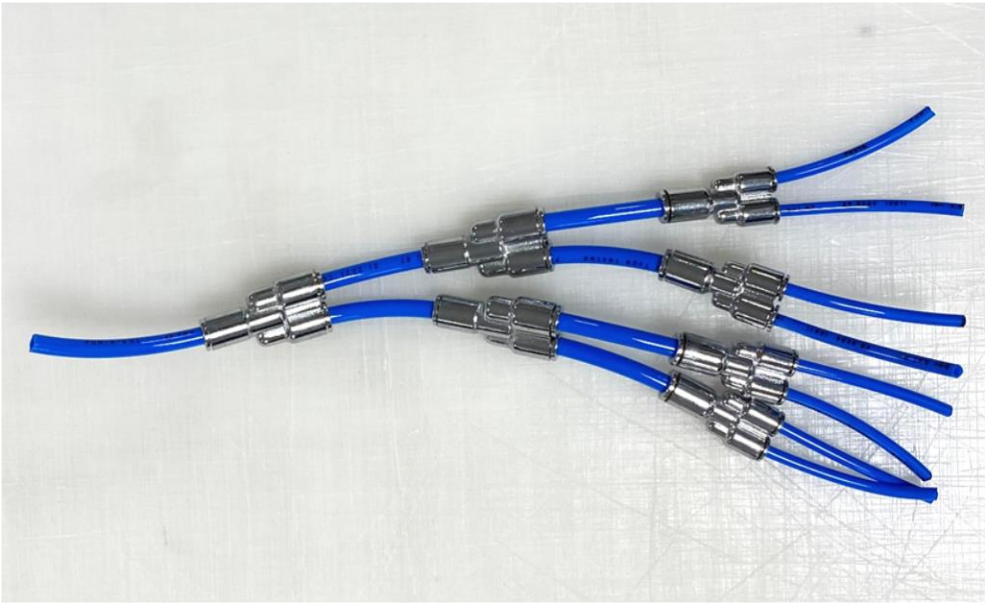

Figure 7-31. The connection set-up from eight tubes to one tube.

It was first thought to develop a stand that the straws would be inserted into during the drinking process but after evaluation and discussion it was decided to develop a universal holder that would hold the straws throughout the whole procedure. Figure 7-32 shows the two different versions.

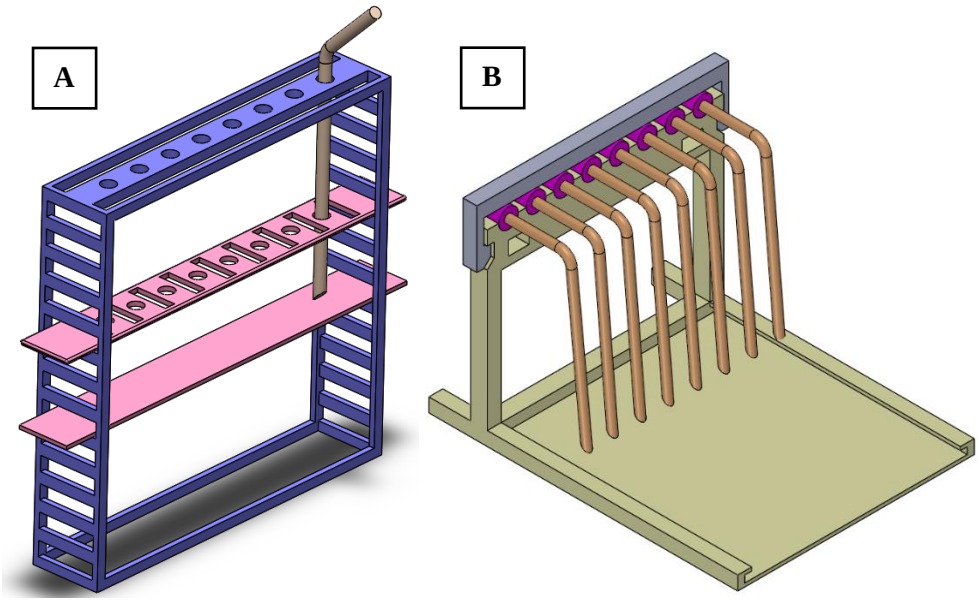

Figure 7-32. (A) Original stand for straws for drinking concept and (B) Universal holder with snap and straws attached.

The decision to change holder was based both on that it would ease the process for the operator since the straws would be fixed throughout the procedure and that it would provide stability for the straws. The universal holder is equipped with eight connectors that connect the straws to the tube, this connector is designed to fit multiple straw diameters and should be manufactured in an elastic polymer for it to be able to "grip" the straw. An extra pressure is applied to the connectors by a snap to increase the pressure, and thus the grip, on the straws. The connector is attached to the water tube on one side and to the straws' short leg on the other side, see Figure 7-33.

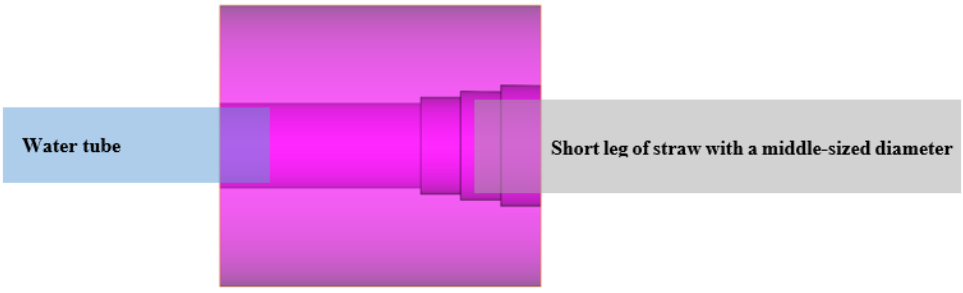

Figure 7-33. Connector between the tube and the straw.

Both the biting clamp and the pinching clamp were first designed to have the grip on the long edge but was then redesigned to have it on the short edge. This change was mainly based on the change of the straw holder, see above, making it impossible to keep the initial construction. The grip on both clamps was also elongated and rounded to make it more ergonomic. In addition to this, some smaller changes were done to the clamps. Figure 7-34 and Figure 7-35 show the first version of the clamps and Figure 7-37 and Figure 7-38 the updated clamps.

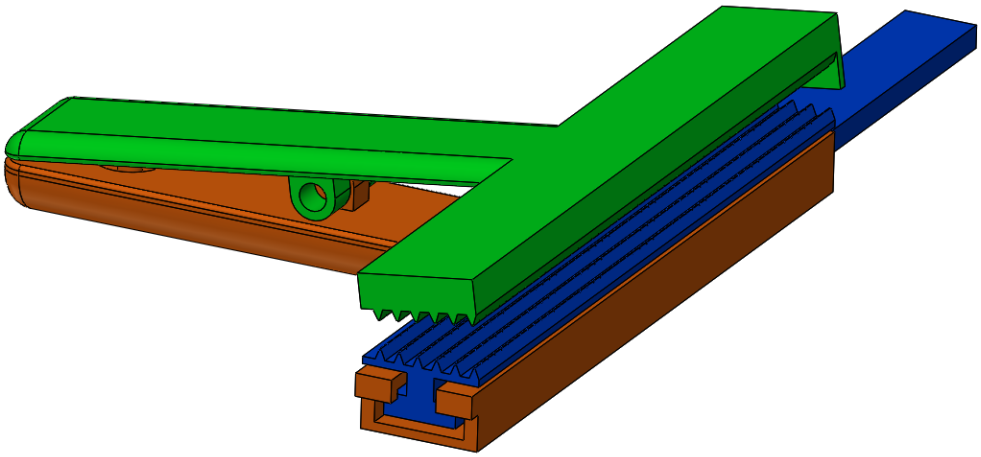

Figure 7-34. The original biting clamp with grip on the long edge and an extra part for grinding.

The biting clamp consist of three parts, one upper clamp with teeth, one lower clamp and one movable lower part with teeth. The movable part enables the clamp to produce a grinding motion between the teeth to increase the resemblance to reality.

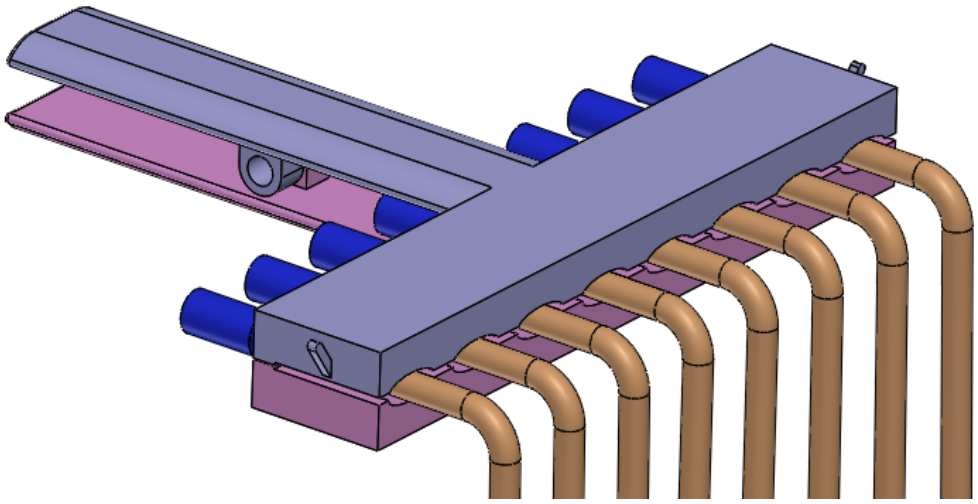

Figure 7-35. The original pinching clamp with grip on the long edge and blue tube connectors to connect to the pump.

The pinching clamp consist of one upper and one lower clamp part and eight tube connectors, these connectors are meant to connect the straws to a pump to be able to transport liquid through the straws. Figure 7-36 shows a close-up and section-view of this connection.

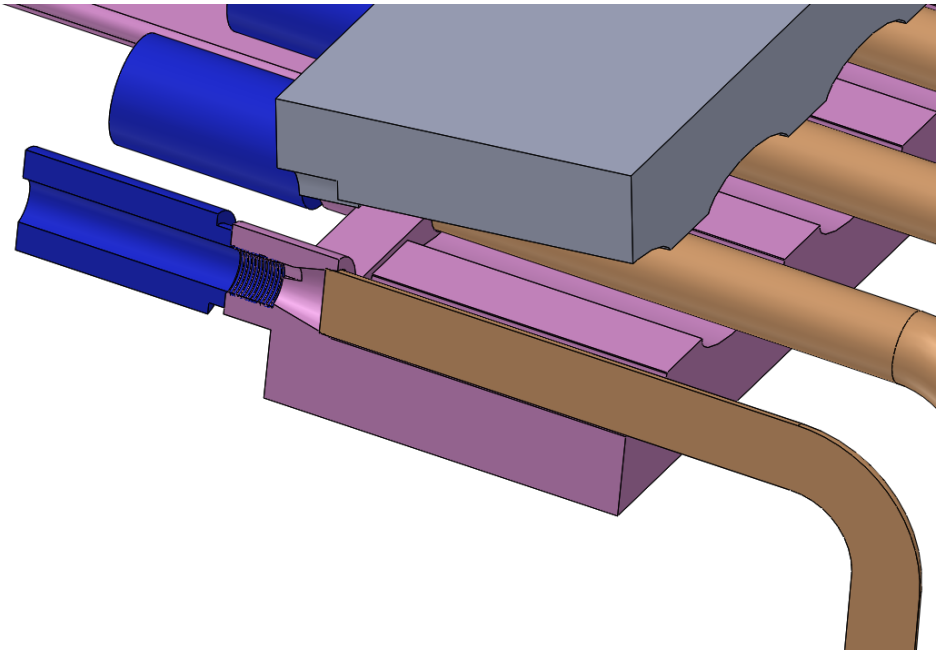

Figure 7-36. Close-up and section-view of connector and clamp with straw.

The updated biting clamp works in that way that the straws' short legs are placed between the teeth rows, this is to mimic the biting action, there is a spring located on the handle keeping the clamp closed. Once the straws have been in this position for a designated time, the upper teeth rows are moved side to side to produce a grinding motion. This motion is accomplished by the operator gripping the blue handle and moving it side to side. Since this teeth part is locked inside the upper part of the clamp, the distance it can move is fixed and the operator dependency minimized.

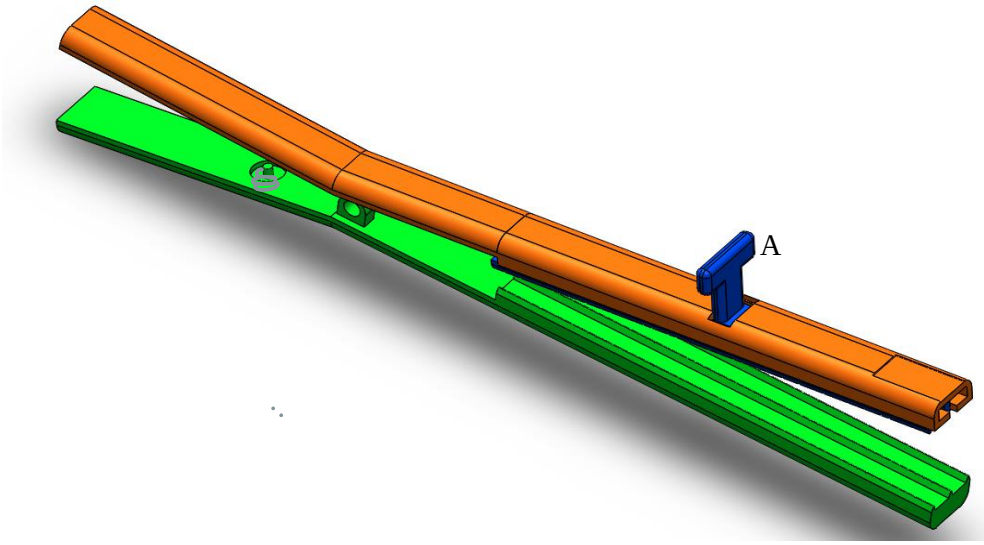

Figure 7-37. The updated biting clamp with handle (A) to be able to move the upper teeth rows to provide grinding motion.

The number of teeth rows have also been decreased to three since the initial number of rows did not provide enough impact on the straws. The force from the clamp will still be the same but the number of points on the straws are decreased and thus cause a bigger impact.

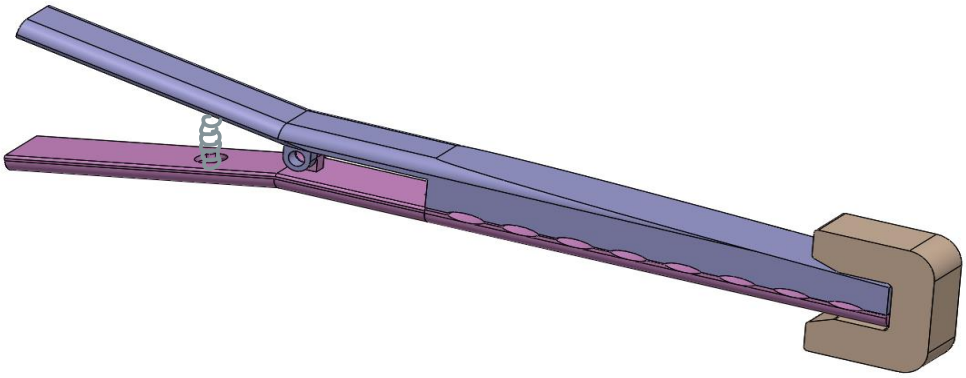

Figure 7-38. The updated pinching clamp with its additional closing clamp.

The pinching clamp has eight carved holes, one per straw that will be pinched. The formation has been constructed to fit different straw sizes but still give the same amount of pressure on the straws, causing them to form in the same way as when pinched with real lips. The pinching position is held in the same way as for the biting clamp, with a spring between the handles. The updated clamps were also provided with an extra closing clamp to keep it closed and to provide a consistent pressure over all eight straws.

7.5.1.1 Evaluation of Phase One

The tube setup, clamp prototypes and holder were tested on plastic straws through a full procedure and were later compared with the pictures of the stresses caused by the children at the preschools. Eight straws were attached to the eight tubes and through this to the pump and the long legs were inserted into a water container, see Figure 7-39.

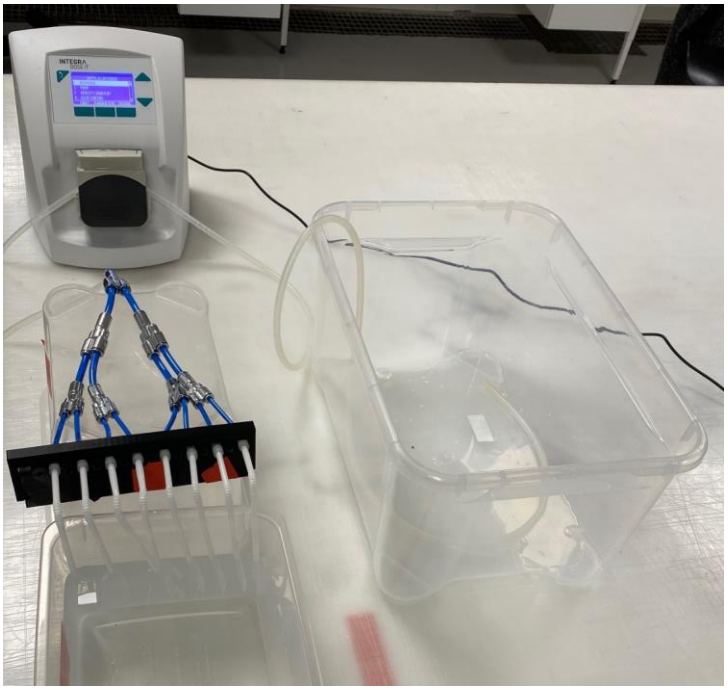

Figure 7-39. Test setup with pump.

The pump settings used during this test are stated in Table 7-9 below and are based on that it takes 15 minutes for children to finish a 200 ml package of still drink, that the duration of each sip is three seconds, and that each sip contains 8 ml of liquid. These values are approximated and were decided by the team members based on their own experiments, inputs from Tetra Pak, and the user study.

Table 7-9. Pump Settings.

Parameter	***Value***
Pump Type	Dispense
Pump Volume	64 ml/pump (8 straws, 8 ml each)
Flow Rate	1000 ml/min
Repetitions	25
Pump Time	3 seconds
Pause Time Between Pumps	33 seconds
Total Time	15 minutes (*)

(*) (33+3 seconds) x 25 = 900 seconds = 15 minutes.

The pinching clamp was attached to the straws for three minutes during the middle of the pump sequence, see Figure 7-40. This was to imitate the fact that the children from the preschool pinched the straws while drinking. The biting clamp was then attached for the same period of time but when the pump sequence had finished, see Figure 7-41.

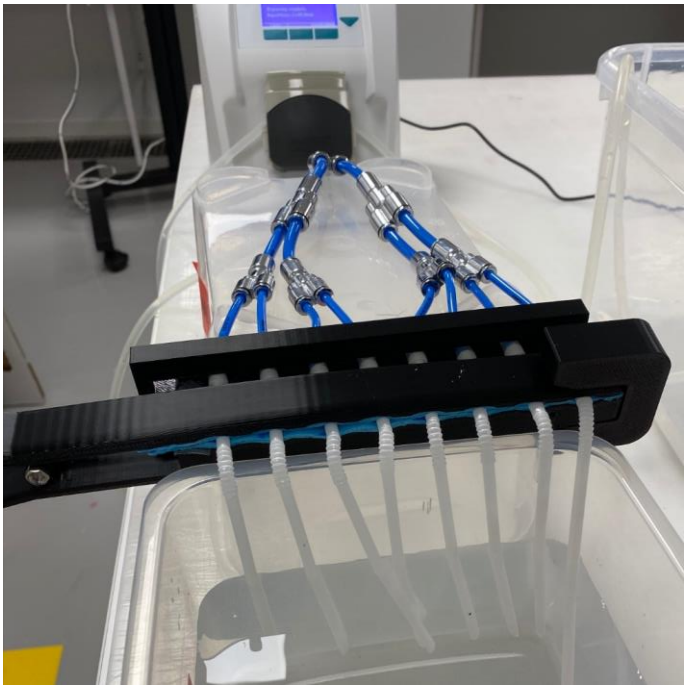

Figure 7-40. Straws with updated pinching clamp.

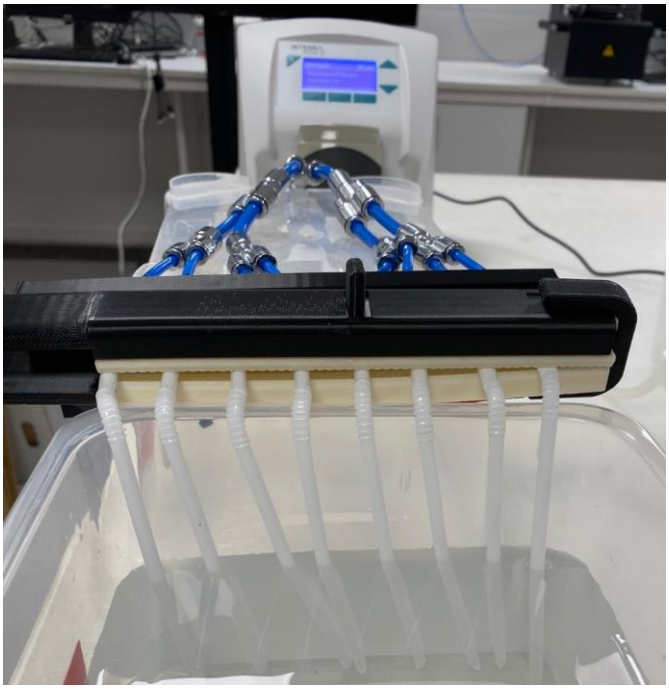

Figure 7-41. Straws with updated biting clamp showing an uneven pressure.

The test resulted in damages on the straws that were somehow alike the damages caused by the children at the preschools. The biggest concern at this stage was that the clamps did not expose the straws to an equal pressure, see Figure 7-41, that the pressure was too low, barely causing any damage to the straws, see Figure 7-42, and that the clamps were operator dependent. It was also discovered that the "grinding motion" did not work as desired since the additional clamp applied a too high force and made the moving motion impossible to perform. Another insight worth noticing is that since the end of the short leg is inserted to the connector, this part of the short leg is not exposed to stresses. However, this was not seen as a big problem since the holder eases the procedure a lot and because most of the short leg is still exposed to stresses.

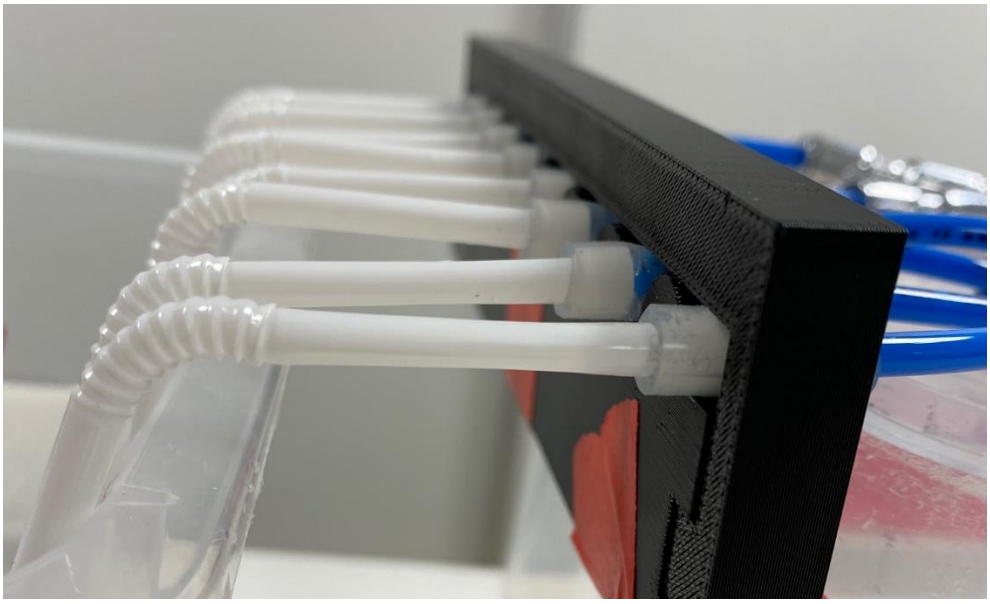

Figure 7-42. The result after performed test.

Due to the uneven pressure applied to the straws, it was investigated how the clamps could be further developed to solve the problem. This investigation resulted in the decision to merge the drinking concept with the other concept categories, creating phase two of the development process. This merge would allow the force of the biting and pinching action to be applied completely from above instead of through a clamp, which among other things would solve the uneven pressure problem.

Further development steps to determine are the time period where the straws are exposed to pinching and biting, the pump settings, how to ease the "jaw movement" with the biting clamp, to further develop the holder, and to integrate the drinking category with the two other categories playing and friction.

7.5.2 **Phase Two of Development Process**

Figure 7-43 shows an overview of the playing and friction concept ideas, these two had initially been developed separately but were now merged together and with the drinking category.

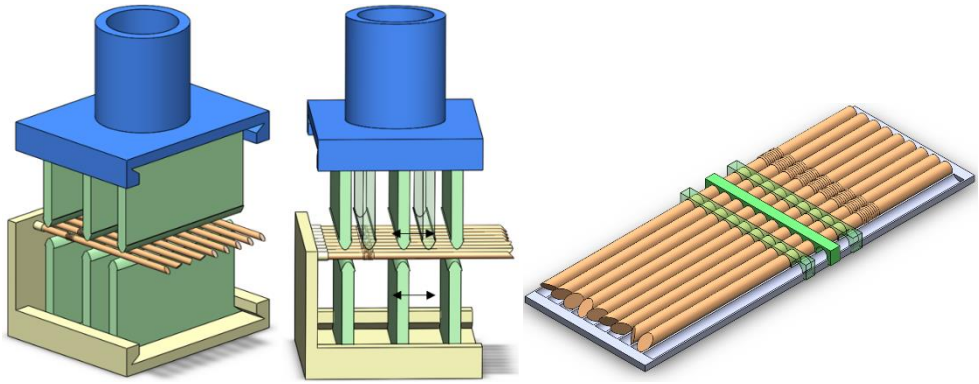

Figure 7-43. Overview of the initial playing and friction concept ideas.

It was decided to develop a stand that would hold plates and that different tools such as “teeth”, “lips” and “fingers” could be attached to the plates. The stand must allow the straws to be in their neutral position during the procedure and is therefore divided into two sections. One smaller for impacts on short leg and one larger that, in combination with the smaller section, impacts long leg. Both sections apply pressure on the straws from above using an external force. Three different angle settings are used, 0 degrees for impacts on short leg, approximately 45 degrees for pinching of corrugation, and 90 degrees for impacts on long leg. See Figure 7-44 for a sketch of the merged concept.

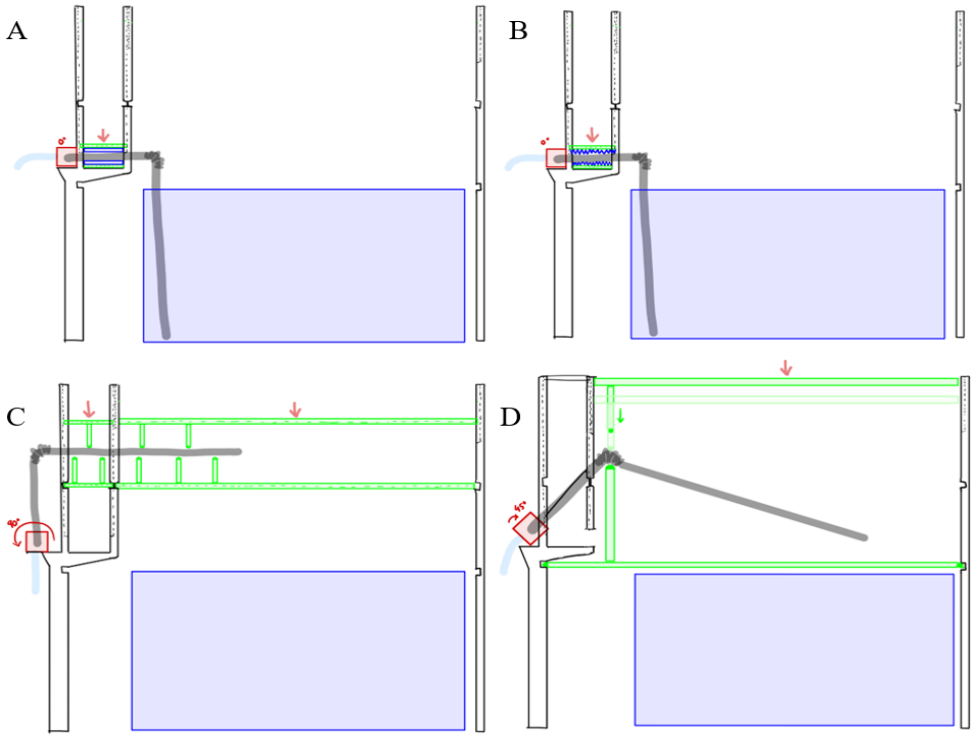

Figure 7-44. Sketch of the merged concept. (A) Pinching with lips, (B) biting, (C) bending and pinching long leg, and (D) pinch of corrugation.

As stated earlier, the development of the merged concept was conducted through two larger iterations containing of multiple smaller iterations. The concept was fully developed, prototyped, and evaluated in each of the larger iterations, and the findings from iteration one was brought to iteration two as a foundation for the following development steps.

7.5.2.1 Iteration One

The first step of iteration one was to combine and redesign the three concept ideas for them to work together. The stand had to be able to operate with the different actions, it had to be easy to use and adjust, stable, and big enough for eight straws and a water container to fit inside.

Figure 7-45 to Figure 7-47 show CAD models of the first version of the concept in three positions - pinching with lips, pinching of long leg, and pinching of corrugation. To be able to produce all requested impacts on the straws, a force will be applied from above and compel the plates to move towards the straws.

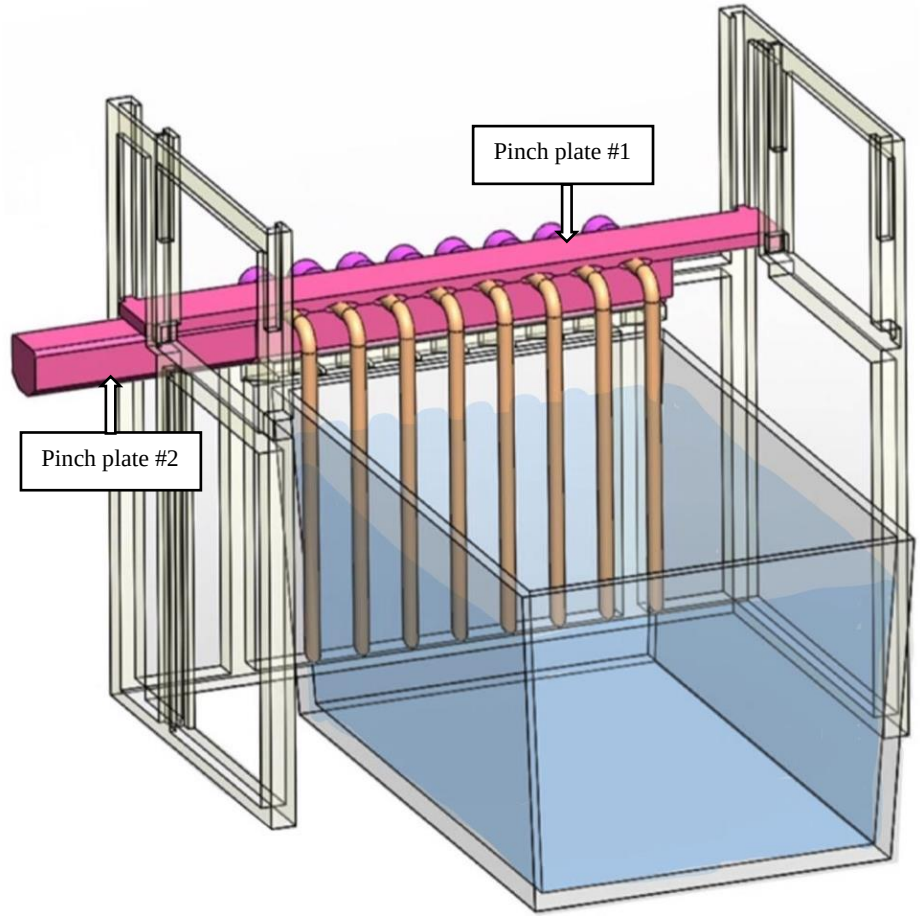

Figure 7-45. First iteration of merged concept stand, pinching with lips.

As seen in Figure 7-45, the short legs are vertical during this action and two correlating plates are above and below the short legs to mimic the pinching with lips action. The width of the pinching plates is approximately 10 mm to correlate with the average length of straw that the children had in their mouths. This straw position is also used during biting and bending of short leg but with different plates applied to the stand. The long legs are in the container during the three actions, and this is based on the user study, where these actions most frequently occurred when the straw was inside the package.

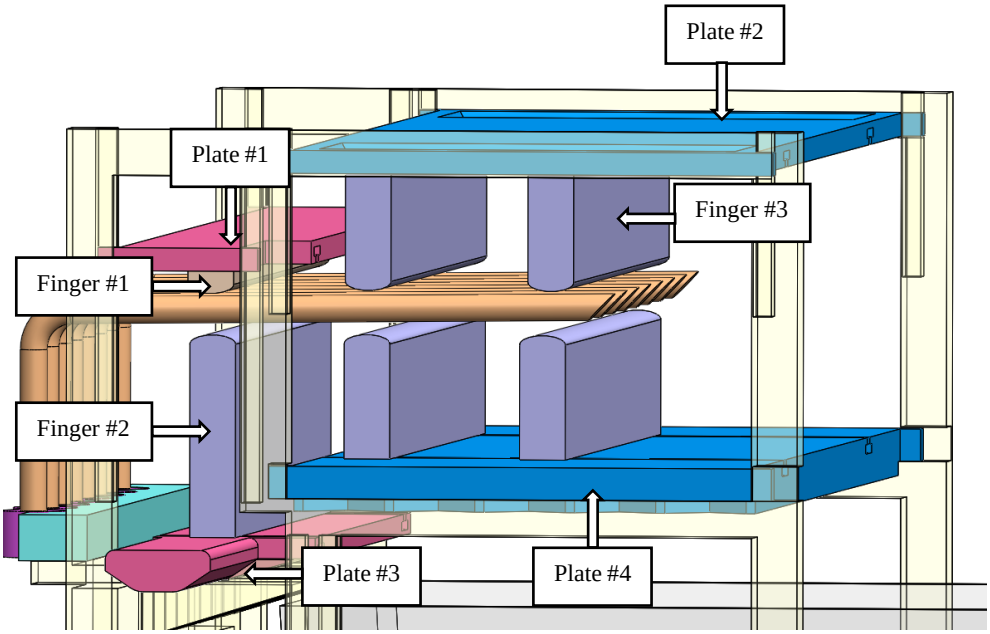

Figure 7-46. Merged concept, pinching of long leg.

Figure 7-46 shows pinching of long leg and as seen in the figure new plates and tools are used to mimic the action. To be able to perform this action, three different "finger" tools with varying heights are used. The same fingers can also be used during bending of long leg but by sliding them to different positions. The short legs are vertical during these actions and the long legs are above the water level since the playing actions occurred when the straws were outside of the package.

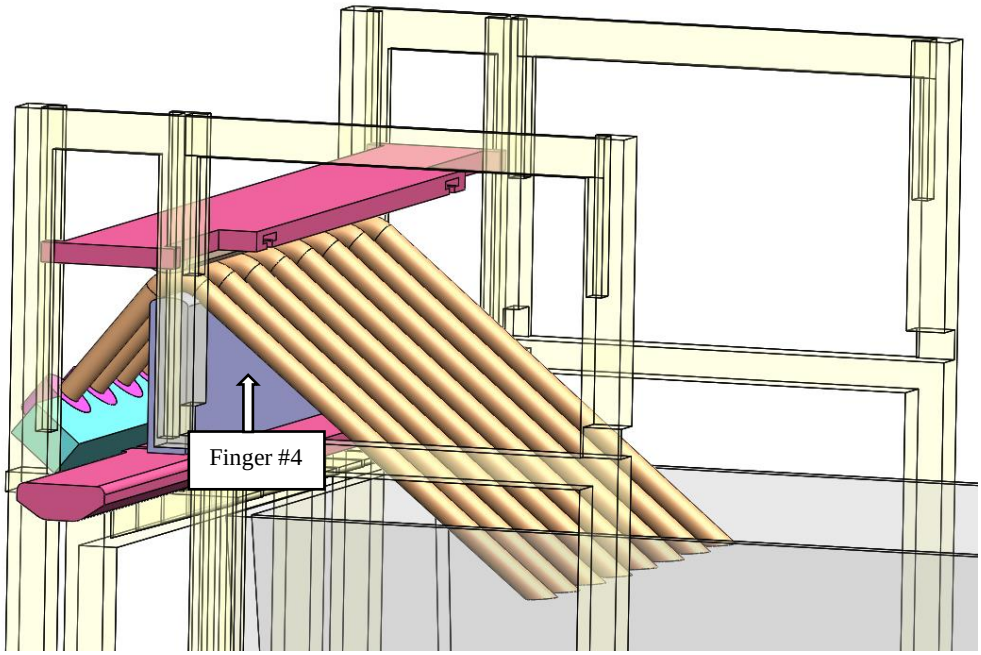

Figure 7-47. Merged concept, pinching of corrugation.

Figure 7-47 shows the third straw position which is used only during the pinching of corrugation action. Two of the fingers used during “impacts on long leg” are used during this action as well but have been moved to align vertically with the corrugation.

The exposure of friction was changed from concept F2 and the use of a friction comb to the use of an actual PPH to increase the level of resemblance to reality. Eight packaging material cut outs with PPHs are inserted into a holder and then punctured by one straw each, both to expose the straw tips to a force from puncturing the PPH, and to expose the sides of the straw to friction by pulling the PPHs up and down the straw. Figure 7-48 shows the PPH holder with and without packaging material cut outs.

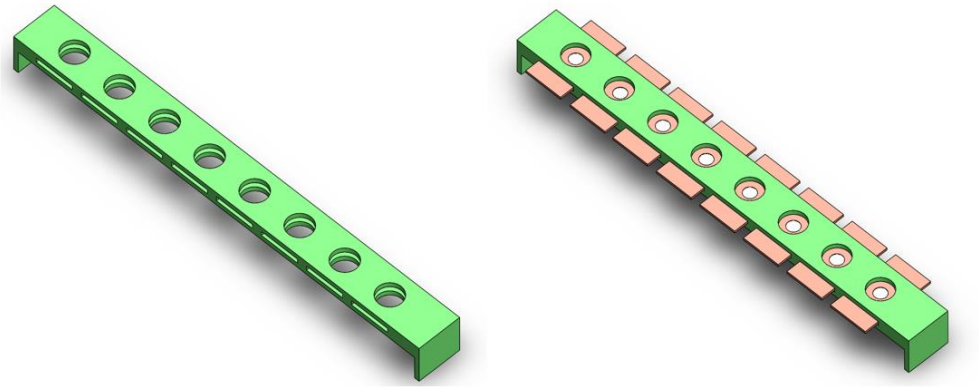

Figure 7-48. PPH holder with packaging material cut out.

This PPH holder was first designed to have eight larger quadratic holes and only one side open to slide in the packaging material through. However, these properties were later changed to eight smaller round holes that are just slightly larger than the largest straw diameters and to having two sides open for the package material to be able to slide all the way through the holder. The first change was based on that a too big of a hole would cause the package material to be pushed down through the hole when the PPH is exposed to a force instead of the PPH being punctured. The second change was to ease the procedure for the operator since the cut out for the first version had to be smaller and more precise, see Figure 7-49.

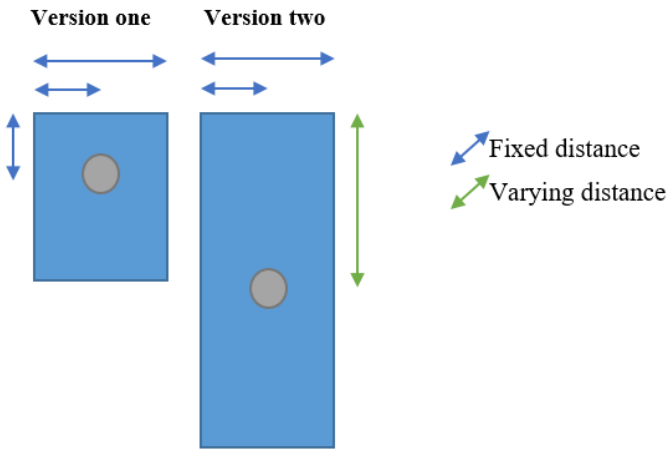

Figure 7-49. Difference in cut out precision between version one and two.

All the procedure steps were gone through in CAD to gain an understanding of which problems the concept might encounter and what changes that had to be done. The findings during these steps lead to multiple smaller iterations within iteration one. The result led to a concept containing of three plates; two bottom plates that can be moved in the horizontal plane and one top plate that can be moved in the

vertical plane. Different additional tools can be applied to these plates through tracks and can together with an external force expose the straws to the different stresses. The external force is applied from above on the top plate. Changing from four plates to three plates was done to make the concept more efficient and easier to manufacture. Figure 7-50 to Figure 7-52 show the final concept of iteration one and how three of the different actions will be performed - biting, pinching of corrugation, and bending of long leg.

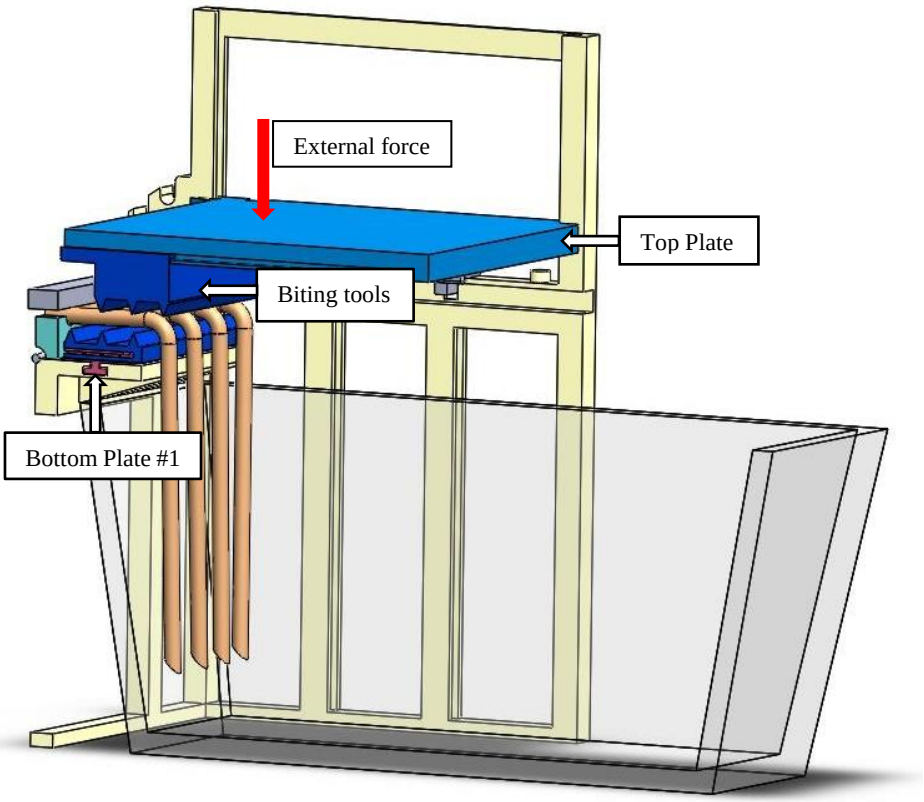

Figure 7-50. Cross-section view of biting action.

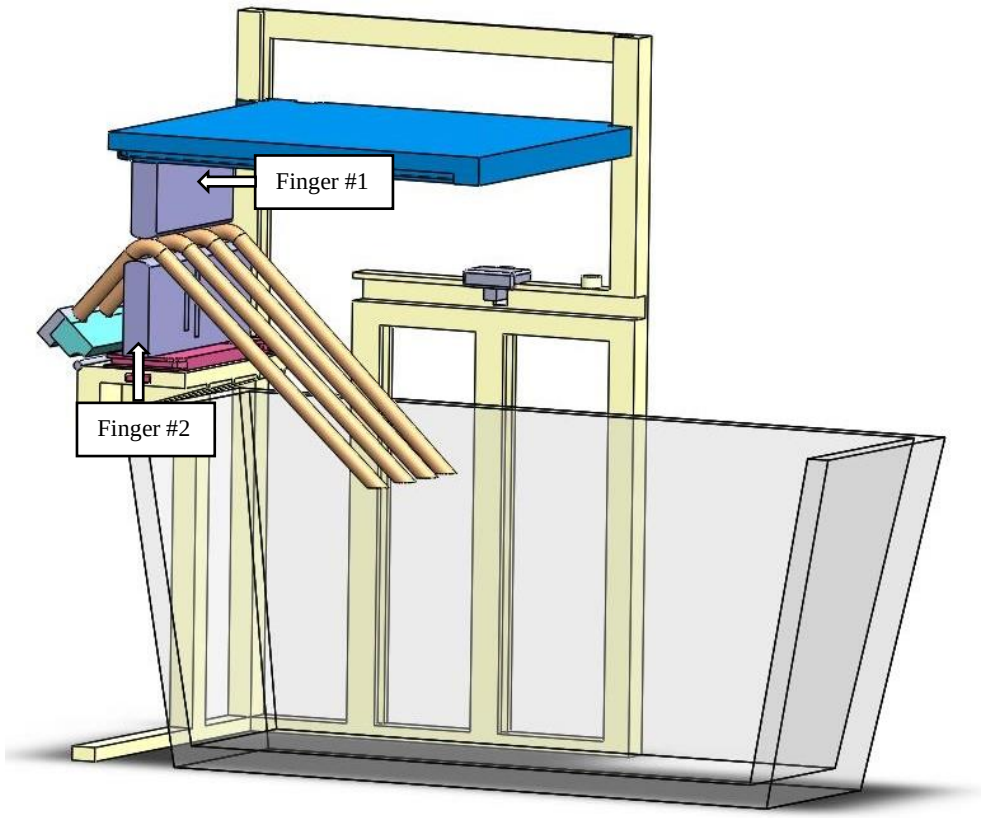

Figure 7-51. Cross-section view of pinch of corrugation.

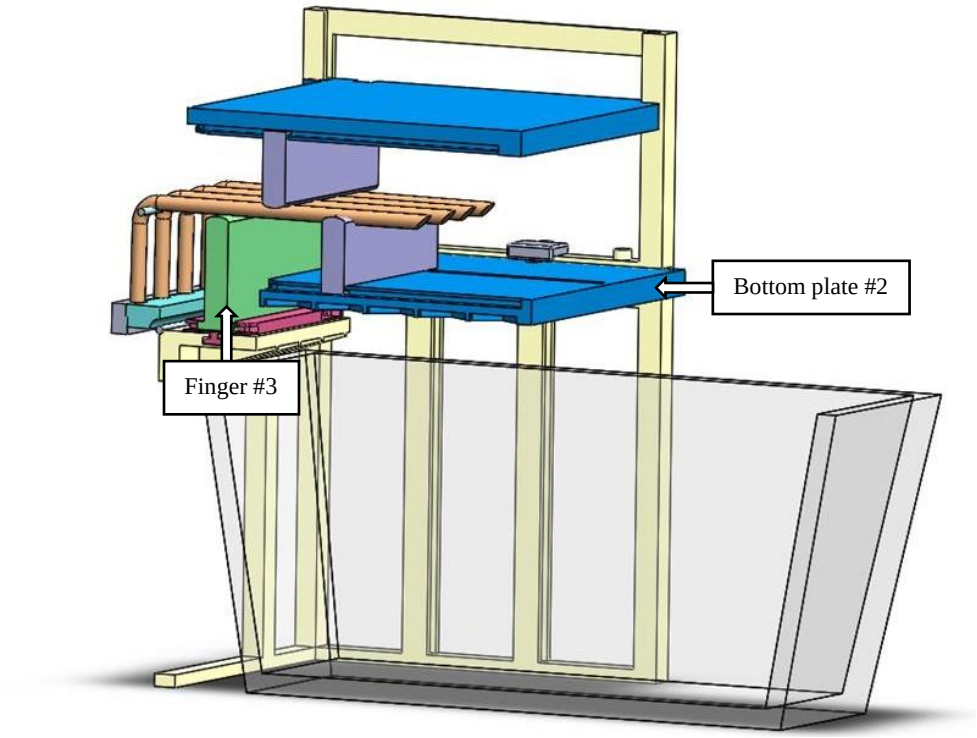

Figure 7-52. Cross-section view of bending of long leg, final version of iteration one.

The figures above show the final concept version for iteration one, the main changes from the initial version are that the number of plates has been decreased and some design modifications.

7.5.2.1.1 Evaluation of Iteration One

All parts of the concept were 3D-printed and assembled to be able to perform the full execution procedure. Plastic straws were inserted and the procedure was conducted step by step to evaluate the concept, weights were used to apply the force. During this evaluation it was discovered that the applied force must be approximately 150 Newton to make similar impacts as the children did on the straws, which results in quite large stresses on the stand. The stand can withstand these stresses but to make it more durable it should be strengthened. The fingers are also exposed to a side force during bend of long leg causing them to be pushed to the side, see Figure 7-53 for forces described in CAD-model and Figure 7-54 for real results. This problem needs to be prevented for the concept to work properly.

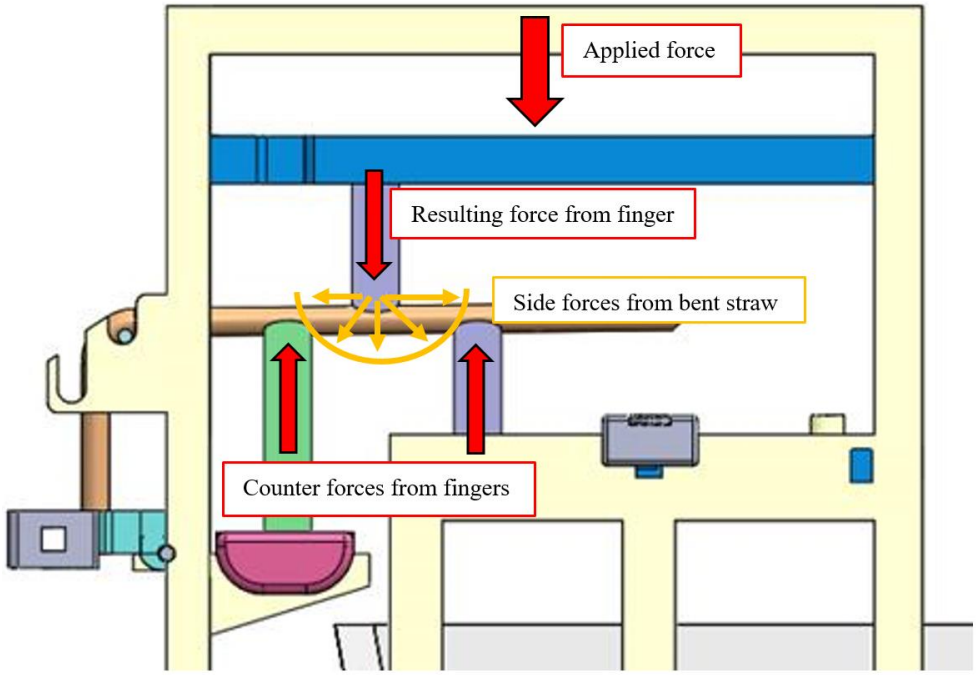

Figure 7-53. Description of side forces during bend of long leg. Red arrows indicate the applied force and the resulting finger forces, orange arrows indicate the caused bend forces in its different directions.

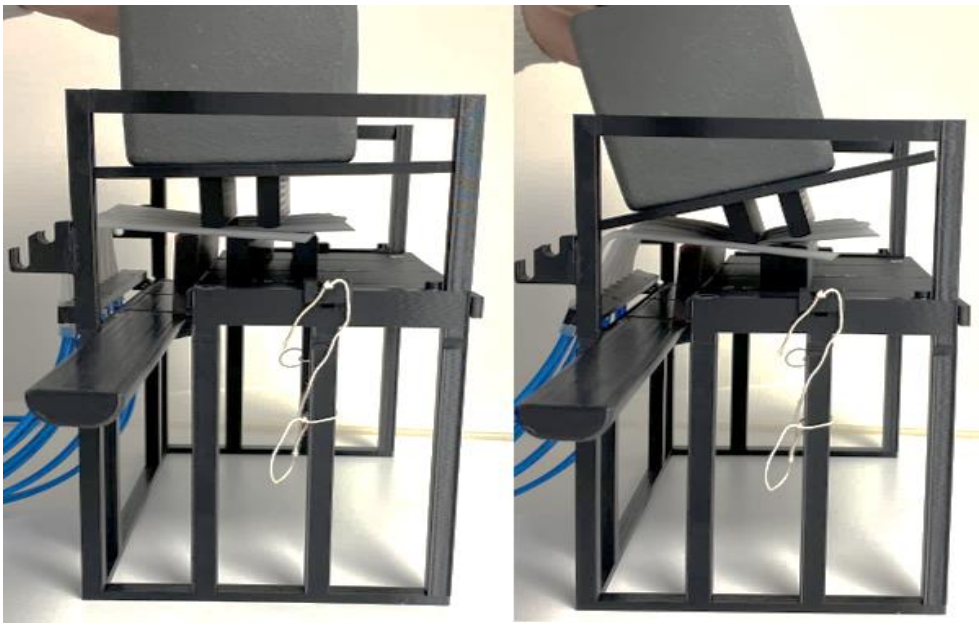

Figure 7-54. Results from bending action. Top plate not horizontal and fingers sliding caused by top forces.

It was also a bit difficult to place the fingers in their correct positions since this had to be done while both plates were in place, this should be made easier. It was discovered that it would be profitable if the top plate could be fixed horizontally while adjusting the position of the fingers.

7.5.2.2 Iteration Two

The changes during iteration two were fewer than during iteration one and concerned how well the concept worked and impacted the straws. The main changes during iteration two was that the fingers were applied to the top and bottom plate from the short edge side, with the aim of preventing the fingers from sliding during bend of long leg. The stand was also strengthened to be more durable and includes metal pillars to hold the top plate. Figure 7-55 to Figure 7-58 show the updated concept.

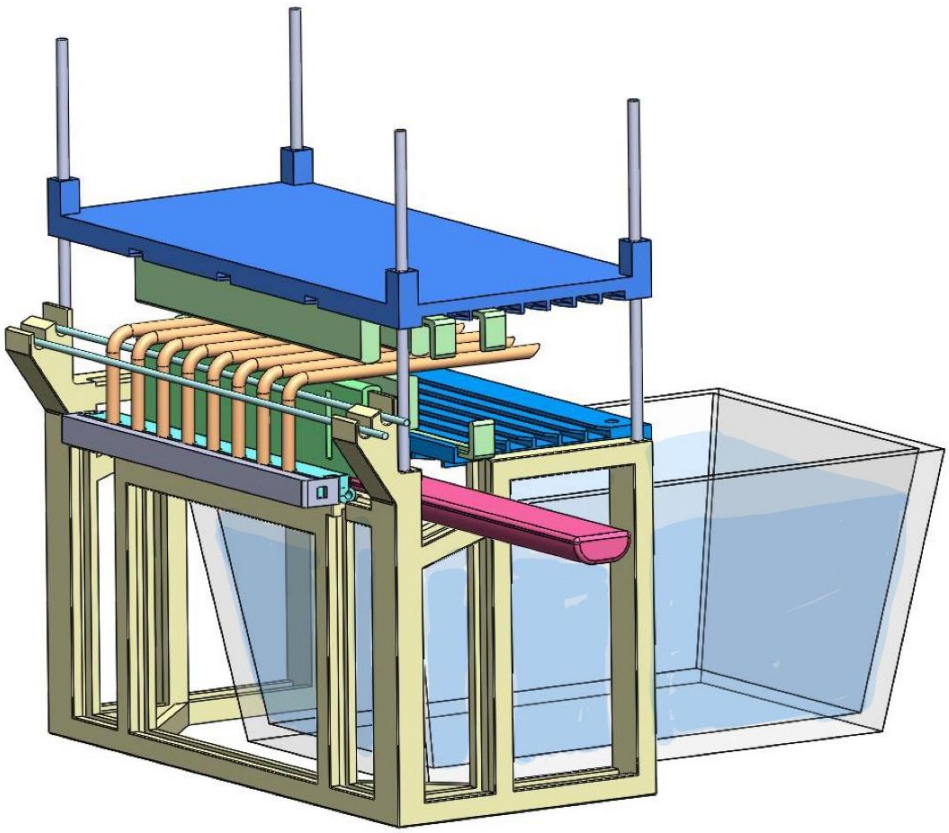

Figure 7-55. Overview of full concept during iteration two.

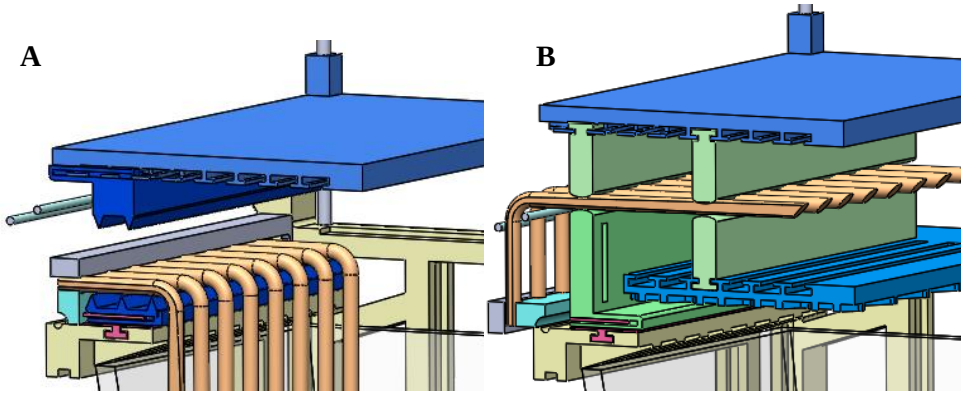

Figure 7-56. Cross-section view of (A) biting and (B) pinching long leg action during iteration two.

To be able to have tools inserted from the long edge side and fingers from the short edge side on the top plate, the plate has crossed tracks in the two directions, see Figure 7-57.

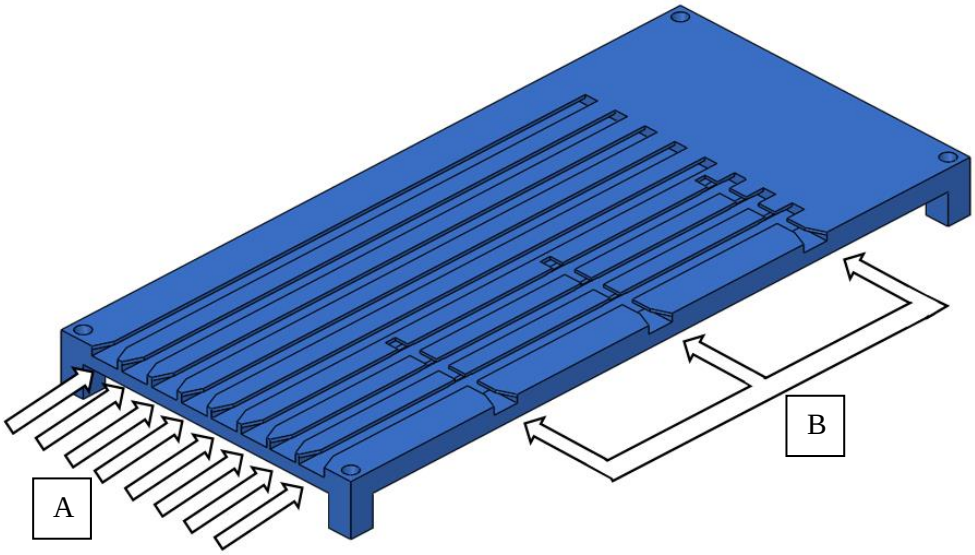

Figure 7-57. View of underside of top plate and its two directions of tracks.

The eight tracks on the short edge side are designed for the finger tool used for impacts on long leg where one tool can be inserted into each track, see position A. The tracks have corresponding tracks on the bottom plate, allowing the tools to align. The three tracks on the long edge side are designed for the tools used for impacts on short leg and only one tool can be inserted at a time and all three tracks are needed for each tool, see position B.

Figure 7-58 shows the stand during iteration two, the stand has been solidified and stabilized since iteration one and has gotten metal pillar to hold the top plate instead

of the polymer pillars used before. The reason for this change was both to increase the stability and to ease the movement of the top plate. Some other additional design changes were added to the stand, both to increase the strength and to ease the use. These design changes include the addition of support pillars between the main sides as well as moving the position for the lock of bottom plate.

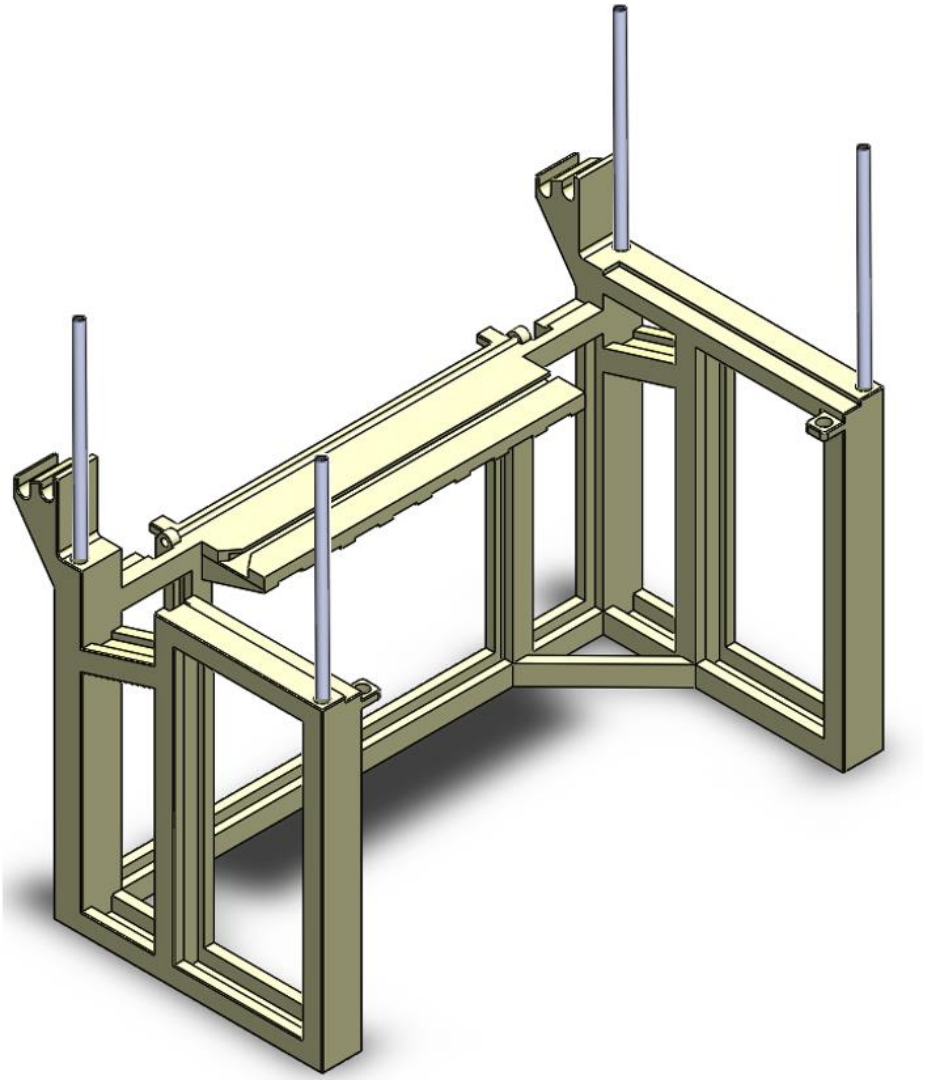

Figure 7-58. Stand during iteration two.

7.5.2.2.1 Evaluation of Iteration Two, Phase Two

Just as during iteration one, the team members assembled the concept and went through the full procedure step by step. No major difficulties or problems were encountered during this evaluation and the found difficulties and problems from

iteration one had all been solved. One 10 kilograms and one 5 kilograms weight were used, these weights were enough for most of the stresses to be performed but some stresses requested an even higher force. Adding a higher force is not possible using the weights due to the number of weights needed and due to ergonomic conditions for the operator, this was not seen as a problem since the final product will use a machine-based force and not weights. However, the prototype shows the principle and produces some impacts, just not as great as the children did and as the final product will.

How easy the concept was to understand and use was taken into consideration, and it was decided to add colors, numbers, and arrows on the different parts to indicate how they should be used. Other improvements made was to use a clamp to fasten the stand to a table and to add numbers to the tracks on the top and bottom plate to make them easier to identify.

All in all, iteration two was declared as fortunate and no further iterations were needed at this point.

7.6 Conclusion of Development Process

The development process started off with a benchmarking and patent search to gather inspiration for the concept generation, which was based on the concept needs that were found in Chapter 6. A lot of time was put into brainstorming different ideas and sketching possible solutions. The ideas were further combined into many concepts and divided into the categories drinking, playing, and friction. Four of the concepts passed the concept screening and were further elaborated, simply prototyped, and tested. A concept scoring was then conducted to help decide what concept to go on with and further develop in each category. The further development process included prototyping and testing. It was divided into two phases where the team members focused on the drinking category in phase one, and a merged concept of all three categories in phase two. One larger iteration in phase one and two iterations in phase two were completed. The final concept that was the outcome of the iterations was further developed by adding colors, numbers, and arrows to easier differentiate the parts from each other. The final concept was to be tested and evaluated by the team members and operators, this was to see if it could produce the wanted actions, expose straws to the same type of stresses as the children from the preschools did and to evaluate how easy it was to operate.

8 Concept Testing

This chapter covers the final testing of the concept, its impacts on straws and how easy it is to use for an operator. The chapter is divided into two parts, one with tests conducted by three Tetra Pak employed operators, and one with tests conducted by the team members.

8.1 Testing by Operators

To evaluate how easy the concept is to use for an operator, three operators were invited to test the concept and to give feedback on the concept and the procedure. These operators were not familiar with the concept but with test methods in general and especially test methods concerning paper straws. The operators were invited one at a time to test the concept to not influence each other and for smaller problems or difficulties to be corrected between tests, they will be referred to as operator A, B and C.

During the tests, one team member was responsible for taking notes and observing the operator and the other team member was responsible for communicating with the operator. The team members tried to let the operator conduct the whole procedure on their own but helped or explained during difficulties. The aim with the tests was not to evaluate the impacts on the straws nor the provided instructions, but rather how easy the concept was to use and understand. Due to this, the operators only used the weights to apply force, and exposed the straws to the force during a shorter period of time than during the actual procedure.

All three tests started with the team members telling the operator about the project and about the concept to let the operator gain an understanding of the scope and objective. This was followed by the operator receiving instructions on how to perform the procedure as well as acquaint herself with the different parts of the concept. The used instructions can be seen in Appendix I. Figure 8-1 shows the test setup with instructions, parts, and pump.

Figure 8-1. Test setup during operator test. Instruction, parts, and pump.

8.1.1 **Operator A**

In general, the test with operator A went smoothly and she understood how the concept worked, however there were some parts of the test that were difficult where she needed further instructions. First, she had some difficulties finding the correct parts and stated that it was because of the names and that some parts were very alike. For example, differentiating the pinching part for top plate and the pinching part for the bottom plate. It was also difficult to differentiate the bottom plate for short leg and the biting part for the bottom plate, see Figure 8-2. Instead of mounting the biting part on the plate she tried to mount the biting part directly into the stand.

Figure 8-2 Bottom Plate Short Leg & Bite – Bottom.

To make the concept easier to understand and to differentiate parts even more from each other, the names were simplified and given a coding with letters and numbers. The parts that were used for the same "test" were given the same letter but different number, for example, *Pinch – Bottom* and *Pinch – Top* were given the names *B1 – Pinch* and *B2 – Pinch*. The names were also written on the parts for further help. Color, text, and arrows were added to some of the parts to further ease the understanding of the concept, see Figure 8-3 and Figure 8-4.

Figure 8-3. Updated plate and bite part to ease the differentiation.

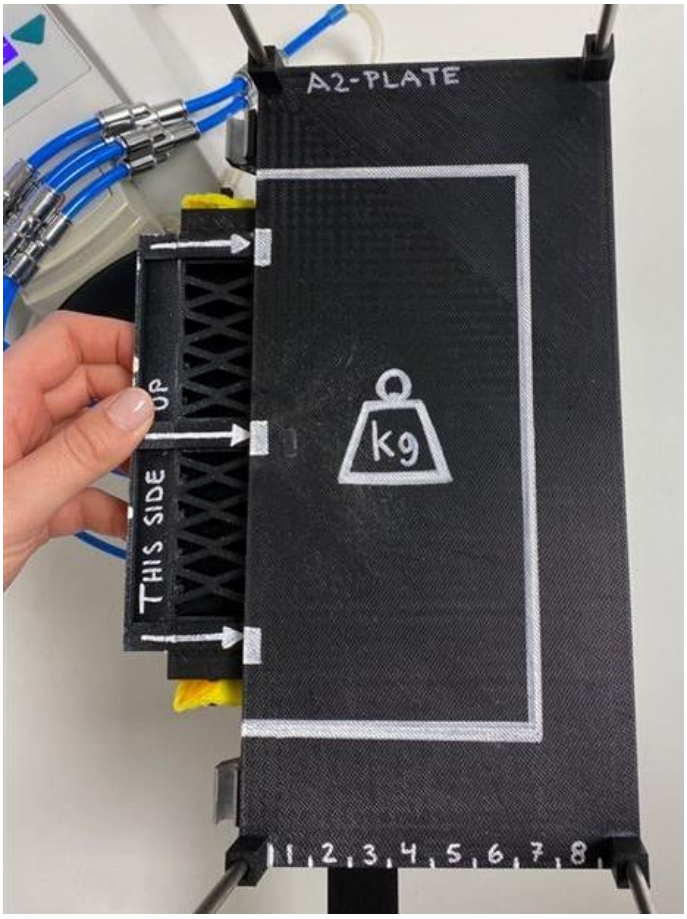

Figure 8-4. Added instructions on parts for better understanding of the concept. Here on A2-Plate and B2-Pinch.

8.1.2 **Operator B**

In general, the test with operator B went well. She did not have any major issues to conduct the test and to understand the concept. The comments she gave afterwards were that there were too many parts and difficult to remember the names of them and that he had to go back in the manual several times. She however thought that this could be resolved by adding some extra pictures and arrows in the manual. The operator also said that she was fully convinced of the usefulness of the concept and that it would be of great benefit for development of straws.

The main change after the test with operator B was that it was stated in the instructions where to stand during the procedure, this would increase the level of understanding.

8.1.3 **Operator C**

Operator C completed the test well without any major problems. She believed that the concept and its steps were in general thoroughly thought through, but that there were a few things that could be refined. For example, puncturing the PPH with eight straws at the same time was a challenging step. The PPH-holder is also dependent of the straws' stiffness, once punctured the PPHs the PPH-holder "hangs" on the straws without any other support, see Figure 8-5. A possible solution for this may be to have some type of support for the PPH-holder to rest on.

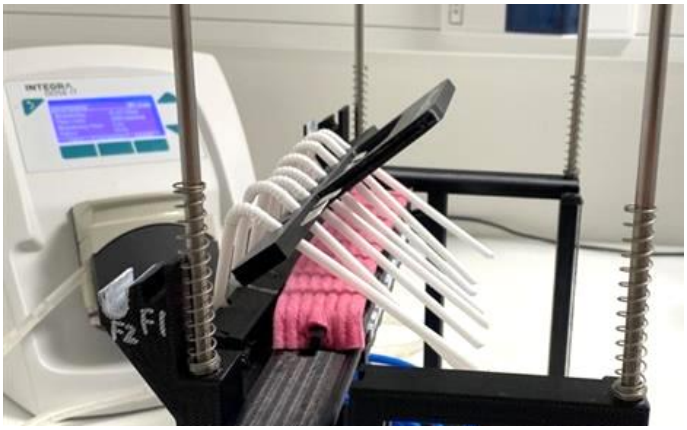

Figure 8-5. PPH-Holder hanging on straws.

The operator also had some difficulties knowing when the bottom plate was in place and ready to lock with the sprints since it was possible to place it further in than what was intended. This could be prevented by making the stops on the plate bigger so that there is no chance for the plate to go beyond its intended position.

Operator C was the person with the most experience of conducting test methods. She stated that there were a lot of steps and parts for the procedure but that they were all needed for the method to be modular. She also stated that the learning curve for the test procedure is steep and that once you have crossed the threshold, it is rather easy to understand and operate.

8.1.4 **Reflection of the Testing by Operators**

All three tests went smoothly, the operators had some smaller comments and difficulties, but none had major problems with neither the procedure nor the use of the concept. However, this was their first time interacting with the concept, and both the team members and the operators strongly believe that the interaction will be even smoother next time they use it. Tetra Pak has as a standard that skilled personnel should support and supervise beginners when executing a test for the first time, which of course would be beneficial in this case as well. The comments that

were given were taken into consideration and the relevant ones were either fixed in between the different tests or stated in subchapter 9.3.

8.2 Testing by Team Members

The aim with this test was to decide the forces and time periods needed for the concept to impact the straws in the same extent as children do. Unlike during the iteration evaluations and the testing by operators, a universal tester was used with the concept to expose the straws to the stresses. Since the available machine was in such a place that it would be difficult to use the pump, this test was conducted without the exposure to water. However, this was not seen this as a problem since plastic straws, which were used during this test, are not affected by water.

Studies have been made on the maximum biting force for children in the age of 3 to 6 years, the outcome from these studies are that the maximum force depend on several factors, such as gender, number of teeth lost, where the bite occurs, and the type of bite [21]. However, it is not reasonable that children use their maximum biting force when drinking with straws, nor was this observed during the user study at the preschools. The aim with this project was not to test the maximum stresses the straws could withstand but rather if they could withstand the stresses that children expose them to. Due to this, it was decided to test different forces to find a reasonable force where the damages on the straws resembled the ones from the user study.

The machine used was an Instron 5566 and it was set to increase the force and stop at 300 N or when a set distance was reached, this setting was used since it would allow the concept to expose the straws to the right amount of pressure without damaging the concept itself. All stresses had the same maximum force but different maximum distances depending on the dimensions of the used tool. The machine was then held at the position for a determined time before returning to its start position. The full procedure was gone through step by step and evaluated if the used force and time was enough.

Figure 8-6 shows the concept placed inside the machine with the metal cylinder that applies the force, and Figure 8-7 and Figure 8-8 below show two of the steps from the procedure, the full procedure and the machine settings used can be seen in Appendix J.

Figure 8-6. Concept placed inside the machine; force is applied on top plate through the metal cylinder.

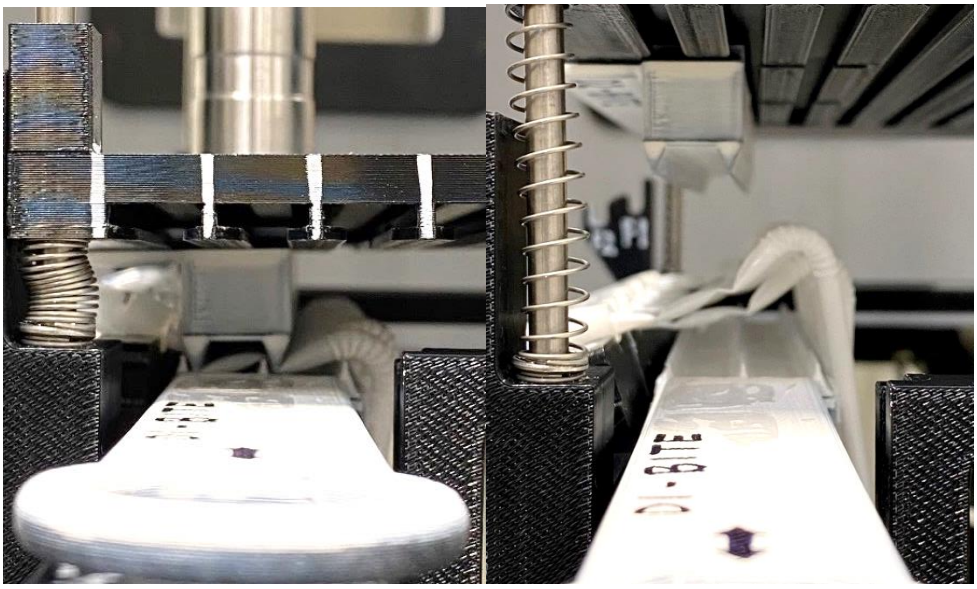

Figure 8-7. Biting action and resulting damages.

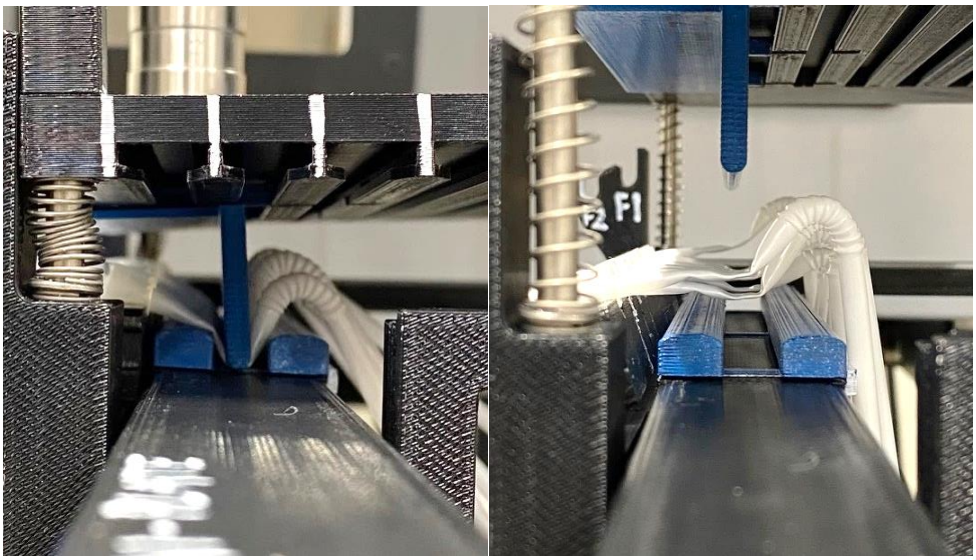

Figure 8-8. Bending of short leg action and resulting damages.

The impacts caused by these stresses were compared to the impacts caused by the preschool children to evaluate how realistic the impacts from the concept were. Figure 8-9 to Figure 8-11 below show the “concept-caused” damages as well as the “children-caused” damages.

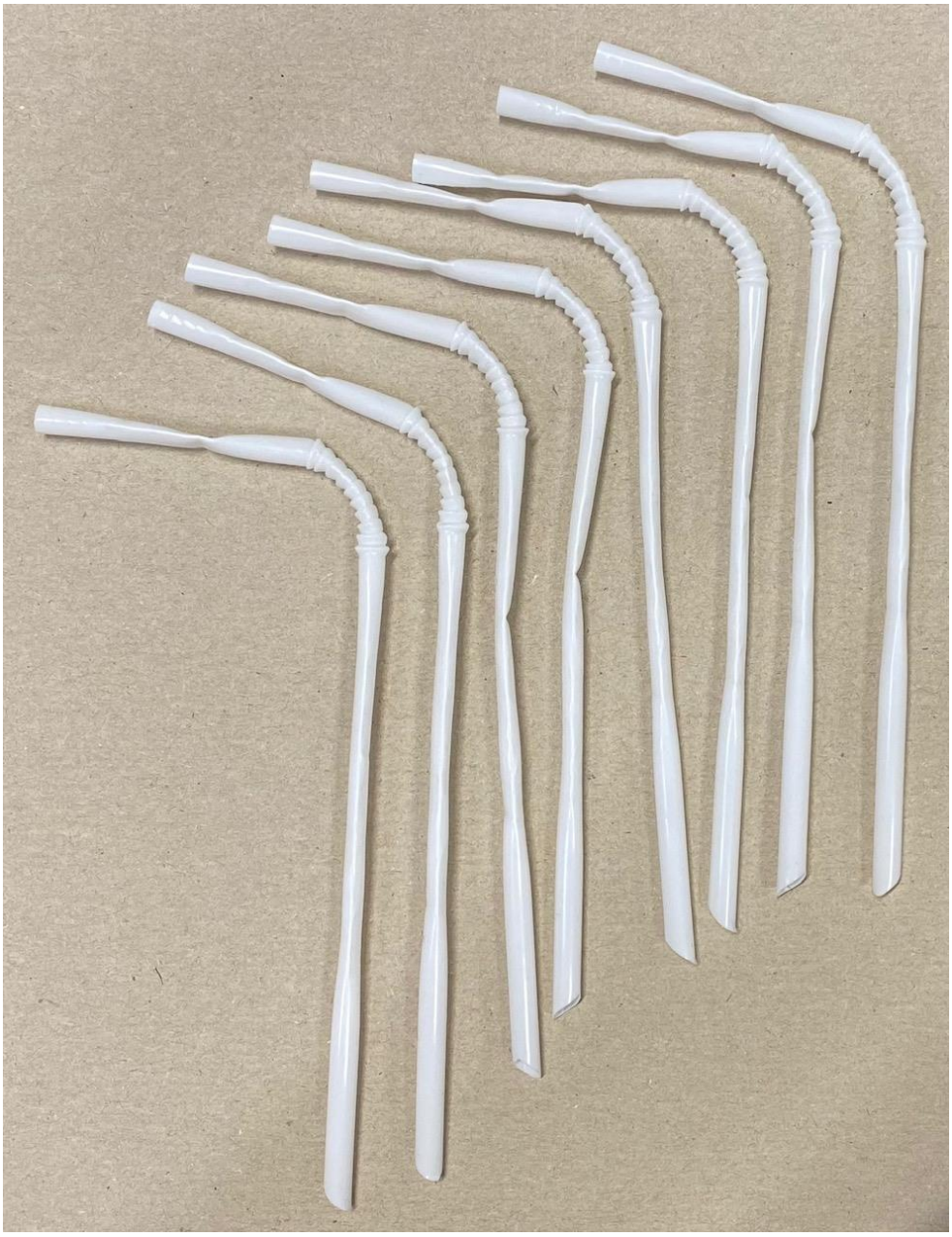

Figure 8-9. “Concept-caused” damages.

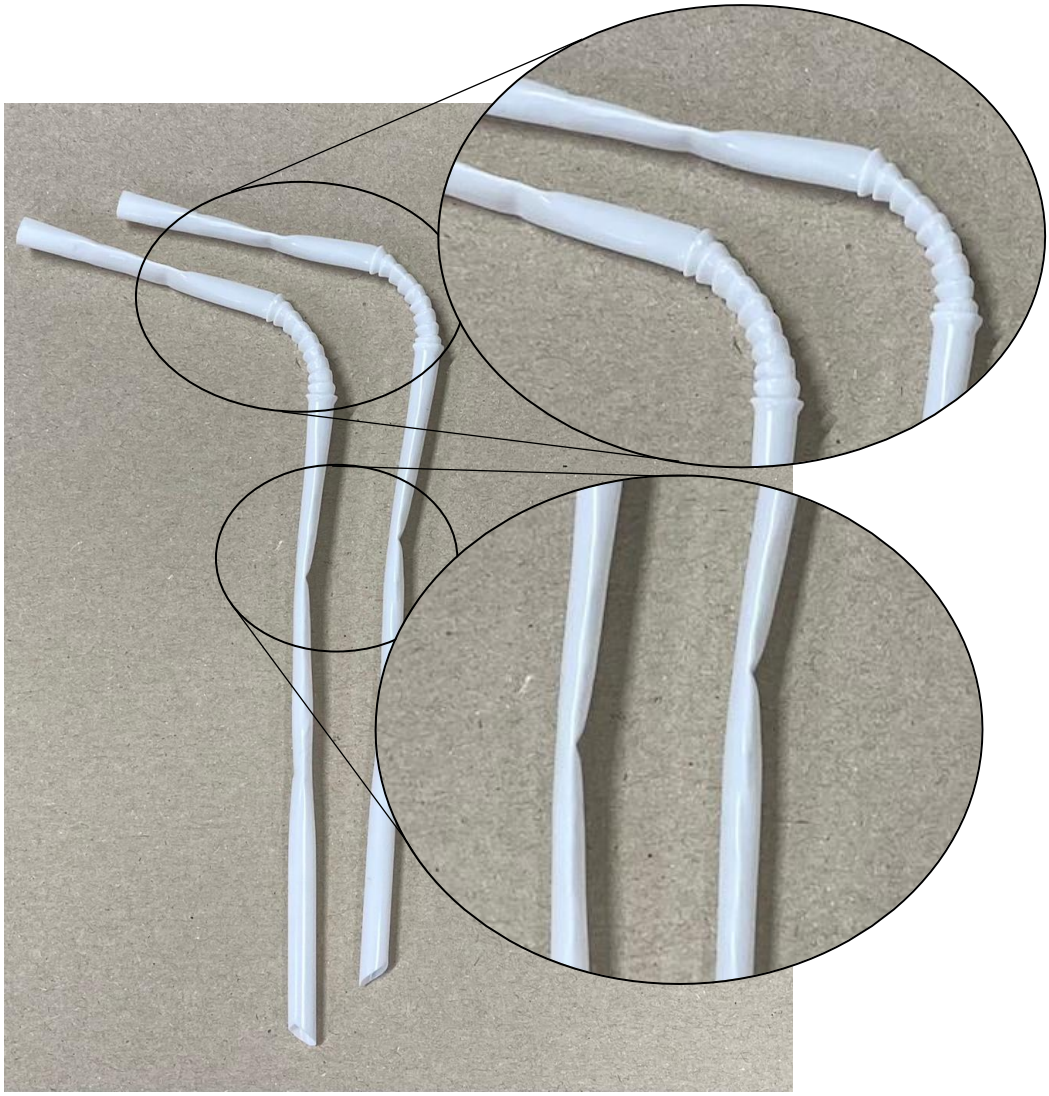

Figure 8-10. Close-up on straw damages.

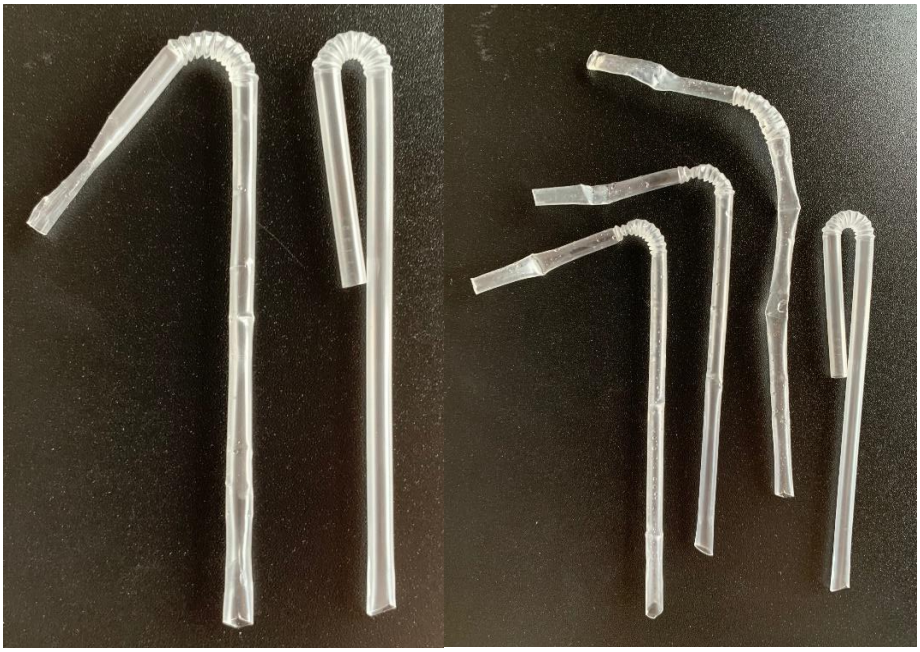

Figure 8-11. The most damaged straws from user study.

The “concept-caused” damages resemble the most damaged straws from the user study in several ways and all straws got somewhat the same damages. It was easy to operate the machine and if Tetra Pak, in the future, would like greater damages it would be easy to increase the applied force.

During the testing, it was realized that some adjustment to the test procedure should be done to receive the desired damages. The biting sequence and bending of short leg had earlier been done during the drinking sequence but was moved to the end of the test. This was to make it more true to life by exposing the straws to more than one bite. The bending of long leg action was also looped to make it more true to life; the full procedure can be seen in Appendix J.

8.3 Conclusion of Concept Testing

Even though the concept procedure consists of multiple steps and the concept itself contains multiple parts, it is easy to use once you get acquainted with it and it produces realistic defects on the straws. The findings from the different tests provided areas of improvement for the concept, most of these requested improvements have been corrected but some will be forwarded to Tetra Pak to resolve after this master thesis is finished, see subchapter *9.3 Further Development for Tetra Pak.*

9 Final Concept

This chapter includes a suggested name for the concept, a detailed description of the final concept, recommendation of use, and suggested further development steps for Tetra Pak.

9.1 Description of Final Concept

The final concept is called the MiDrink, which is an abbreviation of Mimic Drinking. The developed final concept is a fully functional prototype of MiDrink and exposes straws to the main stresses that children expose them to during drinking. The purpose is to ease the development of straws by enabling Tetra Pak to test and evaluate straws. MiDrink consists of a stand with plates which tools can be attached to, these tools allow the concept to mimic the different stresses. Straws are attached to the stand and are impacted by an external force. Figure 9-1 shows an overview of MiDrink placed in the Instron, showing its stand, plates, the pump used, some of the tools and where the straws are placed.

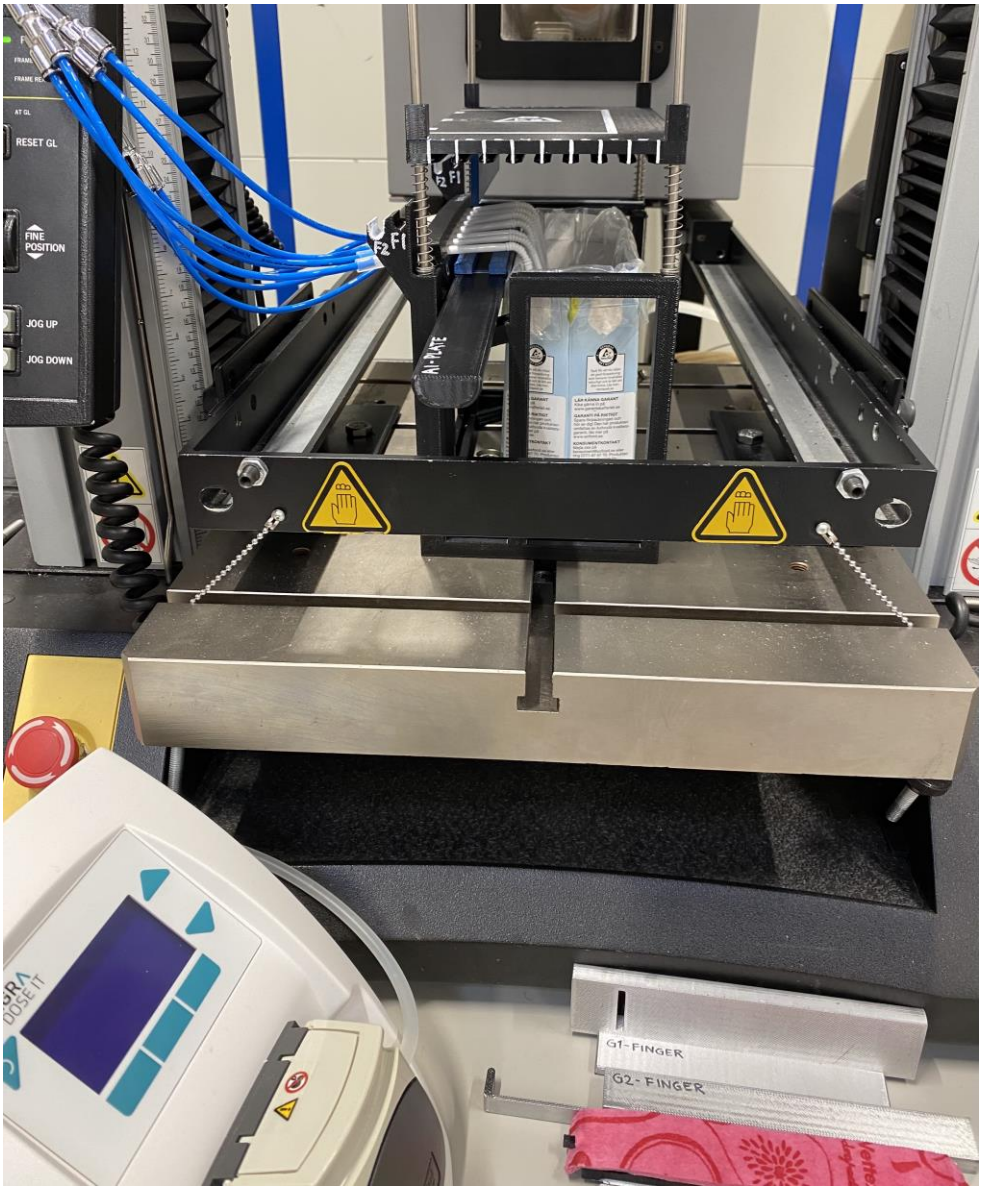

Figure 9-1 MiDrink placed in Instron with pump and some of the tools used.

The outer dimensions of the concept are 13 x 27 x 35 centimeters, and it is easy to move the concept.

MiDrink exposes the straws to stresses alike the stresses from puncturing PPH, drinking, pinching, biting, bending, bending of corrugation, and friction. Since the concept is modular with many different tools and by changing these tools, the operator can choose during if all or only some of these stresses should be used, depending on the test specifications. However, the applied force stays the same

which allows the procedure to be repeatable and with a low operator dependency. The execution time for the full procedure is about 60 minutes.

9.2 Recommendation of Use

As stated above, this is a flexible concept that allows the operator to decide which steps that should be tested, but the full procedure is recommend for general evaluations of straws. MiDrink is neither operator nor environment dependent and can thus be used in any laboratory environment, however a flat surface for it to stand on, water supply, and the presence of a universal tester, or similar, is requested for the concept to fully operate.

9.2.1 **Proposed Execution Procedure**

The first step of the execution procedure proposed is to measure how well the straws work prior to the exposure to the straws. The next activity is to expose the straws to the actions in the following order: drinking, friction, playing, and then drinking again. This order is based on that the children usually drank, played with the straws, and then drank again. The friction exposure is also located after the first drinking exposure since the straws are more impacted when they are wet and since inserting the straw to the package, and thus exposing it to liquid, is the first natural step of the drinking process. Hence, the straw gets wet rather quickly. After the exposure to the different actions, it is proposed that the straws once again should be evaluated on how well they work through conducting the same measurement as before. These results from before and after will provide information to Tetra Pak about how well the straws would withstand children. The execution procedure proposed can be seen in Appendix J.

In addition to this execution procedure, it is suggest that Tetra Pak use the pump settings stated in Table 9-1. The pump should run the same program at the beginning as at the end of the execution procedure, which will result in a volume of 200 ml being transported through each straw.

Table 9-1. Suggested pump settings.

Parameter	***Value***
Pump Type	Dispense
Pump Volume	67ml/pump (8 straws, 8,3 ml each)
Flow Rate	1000 ml/min
Repetitions	12
Pump Time	3 seconds
Pause Time Between Pumps	33 seconds
Total Time	7 minutes and 12 seconds (*)

(*) (33+3 seconds) x 12 = 432 seconds = 7,2 minutes = 7 minutes and 12 seconds.

9.3 Further Development for Tetra Pak

Due to the delimitations of this master thesis, the final concept is only a prototype and some further developments are suggested for Tetra Pak to continue with. These suggestions are based on both findings from the concept testing and smaller changes to make the concept easier to operate. Below follows the suggested developments.

Add magnets or some other kind of fastener between the top plate and the universal tester to both ease the movement of top plate and to ease the change of tools during operation. It is also suggested to develop a way to fasten the stand to prevent it from moving sideways, also to ease the changing of tools. It is also suggested that the snap can be developed further to make it easier to apply and remove, this development was left for Tetra Pak to look at since its highly material dependent and they might have some opinions on the wanted material and dimensions.

The team members are in general satisfied with the tools but suggest that Tetra Pak should extend the length of the finger tools to ensure that all straws are impacted, another suggestion is to decrease the clearance between the corrugation finger and the plate to decrease its ability to move.

To ease the use of the PPH holder, it is suggested that Tetra Pak develops a new holder with similar outer dimensions and design but with one longitudinal track instead of eight transverse tracks for each PPH cut out. It is also suggested that Tetra Pak orders package material test strips with a high density of PPHs so that these can be inserted into the longitudinal track, see Figure 9-2. The PPH strip is inserted

through the top short edge and is pushed all the way down to a closed end, preventing the strip to fall out.

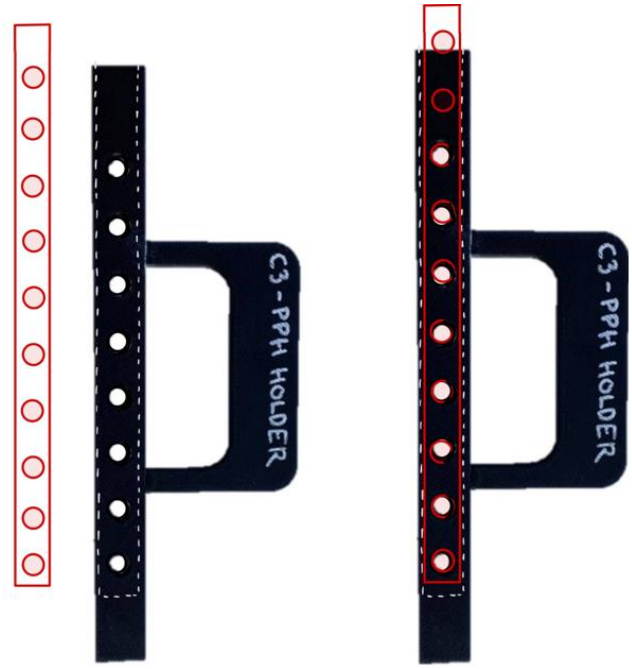

Figure 9-2. Proposed further development of PPH holder and stripe with PPHs.

It is also suggested that Tetra Pak should visit a preschool and do the same kind of study but with paper straws to validate if children expose paper straws to the same stresses as plastic straws.

The MiDrink prototype is adapted to be used with physical weights, why there are markings on the top plate, and not with a universal tester such as the Instron. To moderate the concept, it is suggested that the stand should be made more rigid, and that Tetra Pak conduct tests in the Instron to make sure that the stand's dimensions are suitable. To conduct the entire test where the Instron is located now is not optimal since there is no space for the pump or water container. Tetra Pak should therefore explore possible solutions for it to be completed easily.

As of now, the connection set-up between the straws and the pump is rather heavy, making it difficult to keep the straws in the position where the short leg is horizontal, see Figure 9-3. A possible solution for this could be to create something that the connection set-up can be hung on when this position of the straws is desired. As stated earlier, the connector between the short leg and the tube is now prototyped and a suggestion of what it should look like is shown in Figure 7-33.

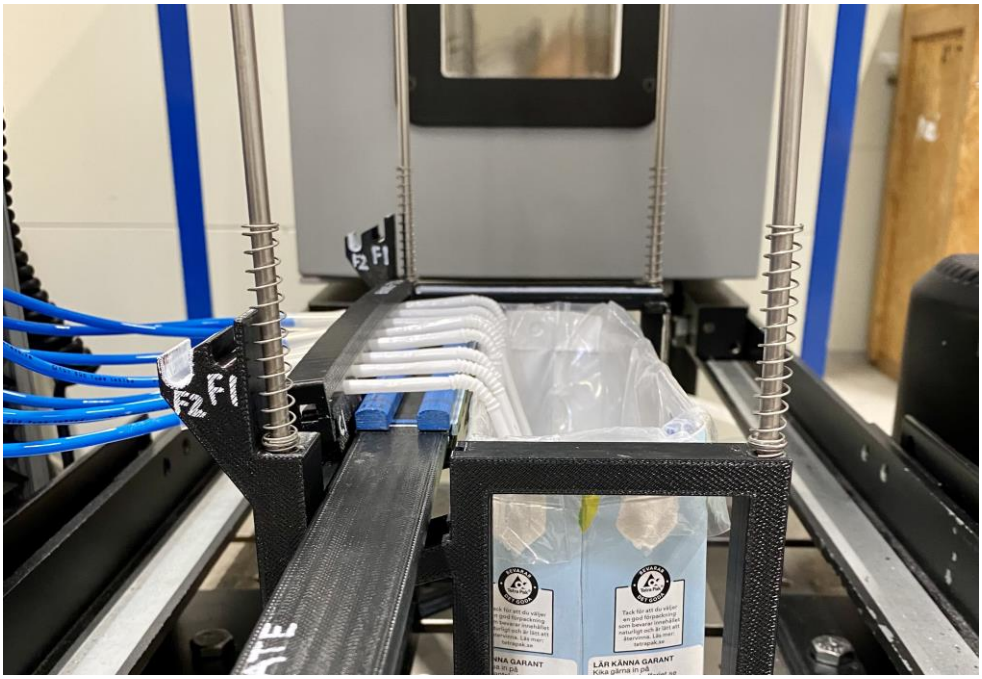

Figure 9-3 Straws in stand with short leg horizontal.

In addition, the concept today only tests eight straws. For the probability theory and the results, it would have been more time efficient if it had tested 16 at once. It is therefore recommended that Tetra Pak investigate this possibility.

10 Discussion

This chapter includes a discussion regarding questions presented in subchapter 1.3 and finishes with a general discussion about the project in its entirety.

10.1 Level of Resemblance to Reality

This subchapter aims to answer the questions “Can drinking from a straw be mimicked in a lab environment?” and “Can the human interaction with the straw be fully mimicked in the lab?”.

All in all, MiDrink resembles the different actions performed during drinking well and is flexible to use. It is also easy to add new or remove actions depending on what is needed. For example, if Tetra Pak in the future wants to expose straws to back teeth instead of front teeth it is very easy to manufacture tools for this and use them in the concept.

The straws are also not forced into an unnatural position during the procedure which was requested by Tetra Pak. The pump settings used to mimic the drinking actions are realistic with the two drinking sessions, but they are also quite general, how fast or slow a child drinks is highly dependent on the child and is not considered in this concept. It is however very easy to change the pump settings if other would be more suitable. It is also believe that the resemblance would increase if the pump settings were designed in such a way that the sips were more randomized in their extent and the pause between them.

Pulling and pushing of the corrugation was removed which facilitated the manufacturing of MiDrink as one unit, this action can however be added on later is requested by Tetra Pak at a later stage. Besides this, all of the most frequently occurred actions can be performed with the concept.

The tools used are designed to resemble the actual body parts of children, the teeth were, for example, designed in accordance with an international standard [19]. However, all tools are manufactured in ABS plastics which is a quite stiff material, and the team members believe that if the fingers would be manufactured in a less stiff material it would resemble reality even more. Since the normal way is to use one straw at a time, the procedure would probably be more realistic if it too used one straw at a time, but this would be greatly inefficient.

Bending of short leg might not resemble exactly what really happens. It is not very likely that they are exposed to a three-point bend but rather a two-point bend where one end is fixed between, for example, teeth. However, the current bending of short leg results in large impacts on the straws which are alike the impacts caused by the children.

There is also an extra unnatural stress on the straws when inserting them into the straw holder, this stress is however very small and does not impact the straws but is still something to take into consideration. It is believed that this stress will decrease when using the proposed straw holder and not the one in the prototype.

Despite these smaller comments, the team members are satisfied with the outcome of this project and believes that the level of resemblance to reality is high.

10.2 Operator Use

This subchapter aims to answer the question “Can the set-up be automated, ergonomically, and easy to use for operators?”.

MiDrink procedure has a lot of steps which might be confusing for a first-time user, but it is strongly believed that this difficulty will decrease remarkably once the operators get acquainted with the concept. It is also not mandatory to conduct all steps if the specific test does not require this.

The color coding and the marking of parts increases the cognitive ergonomics of the concept by helping the operator differentiate the parts from each other and to make it easier to understand which part that should go were.

To puncture all PPHs and the general use of the PPH holder were mentioned by the operators as the trickiest steps of the procedure, which was not surprising since this was the least developed part. A suggestion for future improvements to ease the use has been provided to Tetra Pak.

Only one operator is needed, and the full procedure takes about 60 minutes, unfortunately the procedure leaves some waiting time for the operator. However, during these periods, it is suggested that the operator takes time to prepare for the coming steps and to reflect on the impacts caused on the straws. One potential drawback with the concept is that it can only hold eight straws at a time, which might result in the operator needing to conduct the procedure twice to get enough data points. However, to evaluate straws using the MiDrink is a lot less time consuming and more efficient than conducting a user observation.

Once the operator has gotten acquainted with the concept, it is easy to use and will be even easier to use when the weights are exchanged to the universal tester.

10.3 Comparison with the Current Tests Methods

This subchapter aims to answer the question “Can the eventual mimic drinking instrument produce a quantitative output?” and compares the concept with the current test methods used at Tetra Pak.

The concept MiDrink itself does not produce a quantitative output but it can, alongside with before and after evaluations, provide knowledge on how well the straws managed to withstand the applied stresses. However, it is possible to increase or decrease the time periods or the magnitudes of the forces which can provide quantitative outputs when compared to each other.

The current method for Tetra Pak to expose straws to stresses from use is to place straws fully in liquid during a specified time period, this exposes the straw to liquid but not in a realistic way. Compared to this method, the concept MiDrink resemble reality much more since it both exposes the straws to liquid on the outside, transports liquid, and exposes the straws to different stresses. The main advantages with the current method are that it is simpler and that it is possible to expose a larger quantity of straws at the same time.

10.4 General Discussion

The aim with this master thesis was to develop a set-up that would aid the development of straws through minimizing the need of panel tests when evaluating the functionality of straws and it is considered that this aim has been reached. The final concept MiDrink mimics most of the stresses and load cases that the straws are exposed to during use and does this in a relevant, repeatable, and efficient way. The level of resemblance to reality is high and the concept is easy to use and more realistic than the current method. However, there are some smaller suggestions for further development for Tetra Pak in order for the concept to be even more relevant. These suggestions can be seen in subchapter 9.3.

If this project would have been ongoing for a longer period, some further steps would have been beneficial to conduct. Some examples of these are to perform additional user studies, both in the beginning of the project but also in the end of the project to validate the results. It would also have been beneficial to conduct a user study with paper straws to be able to see how the different straw types differs in use, but this has been handed over to Tetra Pak.

There is not much research done within this subject, but the team members are hopeful that this project will be contributing to knowledge about the use of straws. Once the single-use plastics directive launches it is likely that the research and development within this subject will grow significant.

Since this project was conducted during the spring of 2021 when the Covid-19 pandemic was ongoing, some of the processes and perhaps even some results have been affected. One aspect that most certainly was affected by the pandemic is the relationship between the supervisors and the team members. There would most certainly have been more contact between them which might have prevented the accidental switch in focus to paper straws instead of straws in general. The team members were also forced to work from home when not in need of the lab at Tetra Pak, thus lost the possibility to discuss with other students and since a lot of the employees at Tetra Pak worked from home during the project, the possibility of getting their feedback and expertise were therefore lost. However, both team members had worked at Tetra Pak prior to this project and were not afraid of contacting new people to gain knowledge and useful tips.

Altogether, the team members are satisfied with the outcome of this project and believe that they have been efficient throughout the project and thus have had the possibilities to explore multiple solutions. It has truly been an iterative and creative process where the result is a set-up that hopefully will be beneficial for the future development of straws.

11 Conclusion

This chapter gives a conclusion of the project, the team members are satisfied with the outcome and hopes that their findings will contribute to the further development of straws.

The conclusion that can be drawn is that children expose straws to a wide range of stresses when drinking, and most of the stresses are on the short leg of the straw. It can be concluded that children normally play with the straw while consuming a drink. The time it takes for a child to finish a drink varies but normally lies within 15 minutes and 2 hours, however most children from the observation study were done within 30 minutes. The way of playing is also dependent of the child and therefore varies, however a pattern could be detected during the observations at the preschools. It was common to drink, play, and then drink again, why the proposed concept also stress the straws in the same procedure. The stresses included drinking, biting, pinching, bending of long leg and short leg, pinching of corrugation, and friction from pushing the straw in and out of the PPH multiple times. MiDrink is modular and can expose straws to all of the stresses or some of them, depending on what is desired from the specific test. Worth mentioning is that MiDrink is the extreme case of stresses, which is beneficial when developing new straws, but the forces and time can easily be adjusted to lighter stresses.

The project questions have been answered and the goals of the project have been fulfilled. MiDrink mimics children in a sufficient way by exposing straws to the same type of stresses, however some smaller adjustments to the concept must be done by Tetra Pak. This project was conducted to observe how children drink with the current type of straw and package, the design and material of the package and the straw will most likely change over time why new user studies should be conducted when these transformations occur. The future may hold a completely different way of consuming still drinks.

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Appendix A – Work Distribution and Time Plan

Appendix A includes the work distribution and the time plans presented as Gantt Schedules for this project. The first Gantt-Schedule represent the time plan made in the beginning of the project and the second version represent the final version with the actual time durations.

A.1 Work Distribution

The workload has been distributed equally between the team members throughout this project, both have participated in all discussions, decisions, and activities.

A.2 Project Plan and Outcome

Figure 12-1 shows the initial time plan while Figure 12-2 shows the actual time plan, the different phases and actions are presented by different colors.

Task name	Stard date	End date	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21
Initial Phase	**1/11/2021**	**1/12/2021**																					
Pre-Study	**1/12/2021**	**1/27/2021**																					
Consumer Study	**1/12/2021**	**1/27/2021**																					
In-house Search	1/13/2021	1/14/2021																					
Planning of Study	1/15/2021	1/15/2021																					
Conduct Study	1/21/2021	1/22/2021																					
Summarize & Analyse study	1/22/2021	1/25/2021																					
Translate Human Interaction	**1/28/2021**	**4/23/2021**																					
Brainstorming	1/28/2021	1/30/2021																					
Concept Generation	1/29/2021	2/2/2021																					
Evaluate Concepts	2/2/2021	2/5/2021																					
Build Models	2/2/2021	2/5/2021																					
Select X Concepts	2/5/2021	2/5/2021																					
Develop Concepts	2/8/2021	2/12/2021																					
Evaluate & Choose Final Concept	2/15/2021	2/19/2021																					
Finalize & Manufacture Final Con	2/22/2021	4/23/2021																					
Evaluate Final Concept	**4/26/2021**	**5/7/2021**																					
Final Phase	**5/10/2021**	**6/4/2021**																					
Report Writing	**1/13/2021**	**6/4/2021**																					

Figure 12-1. Initial time plan.

Task name	Stard date	End date	W. 1	W. 2	W. 3	W. 4	W. 5	W. 6	W.7	W. 8	W. 9	W. 10	W. 11	W.12	W.13	W. 14	W. 15	W.16	W. 17	W.18	W. 19	W. 20	W.21
Initial Phase	**2021-01-11**	**2021-01-12**																					
Pre-Study	**2021-01-12**	**2021-01-27**																					
Consumer Study	**2021-01-12**	**2021-01-27**																					
In-house Search	2021-01-13	2021-01-18																					
Planning of Study	2021-01-15	2021-01-18																					
Conduct Study	2021-01-21	2021-01-22																					
Summarize & Analyse study	2021-01-22	2021-01-25																					
Translate Human Interaction	**2021-01-28**	**2021-04-23**																					
Brainstorming	2021-01-28	2021-02-01																					
Concept Generation	2021-01-29	2021-02-19																					
Evaluate Concepts	2021-02-01	2021-02-19																					
Build Models	2021-02-08	2021-02-19																					
Select X Concepts	2021-02-08	2021-02-26																					
Develop Concepts	2021-02-15	2021-04-09																					
Evaluate & Choose Final Concept	2021-03-29	2021-04-09																					
Finalize & Manufacture Final Conce	2021-04-05	2021-04-23																					
Evaluate Final Concept	**2021-04-12**	**2021-05-07**																					
Final Phase	**2021-05-10**	**2021-06-02**																					
Report Writing	**2021-01-13**	**2021-06-02**																					

Figure 12-2. Actual time plan.

Appendix B – Study Template

Nr of children:	**Age:**	**Boys:**	**Girls:**

ÖPPNAR	**Knappt märkbar**	**Liten**	**Stor**
Nyper hårt på sugröret (B/R)			
Tar ut från plastfickan på avvikande sätt			
Råkar böja/bita på sugröret (Ö/I)			
PUNKTERAR PPH			
Klämmer hårt (på sugröret)			
Trycker ner åt fel håll			
Missar hålet/bankar			
DRICKER			
Biter/klämmer mellan läpparna			
Böjs i botten			
Skrapar/drar upp och ner i hål			
EFTER			
Leker			
Stoppar ner hela i förpackningen			

Hur de lekte:

Saker att titta på:

- Hur mycket av sugrören har de i munnen? I förhållande till korrugeringen
- Hur intensivt/hur många gånger de dricker
- Kolla på sugrören efter för att kolla på eventuella bitmärken

Appendix C – Full List of Concept Needs

Table 12-1. User Actions translated into Concept Needs

User Action	***Concept Need*** *- Concept has to be able to produce*
OPENING	
Pinching hard on straw	**Dry straw** - Expose straw to a force
Removes from plastic wrap on a deviating manner	**Dry straw** - Expose corrugation to a force
Bends/Bites on straw	**Dry straw** - Expose straw to sharp concise forces - Bend straw
PUNCTURE PPH	**Dry straw** - Expose tip of the straw to a force
Holding high up on the straw	**Dry straw** - Bend straw
Pushes down straw the wrong way	**Dry straw** - Expose straight end to a force
Misses the hole/hammers straw	**Dry straw** - Produce a hammering motion
DRINKING	**Wet straw** - Transport liquid - Expose straw to liquid on both sides - Expose straw to a force
Bites/squeezes between lips	**Wet straw** - Expose straw to a force - Expose straw to sharp concise forces
Bends in the bottom	**Wet straw** - Expose tip of the straw to a force
Scrapes the straw up and down in the hole.	**Wet straw** - Produce friction along sides of the straw
AFTER	
Blowing into the straw, with and without surrounding liquid	**Dry/wet straw** - Produce inside (and outside) pressure
Flipping the straw and drinking from the other side	**Wet straw** - Transport liquid both ways
Bends straw with hands	**Wet straw** - Bend straw
Spraying drink on each other	**Wet straw**

	- Transport liquid both ways
Spinning the straw around the hole to make it bigger	**Wet straw** - Produce centered friction - Expose straw to sharp concise force - Bend straw
Pounds on straw	**Wet straw** - Expose whole straw to a force
Stretching out straw	**Wet straw** - Pull straw
Bending the straw by the corrugation	**Wet straw** - Bend corrugation
Pulling and pushing the corrugation	**Wet straw** - Pull and push straw
Bending the straw around the package	**Wet straw** - Expose straw to concise forces - Bend straw
Shoots away the straw from package	**Wet straw** - Produce one sided pressure
Pushes down the whole straw in package	**Wet straw** - Expose whole straw to liquid

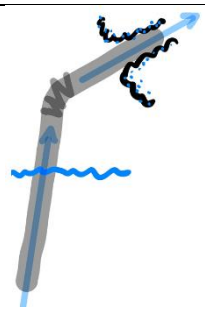
Appendix D – Full List of Evaluated and Grouped Concept Needs

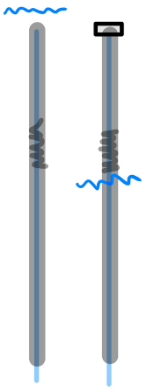
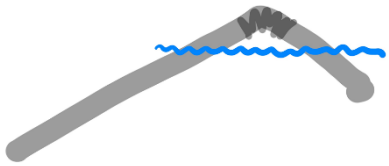
Table 12-2. Full list of evaluated and grouped concept needs.

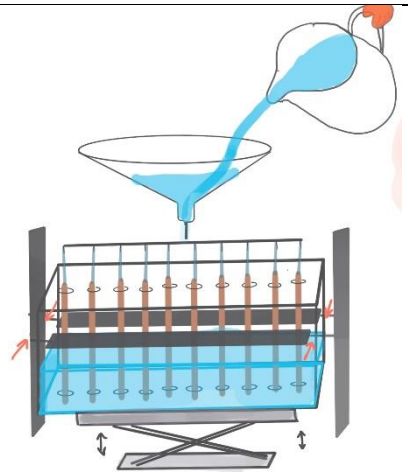
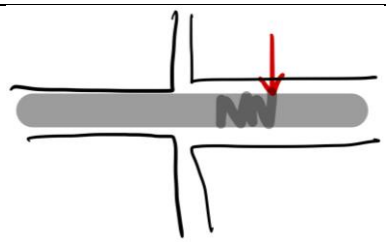
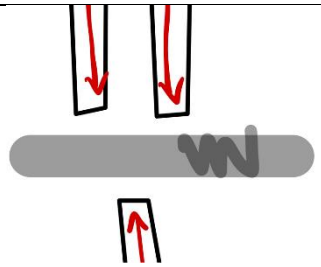
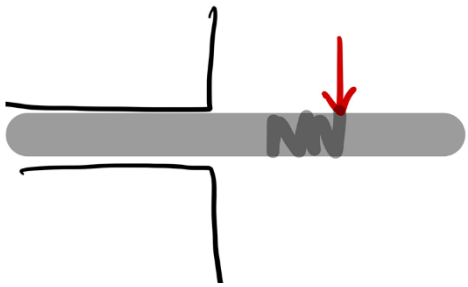
Category of Use (I/F/U)	***Need Number***	***User Action***	***Concept Need*** *Concept has to:*	***Predicted Impact on Paper Straw***	***Relative Importance***
F	1	Pinching on dry straw	*Dry:* Expose straw to a force	*	3
F	2	Removes from plastic wrap on a deviating manner	*Dry:* Expose corrugation to a force	*	3
F	3	Bends/Bites on dry straw	*Dry:* Expose straw to sharp concise forces	**	3
U	4	Bends/Bites on dry straw	*Dry:* Bend straw	**	2
I	5	Puncturing PPH	Dry: Expose tip of the straw to a force (z-direction)	******	***5***
F	6	Holding high up on the straw	*Dry:* Mimic fingers high up on long leg of straw	*	2
U	7	Pushes down straw the wrong way	*Dry:* Expose straight end of the straw to a force	*	2
F	8	Misses the hole/hammers dry straw	*Dry*: Produce a hammering motion	*	2
	9	**Compressing straw**	***Wet:* Expose straw to compression (x- and y-direction)**		5
I		*Drinking*	*Wet: Mimic fingers on straw while transporting water*	*	
U		*Pounds on wet straw*	*Wet: Expose straw to compression*	***	
F		*Squeezes between lips*	*Wet: Mimic lips on straw*	***	

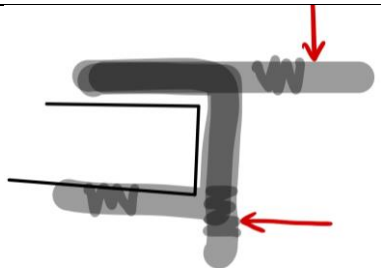
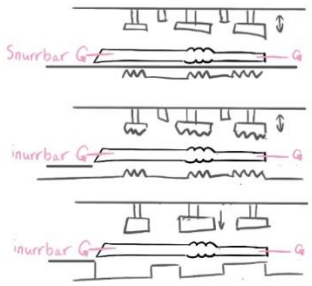
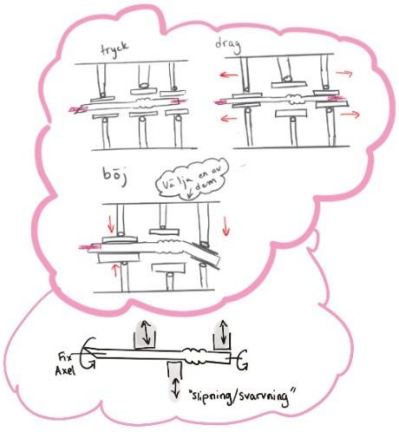
U		*Pushing corrugation on wet straw*	*Wet: Mimic fingers on straw and expose corrugation to compression*	**	
F	10	Bends in the bottom	Dry: Expose tip of the straw to a force (z-direction)	*	2
	11	**Produce friction**	***Wet:* Produce friction along sides of the straw**		4
F		*Scrapes up and down in the hole.*	*Wet: Produce friction along sides of the straw*	**	
U		*Spinning straw around the hole to make it bigger*	*Wet: Produce concise friction on straw*	**	
U	12	Blowing into straw, without surrounding liquid	*Dry:* Expose inside of straw to pressure	*	2
U	13	Blowing into straw, with surrounding liquid	*Wet:* Expose inside of straw to pressure	*	2
	14	**Drinking**	**Wet: Transport liquid**		*5*
U		*Flipping straw and drinking from the other side*	*Wet: Transport liquid both ways*	*	
U		*Spraying drink on each other*	*Wet: Transport liquid both ways*	*	
I		*Drinking*	*Wet: Transport liquid*	*	
I		*Drinking*	*Wet: Expose straw to liquid on inside and outside*	**	
	15	**Bending straw**	***Wet:* Produce bending motion**		5
F		*Bends wet straw with hands*	*Wet: Bend straw*	***	
F		*Bending wet straw by the corrugation*	*Wet: Bend corrugation*	***	
U		*Bending wet straw around the package*	*Wet: Bend straw at multiple spots*	***	
U		*Spinning straw around the hole to make it bigger*	*Wet: Bend straw*	**	
	16	**Pulling and pushing straw**	***Wet*: Produce pulling and pushing motion**		4
U		*Stretching out wet straw*	*Wet: Pull straw*	**	
U		*Pulling and pushing the corrugation of wet straw*	*Wet: Pull and push corrugation*	**	
F	17	Biting straw	Wet: Mimic biting action on straw and produce concise forces	***	5
U	18	Shoots away straw from package	*Wet:* Expose outside of straw to pressure	*	1
U	19	Pushes down whole straw in package	*Wet:* Expose whole straw to liquid	*	1

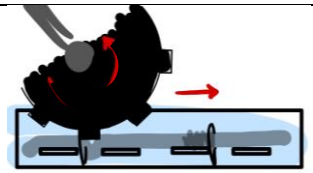
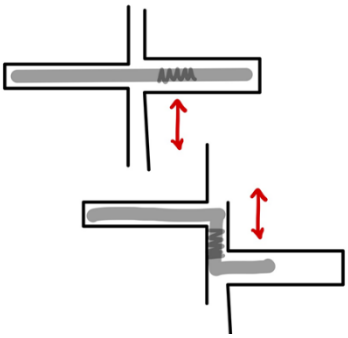
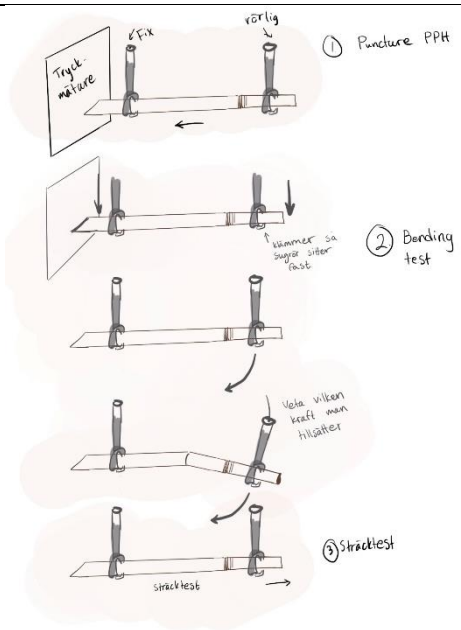
Appendix E – Concept Ideas

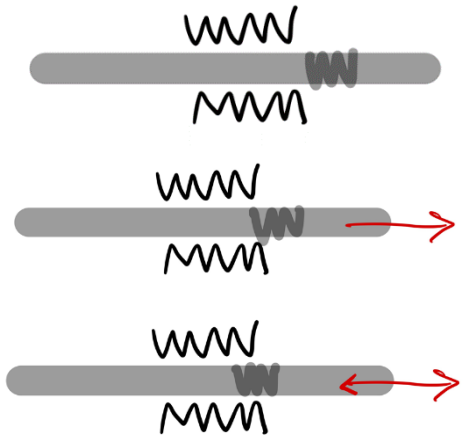
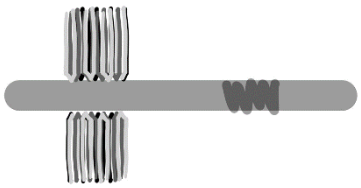
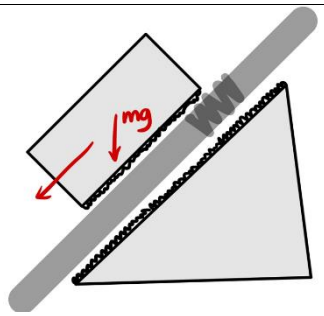
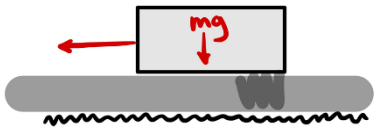
General thoughts: - Use of Multi-Purpose Solution instead of water? - Test with multiple kinds of liquids/temperatures? - Fixture for straw that follows the straw during different operations? - Should straws be straight or slightly bended?		
Drinking		
Description	***Figure***	***Comment***
Long leg in water, short leg exposed to damp cloth. Liquid is transported through straw: - X ml is being pumped every x second, *or* - X ml is poured through straw every x second.		Looks promising, keep.

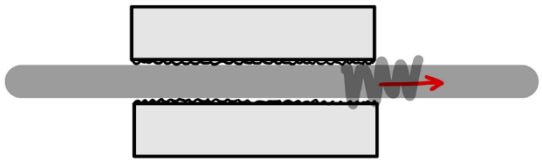
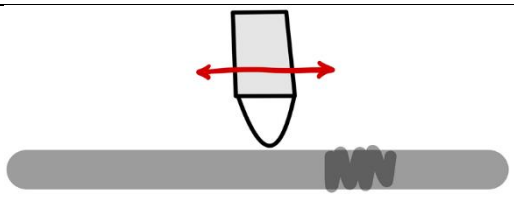
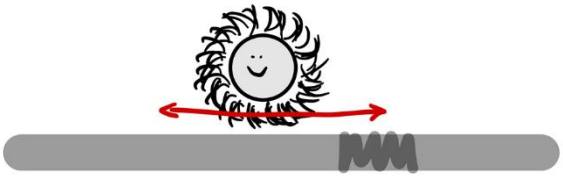
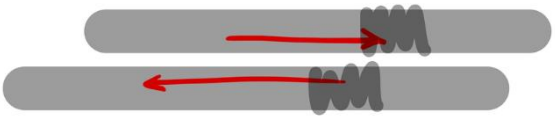
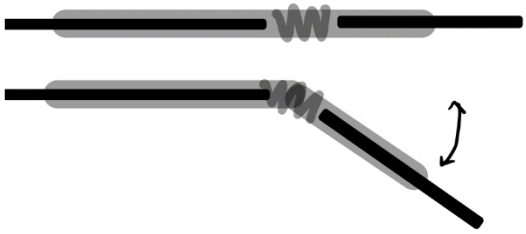
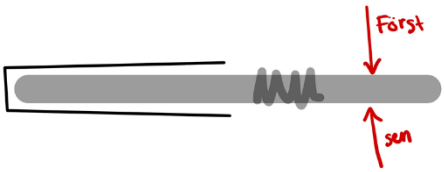
Trasa (något väldig absorberande material) i sugröret som blöts -> gör att det blir blött på insidan, nedre halvan i vatten		Unnecesserly difficult, remove.
Original method		Evaluate level of resemblance to reality.
Operator pours liquid through straw using a funnel.		Similar to another, more promising concept. Remove.
Whole straw is inserted to liquid, clamp closes the opening at short leg. Straw is the halfway removed from liquid. Keeps liquid inside.		Intresting, keep.
Hela sugröret sänks ner i vatten, sedan tas böjen upp medan resten får stå i vatten		Maybe not so promising, but keeps to investigate further.

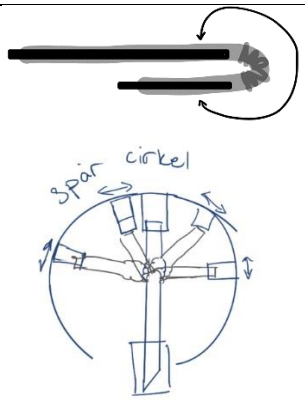
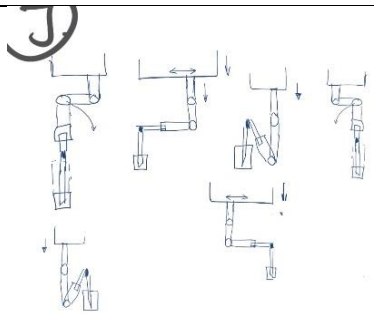
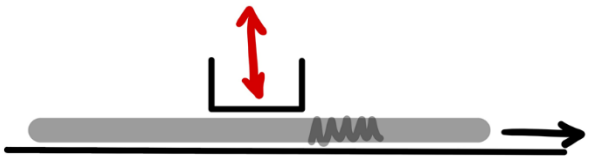
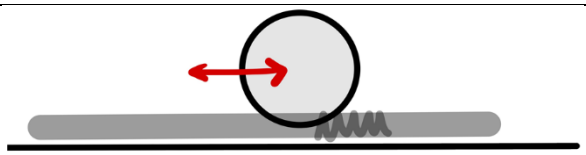
Drinking test Stand in water and pour water		Looks promising, keep.
Bend		
Description	***Figure***	***Comment***
Straw is fastened at two plates that bends.		Looks promising, keep.
Two sticks from above and one from below, moves towards each other and bends straw at one position. - Possible to spin straw		Similar to another concept but less efficient, remove.
Long leg is fixed, short leg is exposed to force that bends straw.		Similar to another concept but less efficient, remove.

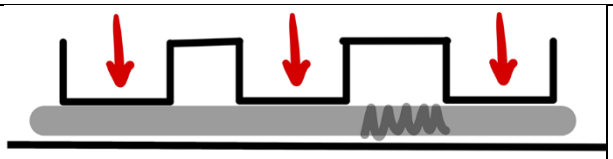
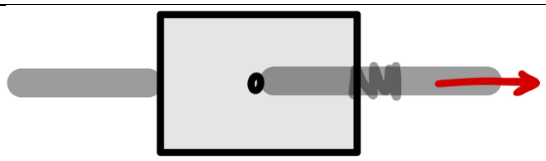
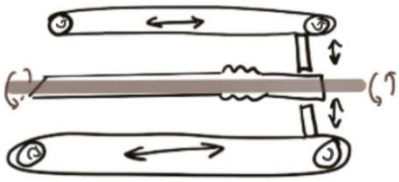
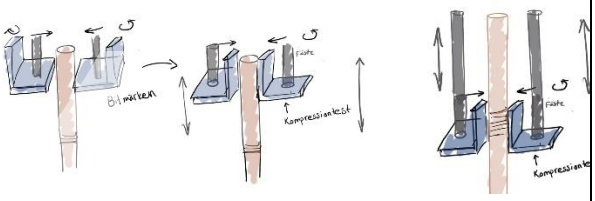
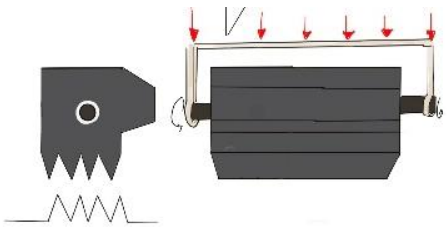
1/3 of straw is fixed, 2/3 of straw is bended and 1/3 is bended again.		Looks promising, keep.
Straw is exposed to a force from above, cavity underneath.		Similar to another concept but less efficient, remove.
Straw is fastened on ground. Replaceable heads to mimic biting, pinching, and bending. - Possible to spin straw		Looks promising, keep.
Straw is "floating". The heads are joint in order to follow the straw. Replaceable and can go up and down. - Possible to spin Bending, biting, pinching, and friction		Looks promising, keep.

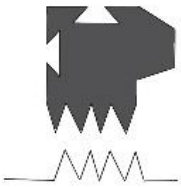
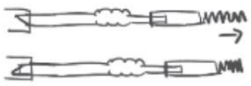
Gearwheel and plate with cavities.		Looks promising, keep.
Long leg is fixed, a cylinder is applied to short leg and moved up and down.		Looks promising, keep.
Straw is clamped between two claws that can move sideways. A scale or similar where the force is measured. One claw is fixed and the other is flexible. Bending test, compression, pinching, and tensile test		Similar to another concept but less efficient, remove.
Bite		
Description	***Figure***	***Comment***

Two rows of teeth, one on each side of straw. - Possible to spin - Bite and pull - Bite and pull/push		Looks promising, keep.
Four rows of teeth, one on each side of straw.		Not possible to spin and difficult to manufacture ? Remove.
Two plates with spikes - Possible to spin		Similar to another concept but less efficient, remove.
Friction		
Description	***Figure***	***Comment***
Inclined plane		Unnecesserly difficult, remove.
Pull straw on plate with high friction, mass upon straw		Similar to another concept but less efficient, remove.

Straw is pulled between two surfaces with high friction		Looks promising, keep.
Finger/stick with high friction - Possible to spin		Looks promising, keep.
Spinning brush - Possible to spin		Out of scope, remove.
Two damp straws that are pulled on top of each other		Out of scope, remove.
Böj av korrugering		
Description	***Figure***	***Comment***
Two sticks that are inserted into the straw, bends the straw		Similar to another concept but less efficient, remove.
Long leg is fixed, short leg is exposed to a force that bends the corrugation.		Looks promising, keep.

Two sticks that are inserted into the straw, can bend the straw in 360 degrees. Fixed in bottom. Top stick rotates in a circular track.		Looks promising, keep.
Arm with joints. Straw is fastened in bottom.		Looks promising, keep.
Pinch		
Description	***Figure***	***Comment***
Straw is moving and a force is applied from above.		Similar to another concept but less efficient, remove.
Whole straw is compressed at once.		Looks promising, keep.
The straw is being rolled.		Looks promising, keep.

Compressed at multiple positions. - Possible to spin		Looks promising, keep.
Straw is pulled through a thin opening		Out of scope, remove.
Straw is pulled through a small hole.		Out of scope, remove.
Straw is fastened and belt to move the biting head. - Possible to spin		Similar to another concept but less efficient, remove.
Tool is rotatable and has different sides for biting and compression. Straw is fixed and tool moves up and down.		Similar to another concept but less efficient, remove.
Tool has different sides, rotatable. Shaft through. Straws are placed on table. Compression and biting.		Looks promising, keep.

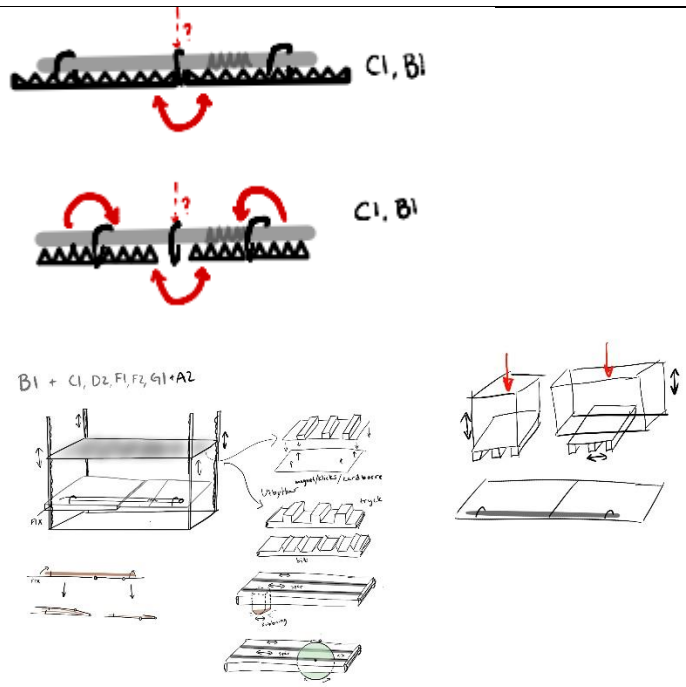
Tool with different profiles. Slides on. Operator switches profiles by hand. Compression and biting		Looks promising, keep.
Pull and push		
Description	***Figure***	***Comment***
One clamps on each side of the straw, pulls and pushes.		Similar to another concept but less efficient, remove.
Long leg is fixed, pull and push on short leg using a clamp.		Looks promising, keep.
A mass is applied to the bottom of the straw, gravity cause a pulling motion.		Not so promising, remove.
Straw is pulled through a small hole.		Out of scope, remove.
Straw is fastened and tensile strength is tested with spring		Unnecesserly complicated, remove.

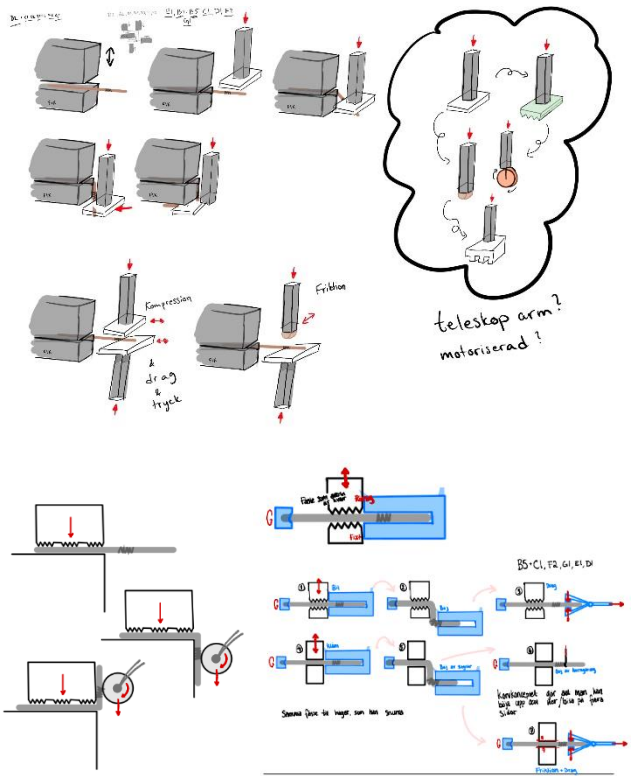
Appendix F - Concept Combinations

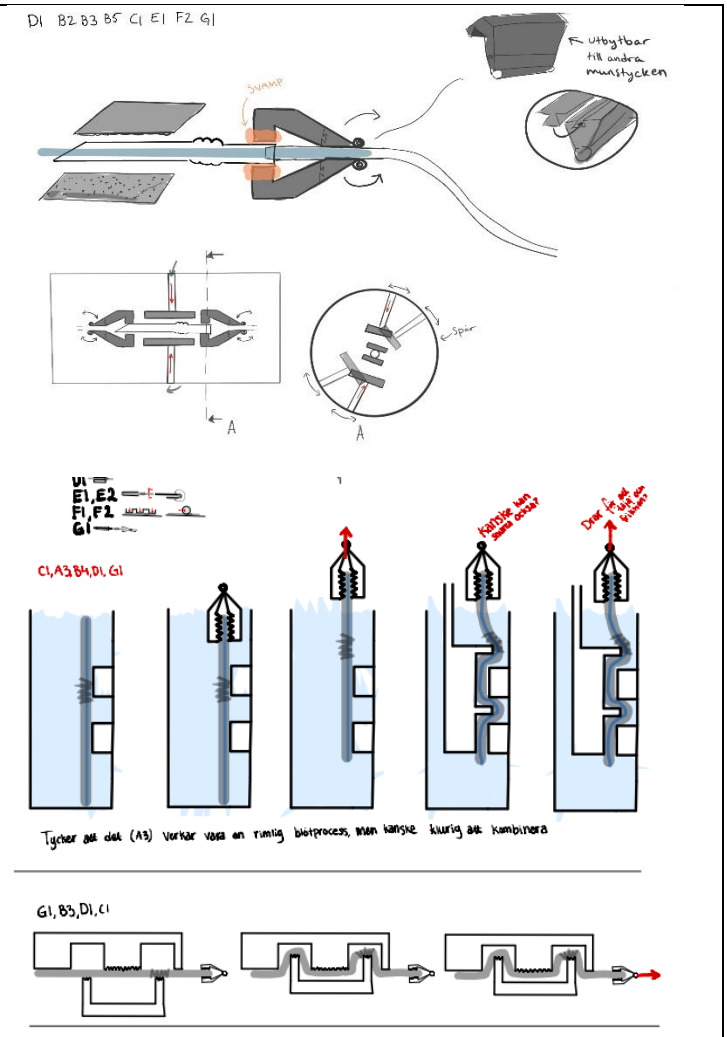
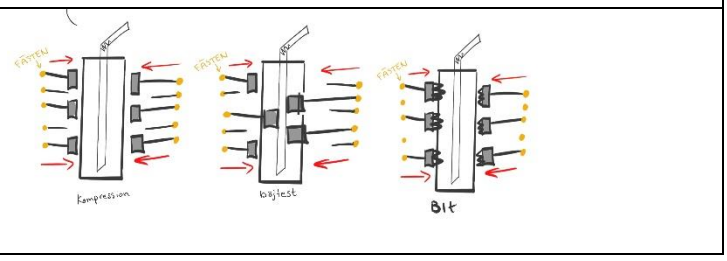
Concept	***Possible to combine with***
A1	C1, F2
A2	B1, B3, B4, D2, F1, F2
A3	C1, (F2*)
A4	
B1	A2, C1, D2, F1, F2, G1
B2	C1, D2, E1, F1, F2, G1
B3	A2, C1, D1, D2, F2, (G1*)
B4	A2, C1, D2, F1
B5	C1, D1, E1, E2, F2, G1
C1	A1, A3 B1, B2, B3, B4, B5, D1, E1, E2, F1, F2, G1
D1	B2, B3, B5, C1, E1, F2, G1
D2	A2, B1, B2, B3, F1, F2
E1	B2, B5, C1, D1, F2, G1
E2	B5, C1, F1, F2
F1	A2, B1, B2, B4, C1, D2, E2
F2	A1, A2, (A3*), B1, B2, B3, B5, C1, D1, D2, E1, E2, G1
G1	B1, B2, (B3*), B5, C1, D1, F2, E1

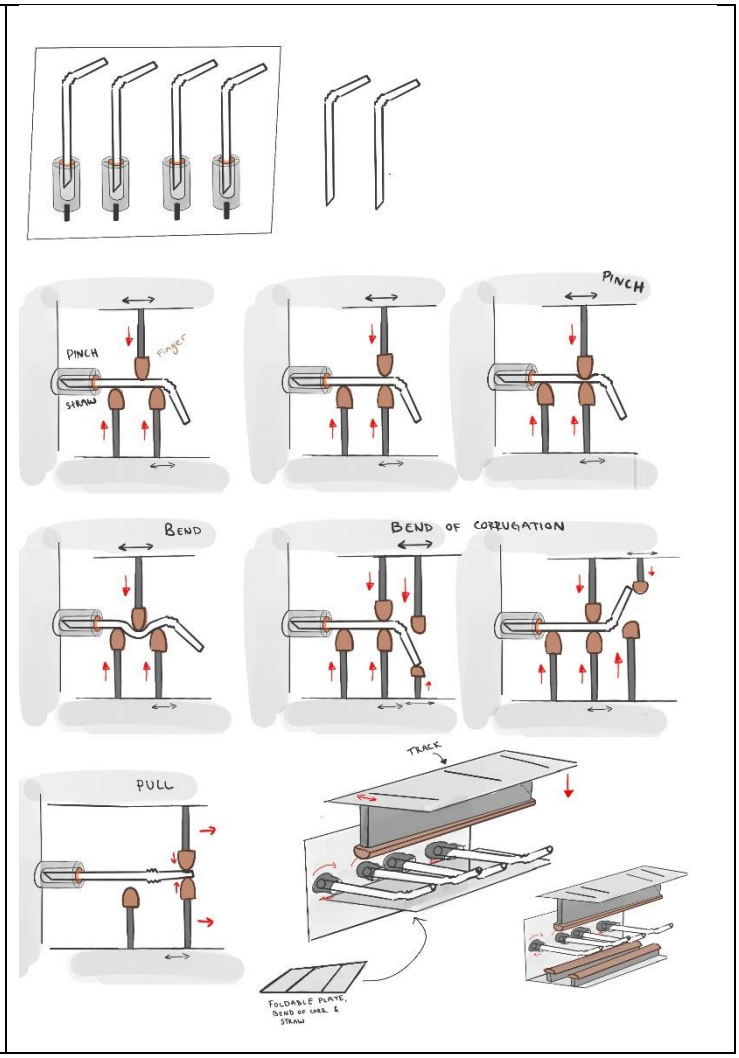
*Some difficulties but might be possible

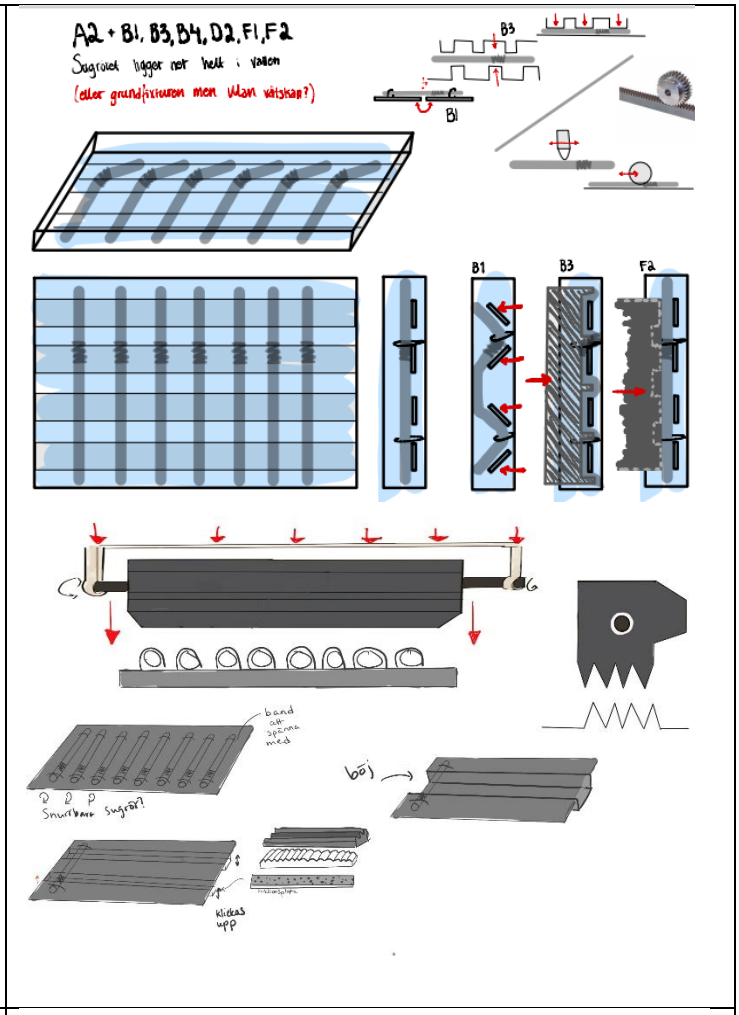
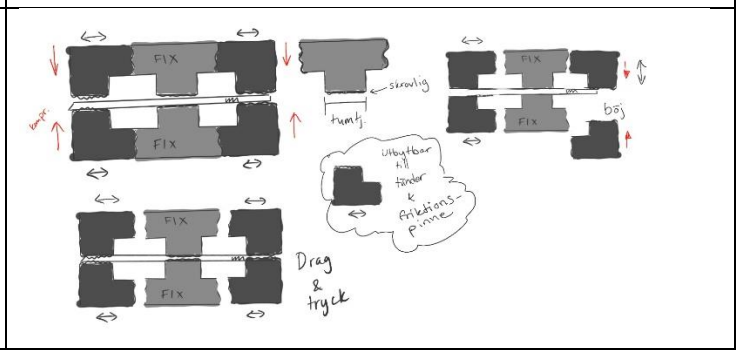
Appendix G – Combined Concepts

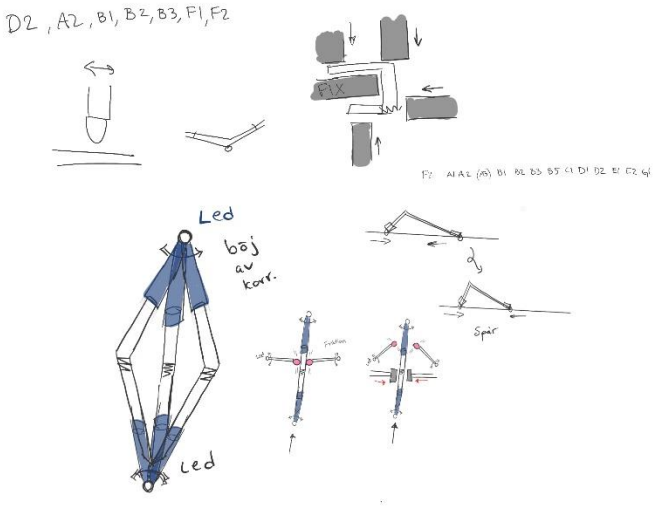
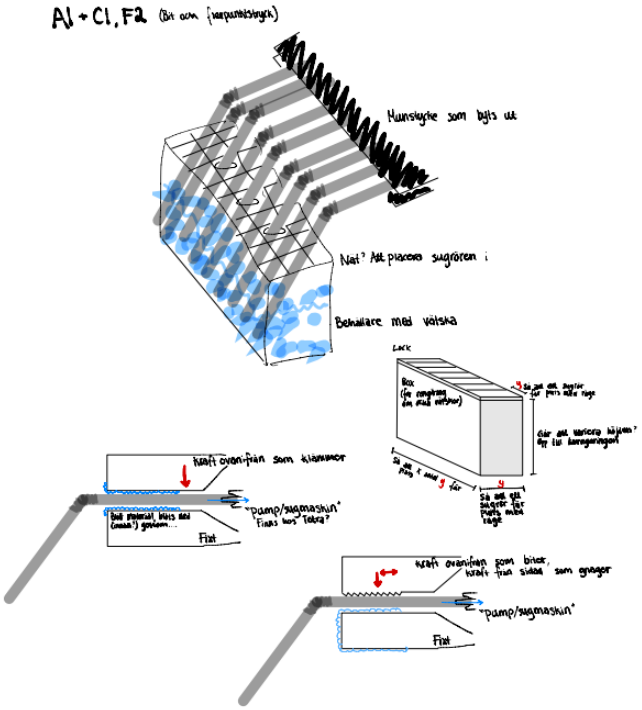
Concept Number	*Combination of Concept Needs*	*Description*
1	B1, C1, D2, F2, G1	

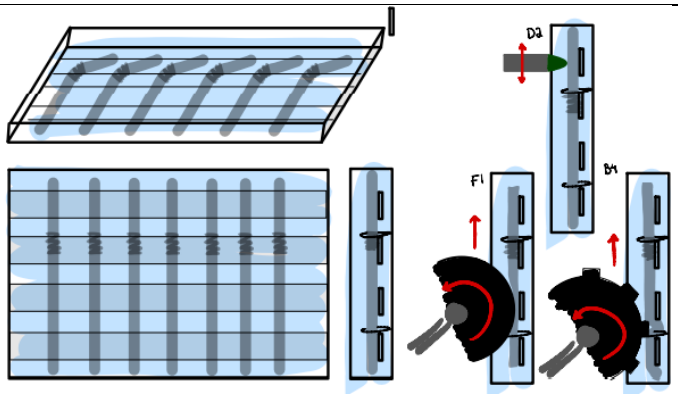
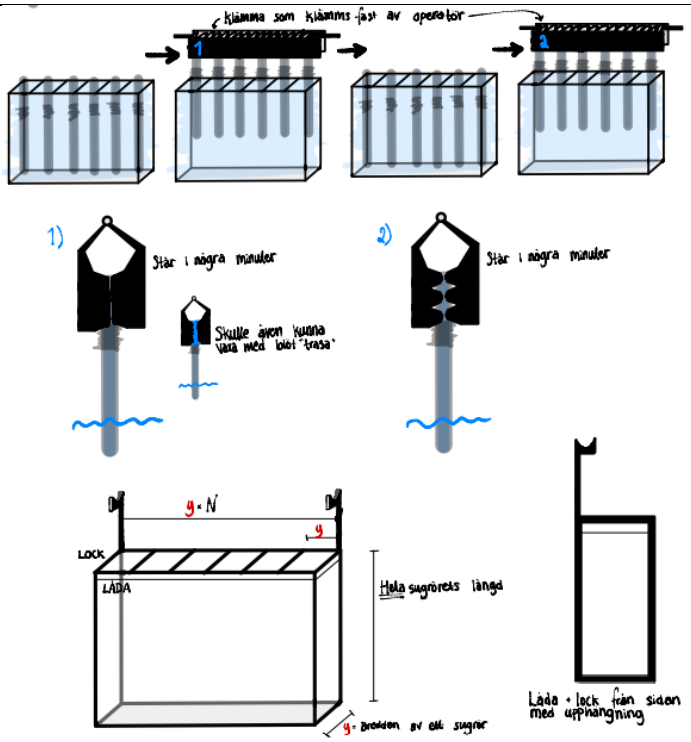
2	B5, C1, E1, F2, G1	

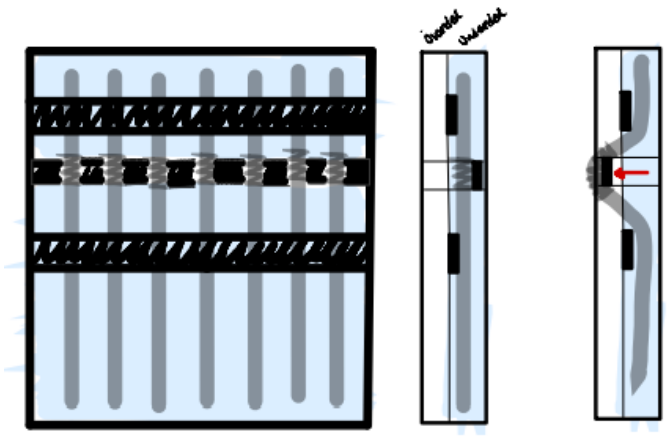
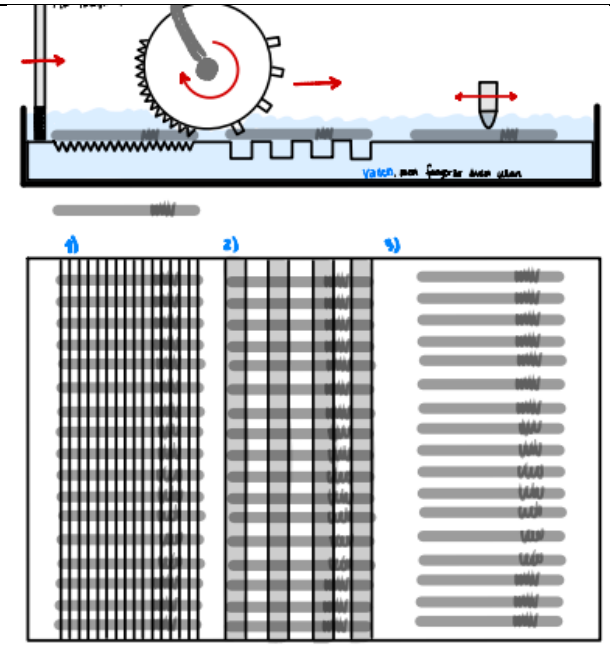
3	C1, D1, E1, F2, G1	
4	B3, C1, E1, F2	

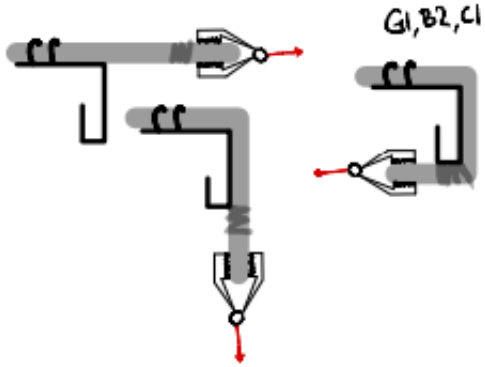

PINCH
Finger
STRAW
PINCH
BEND
BEND OF CORRUGATION
PULL
TRACK
FOLDABLE PLATE,
BEND OF CORR. &
STRAW

5	A2, B1, B3, B4, D2, F2	
6	B5, C1, E1, F2, G1	

7	D2, E2, F1, G1	
8	A1, C1, F2	

9	A2, B4, D2, F1	
10	A3, C1, F2	

11	A4	
12	B4, C1, D2, F1	

13	B2, C1, G1	

Appendix H – Test of Drinking Concepts

Table 12-3. Procedure for test of drinking concepts

Step	***Description***
1.	Insert straw 1 to glass of water, long leg in water and short leg above water. Insert straw 2 to glass of water, both long leg and short leg in water. Insert straw 3 fully into glass of water, apply damp cloth and clamp to short leg. Remove half of straw from water, long leg in water and short leg above water. Insert straw 4 to glass of water, long leg in water and short leg above water. Put straw inside funnel with damp cloth.
2.	Take two sips, approximately 15 ml, of water from straw 1 and pour 15 ml of water into straw 4 through the funnel, see Figure 12-3.
3.	Wait 1 minute and repeat step 2. Redo this step five times (five minutes).
4.	Remove the straws from the glasses.
5.	Using the index finger, press on the marked position on the short leg twice on all straws. Use the other hand to hold the straw in place. Evaluate the perceived force needed. Do this on all compression positions. Bend straws according to Figure 12-4 and evaluate the perceived force needed.
6.	Redo step 1.
7.	Redo step 2 once every minute for ten minutes.
8.	Redo step 4 to 6.
9.	Let the straws sit in water for 45 minutes. Take two sips with straw 1 after the 45 minutes have passed, evaluate the difficulty to drink.
10.	Redo step 4 to 6.
11.	Let the straws sit in water for 1 hour. Take two sips with straw 1 after the hour has passed, evaluate the difficulty to drink.
12.	Redo step 4 and 5.

Figure 12-3. Procedure for straw 4, pouring 15 ml of water into the straw.

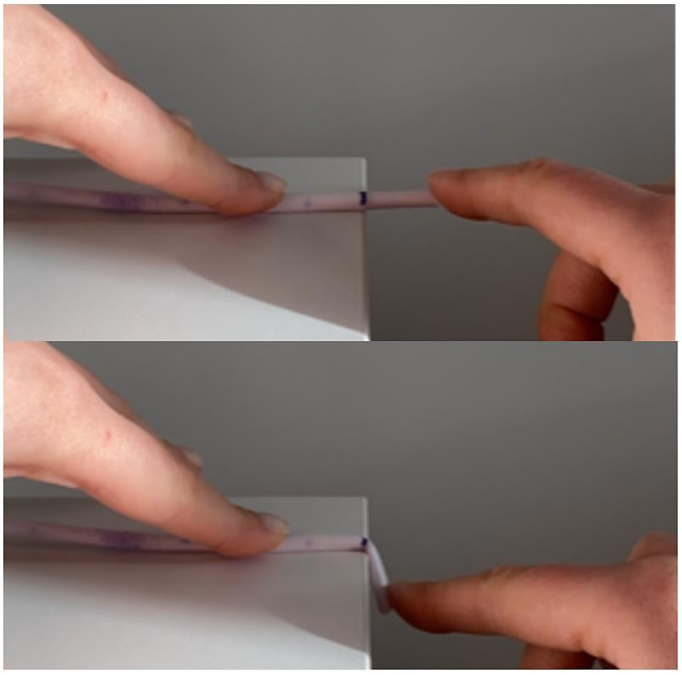
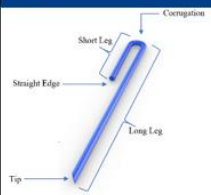


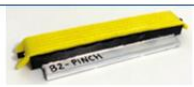
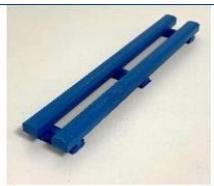
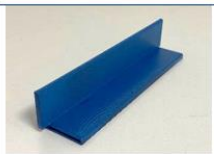
Figure 12-4 Procedure for bending test

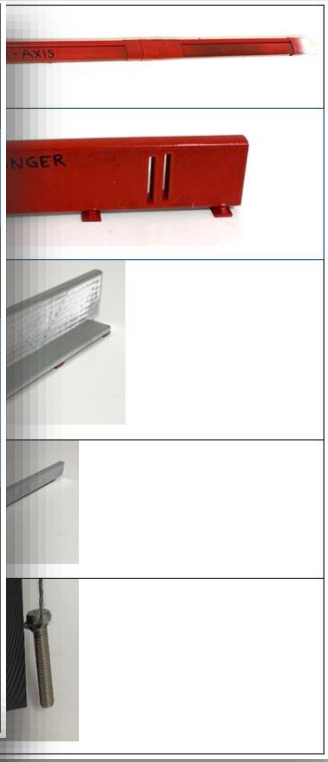
Appendix I – Concept Testing Instructions

1 Parts

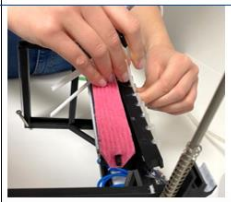
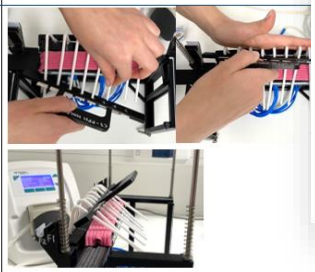
Part Name	Picture
Short leg	
Long leg	
PPH cut out	
Water container 1	
Water container 2	

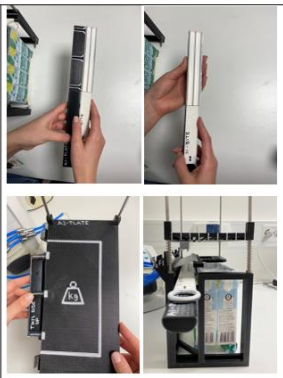
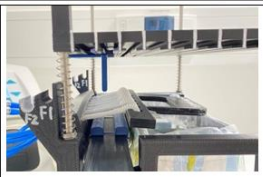
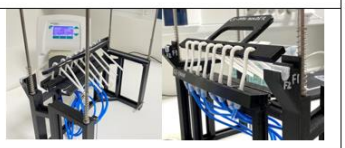
Stand	
A1 - Plate	
A2 - Plate	
A3 - Plate	

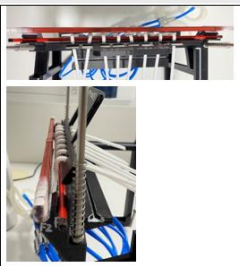
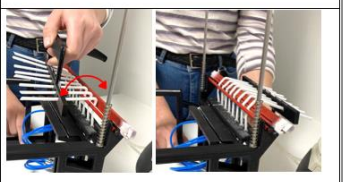
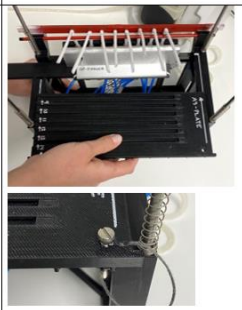
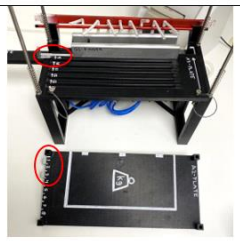
B1 – Pinch	
B2 – Pinch	
C1 - Straw Holder	
C2 - Snap	
C3 – PPH holder	
D1 - Bite	
D2 - Bite	
E1 – Finger	
E2 – Finger	
F1 - Axis	

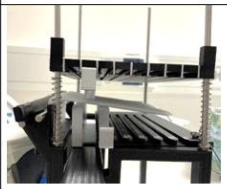
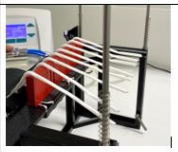


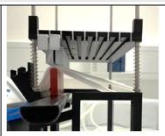
2 Test Execution

Step	Action	Picture/Comment
1.	Apply B1 – Pinch to A1 – Plate and place them in Stand – see picture.	
2.	Insert short leg on 8 straws into C1 - Straw Holder up to the marked line. Apply C2 - Snap to lock the straws in place.	
		
3.	Insert eight PPH cut outs into C3 - PPH holder.	
4.	Puncture all PPHs with one straw each, using the long leg, leave the straws in C3 - PPH holder.	
5.	Place water container 1 in its correct position and rotate C1 - Straw Holder to the start position. Note! The short legs should be horizontal, and the long legs should be in the container.	
6.	Place A2 - Plate in its correct position.	
7.	Place B2 - Pinch in its correct position on A2 - Plate.	
		
8.	Start the pump.	
9.	**Pinching with lips:** After 2 minutes; place 15 kg weight inside the white square of A2 - Plate to pinch short leg.	

10.	When the pump has stopped; remove weights and replace B1 – Pinch with D1 – Bite. Then replace B2 – Pinch with D2 – Bite.	
11.	**Biting:** Place 15 kg weight on A2- Plate. After 1 minute, remove 5 kg and pull D1 – Bite back and forth 10 times to produce a grinding motion. Note! The movement is very little – 2 mm.	
12.	Remove all weights and replace D1 – Bite with E1 – Finger, and D2- Bite with E2 – Finger.	
13.	**Bending short leg:** Apply 15 kg weight. After 1 minute, remove weight, A1 – Plate and A2 – Plate, and water container 1.	
14.	Rotate C1 - Straw Holder 90 degrees so that the straws' short leg is vertical instead.	

15.	Place F1-Axis and F2 – Axis in their marked positions on Stand. F1 should go "under" the corrugation and F2 on the outside – see picture.	
16.	**Friction:** Pull C3 - PPH Holder back and forth 15 times along the straws' long leg.	
17.	**Bending of corrugation:** Use C3 - PPH holder to bend the straws' corrugation 180 degrees 15 times. C3 should be approximately on the middle of long leg.	
18.	Remove C3 - PPH holder.	
19.	Apply G1 – Finger to A1 – Plate and put them into stand. Make sure all straws are above G1 – Finger.	
20.	Place A3 – Plate in Stand and lock with Sprints – see picture.	
21.	Place G2 – Finger in track 9 on A3 – Plate. Place G2 – Finger in track 1 & 3 on A3 – Plate.	

22.	Place A2 - Plate in its correct position on Stand.	
23.	**Pinching of long leg:** Apply 15 kg weight to A2 – Plate, remove weights after 1 minute.	
24.	**Bending of long leg:** Remove G2 – Finger from track 3 and move G2 – Finger from track 1 to track 2. Note! You may need to lift the plate to insert the finger. This is to make sure the straws stay on top of fingers on the bottom plate.	
25.	Apply 15 kg weight to A2 - Plate, remove weights after 1 minute.	
26.	Change position for G2 – Finger on A2 - Plate to track 4.	
27.	Apply 10 kg weight to A2 - Plate, remove weights after 1 minute.	
28.	Remove A2 – Plate and A3 – Plate.	
29.	**Pinching of corrugation:** Replace G1 – Finger with F3 – Finger.	
30.	Remove F1 – Axis and F2 – Axis.	
31.	Rotate C1 - Straw Holder approximately 45 degrees and let the corrugations rest on F3 - Finger.	

32.	Insert two G2 – Finger to track 1 and 2 and place A2 - Plate on Stand.	
33.	Apply 15 kg weight to A2 - Plate, remove after 2 minutes.	
34.	Remove A1 - Plate and A2 – Plate and place Water Container 1 back in its correct position. Rotate C1 - Straw Holder back to the start position. Note! The short legs should be horizontal, and the long legs should be in the container.	 
35.	Start the pump. The test is finished when the pump has stopped, good job!	

The settings below were used by the team members during tests in the Instron, the procedure was the same as above but without the pump steps. The values for extension are maximum values, meaning that the machine will stop if this distance have been reached before the maximum force have been reached. The extension values depend on the starting position and the tools used.

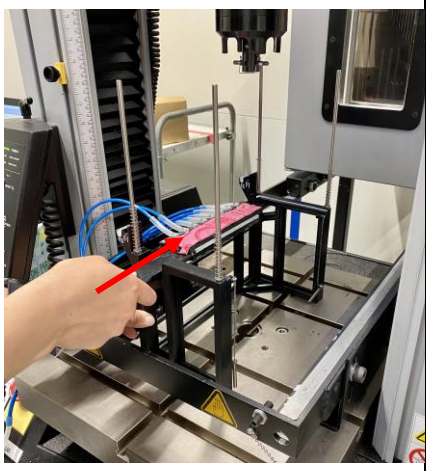
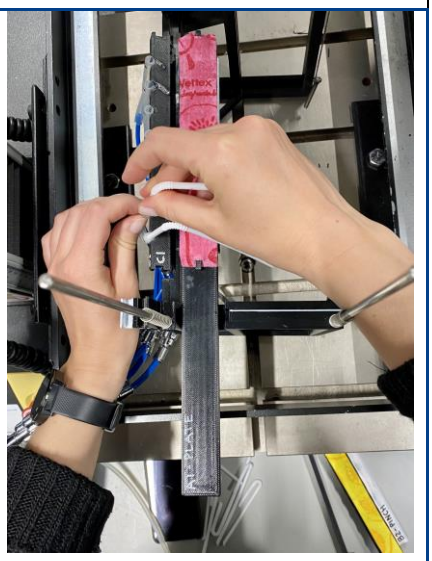
Start settings	
Maximum Force	300 N
Start Position of Instron	550 mm

Action	***Extension (mm)***	***Time (min)***	***Number of times***
Pinch with lips	80	3	
Pinch long leg	45	5	
Bend long leg	60	-	4
Bend long leg	60	5	
Bend long leg second pos.	60	-	4
Bend long leg second pos.	60	5	
Pinch corr.	45	5	
Bending of short leg	80	5	
Bite	85	5	
Bite - Grind	77	-	10

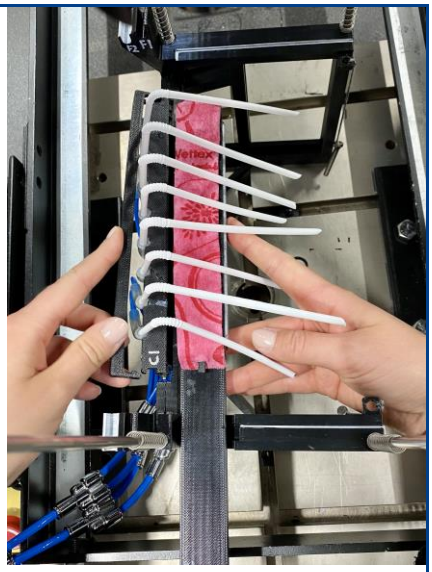
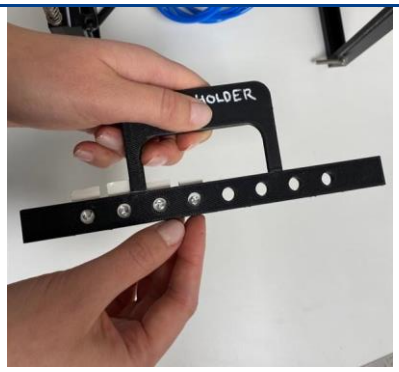
Appendix J – Proposed Execution Procedure

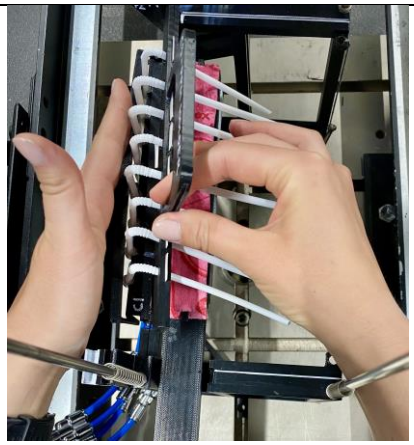
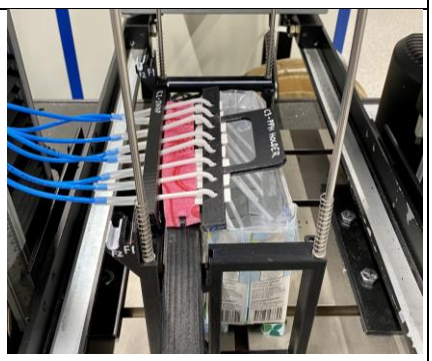
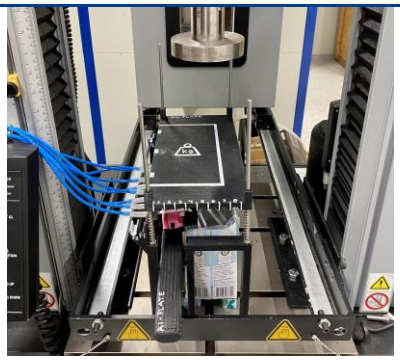
Note! This procedure applies to the prototype and to plastic U-straws, another procedure might be needed for the actual concept and for paper straws.

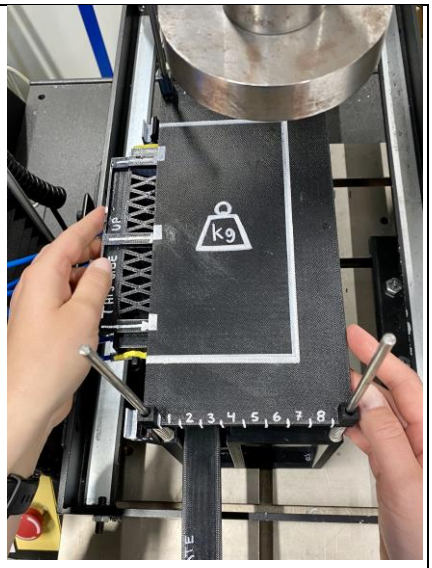
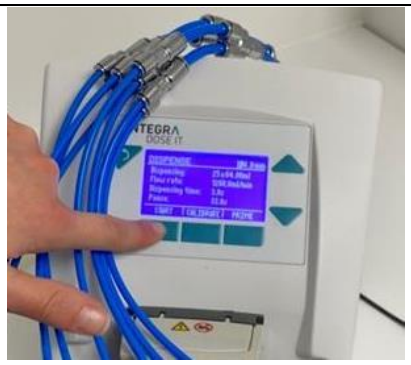
Step	***Action***	***Picture***
1.	Place Stand inside Instron and turn Instron on.	

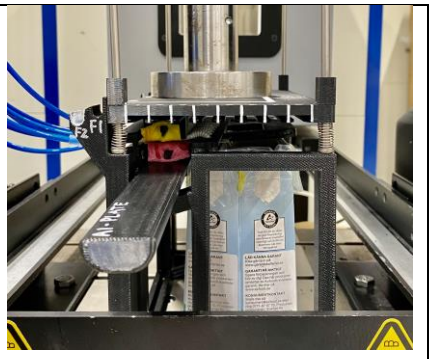
2.	Apply BI – Pinch to A1 – Plate and place them in Stand – see picture for description of where.	 
3.	Insert short leg on 8 straws into CI - Straw Holder up to the marked line. Apply C2 - Snap to lock the straws in place.	

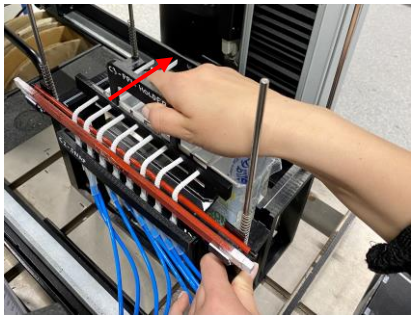
		 

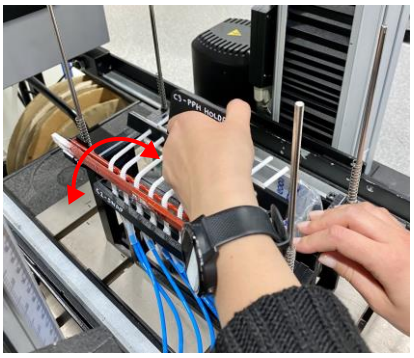
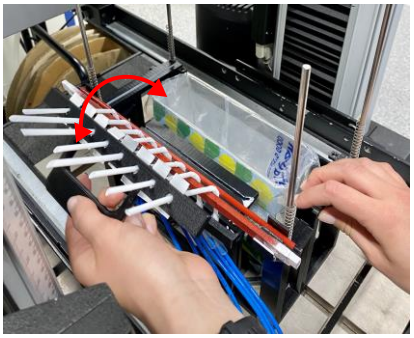
		
4.	Insert eight PPH cut outs into C3 - PPH holder.	
5.	Puncture all PPHs with one straw each, using the long leg, leave the straws in C3 - PPH holder.	

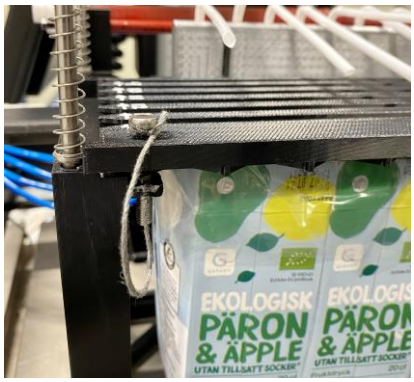
		
6.	Place water container 1 in its correct position and rotate C1 - Straw Holder to the start position. Note! The short legs should be horizontal, and the long legs should be in the container.	
7.	Place A2 - Plate on stand.	

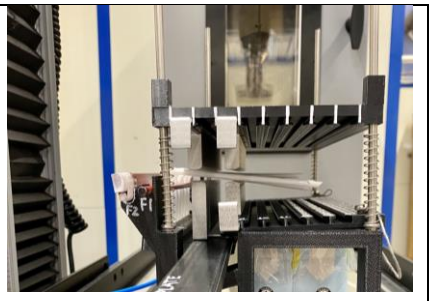
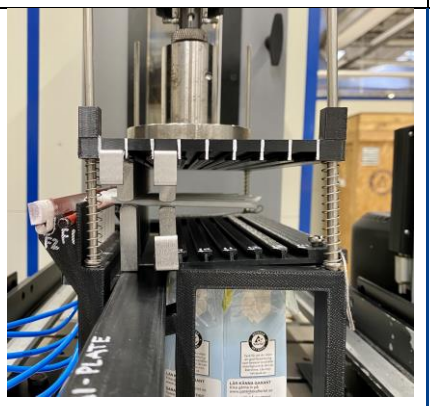
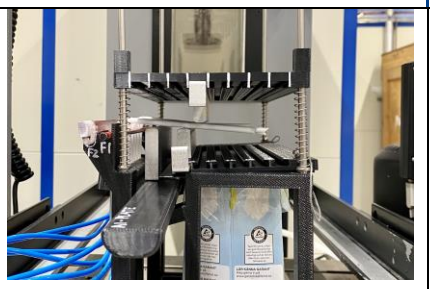
8.	Place B2 - Pinch on A2 - Plate.	 
9.	Start the pump.	

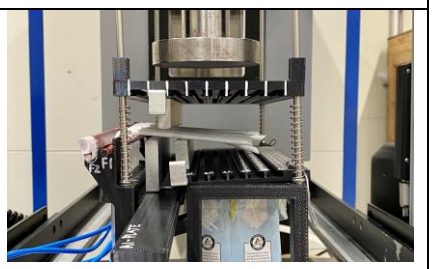
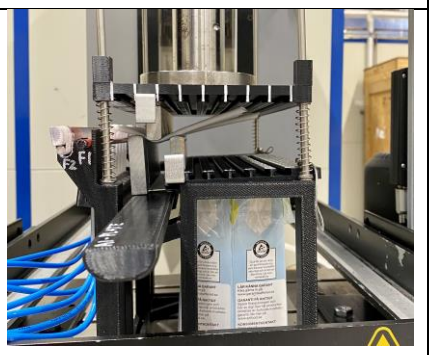
10.	**Pinching with lips:** After 2 minutes; start the Instron so that the straws are pinched.	
11.	When the pump has stopped; return the Instron to its start position.	
12.	Rotate C1 - Straw Holder 90 degrees so that the straws' short leg is vertical instead.	

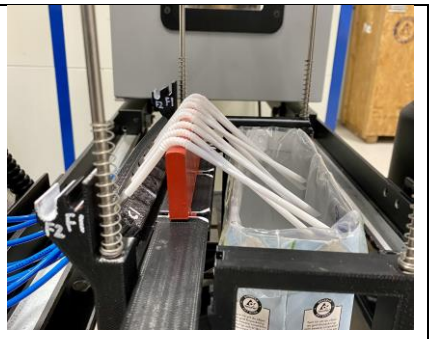
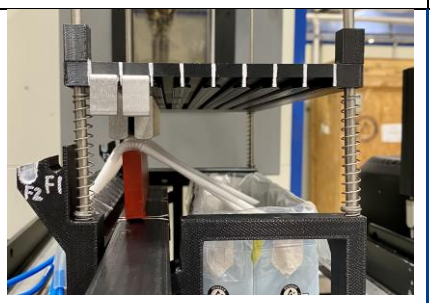
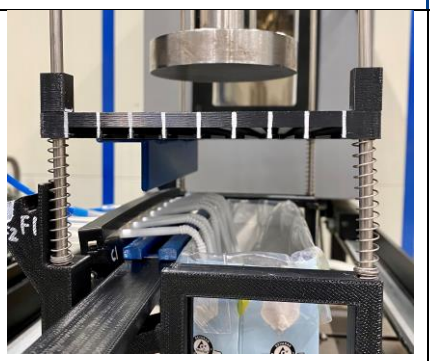
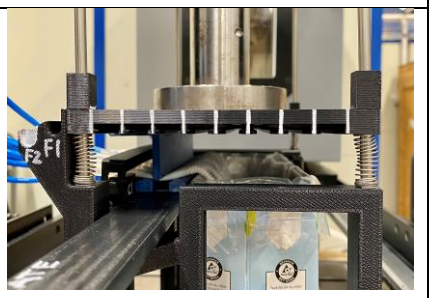
13.	Place F1 - Axis and F2 – Axis in their marked positions on Stand. F1 should go "under" the corrugation and F2 on the outside – see picture.	 
14.	**Friction:** Pull C3 - PPH Holder back and forth 15 times along the straws' long leg.	 

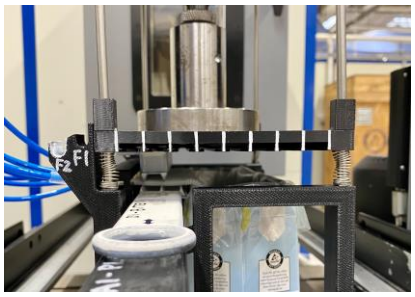
15.	**Bending of corrugation:** Use C3 - PPH holder to bend the straws' corrugation 180 degrees 15 times. C3 should be approximately on the middle of long leg.	 
16.	Remove C3 - PPH holder.	
17.	Apply G1 – Finger to A1 – Plate and put them into stand. Make sure all straws are above G1 – Finger.	

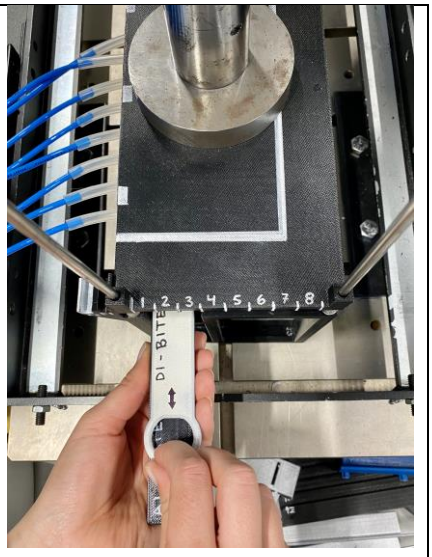
18.	Place A3 – Plate in Stand and lock with Sprints – see picture.	 
19.	Place G2 – Finger in track 9 on A3 – Plate. Place G2 – Finger in track 1 & 3 on A3 – Plate.	

20.	Place A2 - Plate in its correct position on Stand.	
21.	**Pinching of long leg:** Start Instron, return to its start position after 5 minutes.	
22.	**Bending of long leg:** Remove G2 – Finger from track 3 and move G2 – Finger from track 1 to track 4. Note! You may need to lift the plate to insert the finger. This is to make sure the straws stay on top of fingers on the bottom plate.	

23.	Start the Instron, when it has stopped, immediately return it to its start position. Repeat 4 times, on the 5th time – wait 5 minutes before returning the Instron to its start position.	
24.	Change position for G2 – Finger on A2 - Plate to track 2.	
25.	Start the Instron, when it has stopped, immediately return it to its start position. Repeat 4 times, on the 5th time – wait 5 minutes before returning the Instron to its start position.	
26.	Remove A2 – Plate and A3 – Plate.	
27.	**Pinching of corrugation:** Replace G1 – Finger with F3 – Finger. Remove F1 – Axis and F2 – Axis.	

28.	Rotate C1 - Straw Holder approximately 45 degrees and let the corrugations rest on F3 – Finger.	
29.	Insert two G2 – Finger to track 1 and 2 and place A2 - Plate on Stand.	
30.	**Bending of Short leg:** Replace G2 – Fingers and F3 – Finger with E1 – Finger and E2 – Finger. Rotate C3 – Straw Holder so that the short legs are horizontal and long legs in the water container.	
31.	Start Instron, return to its start position after 5 minutes.	

32.	**Biting:** Replace G2 – Fingers with D2 – Bite and F3 – Finger with D1 – Bite. Start the Instron, return to its start position after 5 minutes.	  

33.	Start the Instron, when it has reached its lower position, pull <u>D1 – Bite</u> back and forth 10 times to produce a grinding motion. Note! The movement is very little – 2 mm.	
34.	Return the Instron to its start position.	
35.	Start the pump.	

Appendix K – CAD Parts

Tetra Pak Assembly Number: 3679428-0101.asm

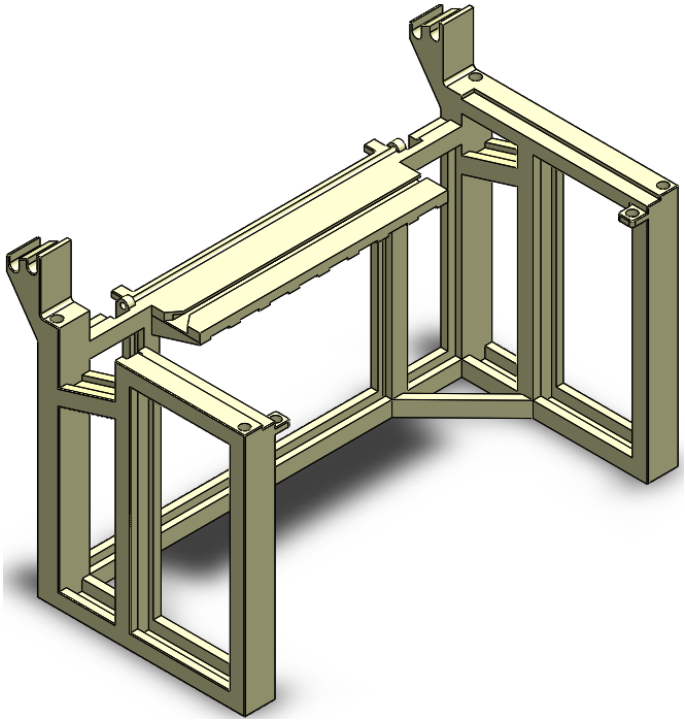


Figure 12-5. Stand

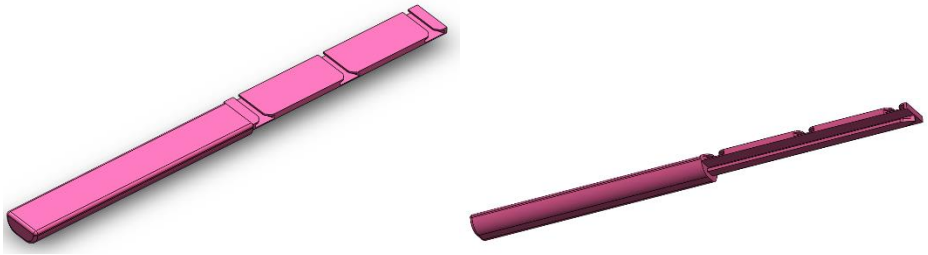


Figure 12-6. A1 – Plate

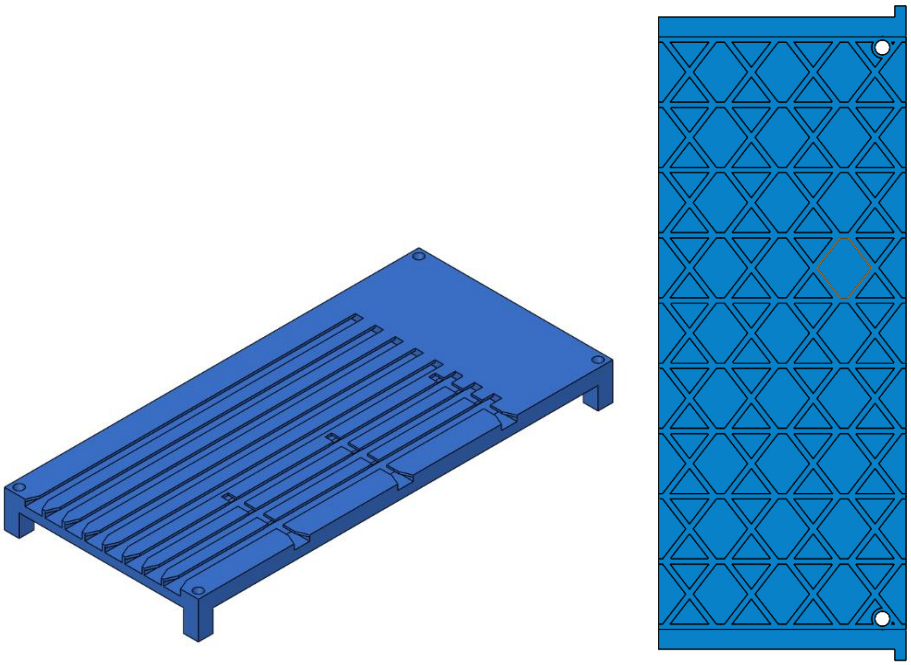


Figure 12-7. A2 – Plate

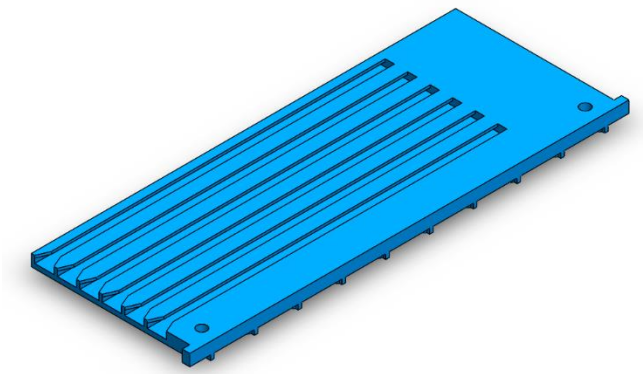


Figure 12-8. A3 – Plate

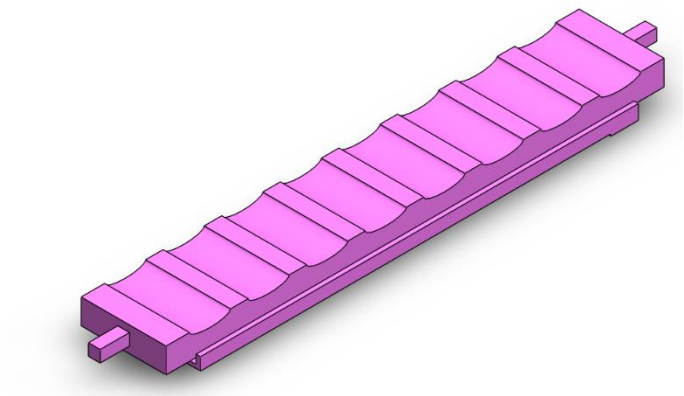


Figure 12-9. B1 – Pinch

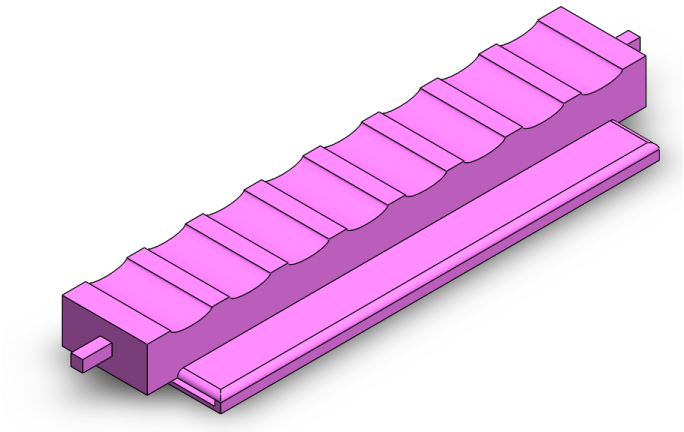


Figure 12-10. B2 – Pinch

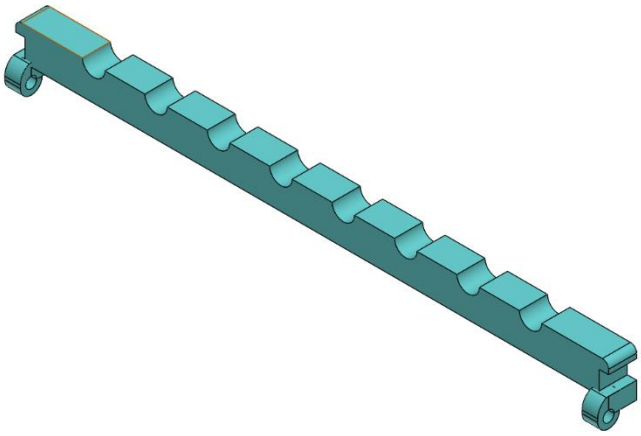


Figure 12-11. C1 - Straw Holder

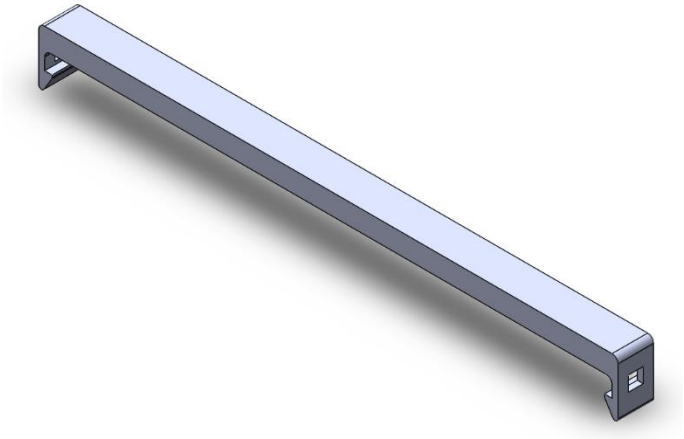


Figure 12-12. C2 - Snap

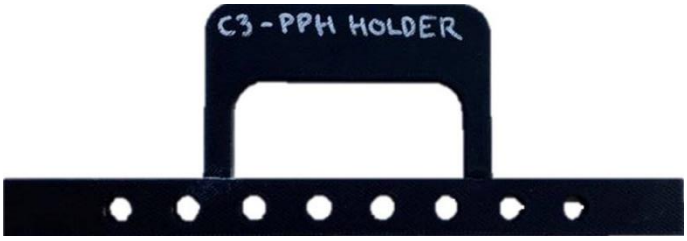


Figure 12-13. C3 - PPH Holder

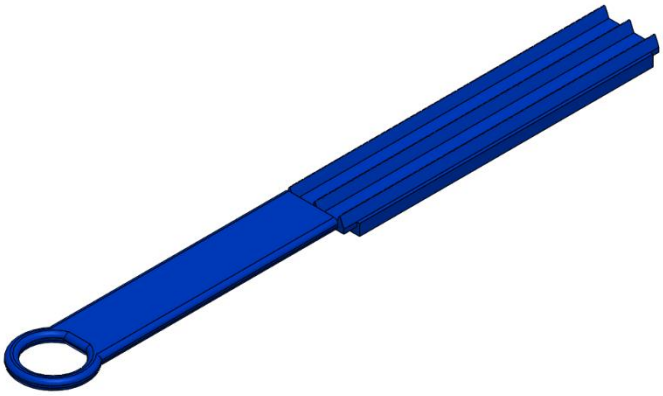


Figure 12-14. D1 – Bite

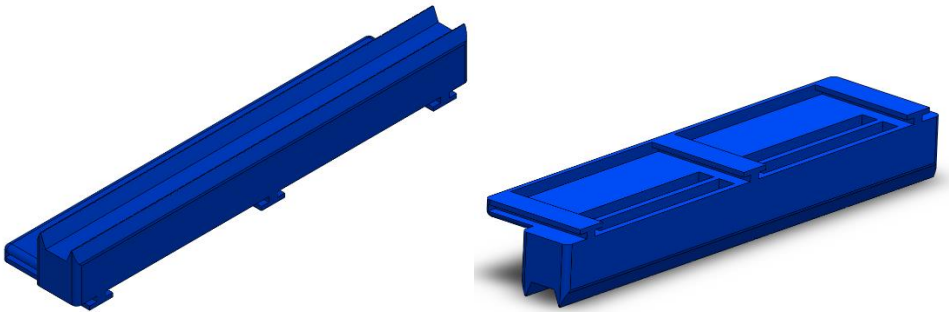


Figure 12-15. D2 – Bite

Figure 12-16. E1 – Finger

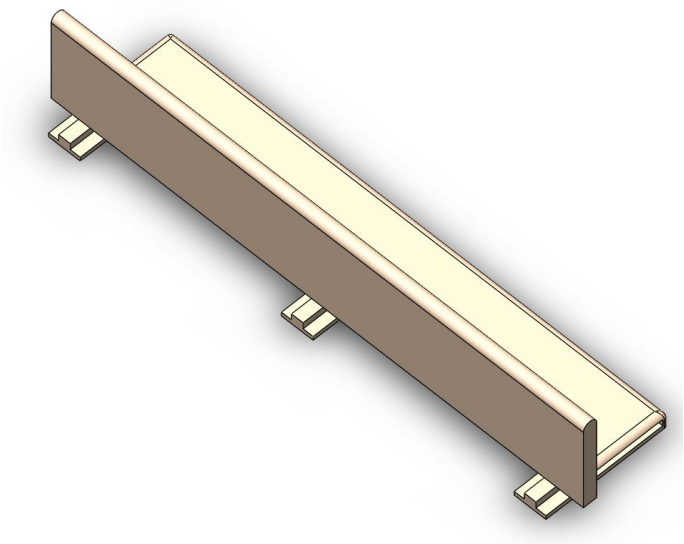


Figure 12-17. E2 - Finger

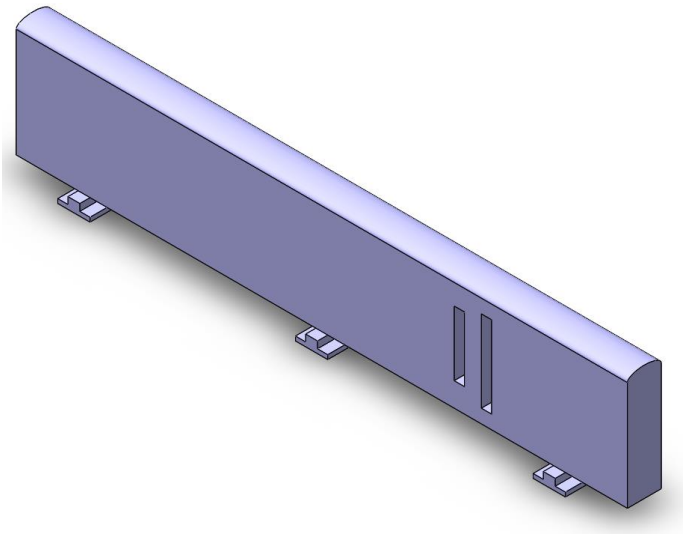


Figure 12-18. F3 – Finger

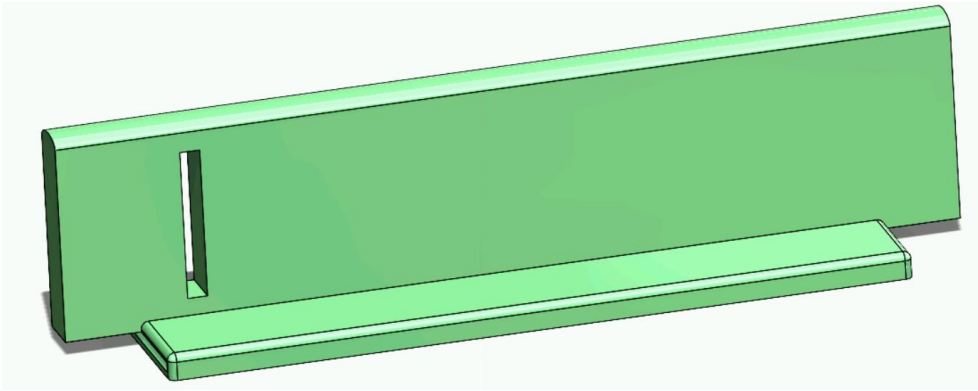


Figure 12-19. G1 - Finger

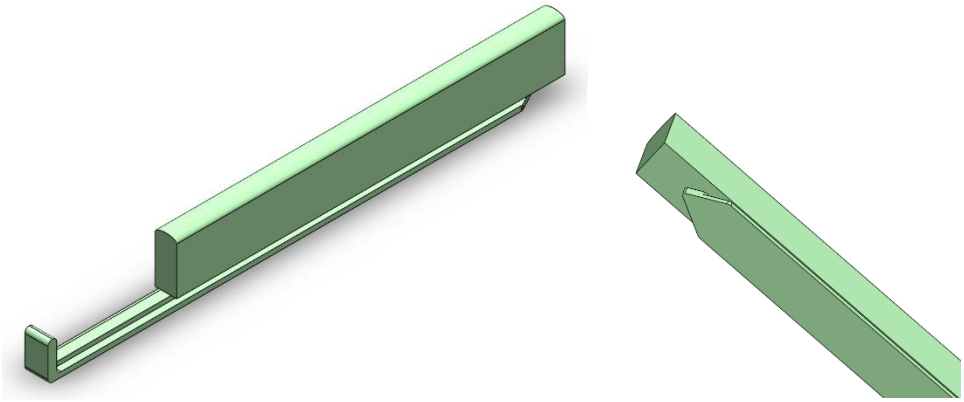


Figure 12-20. G2 – Finger