

Concept Development of Recline Functionality in CRS

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Concept Development of Recline Functionality in CRS

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Abstract

This master's thesis was done in collaboration with Thule Group during the spring of 2026. The purpose was to perform a concept development process in Child Restraint Systems (CRS), more commonly known as child car seats. These products are strictly related to crash safety as well as child ergonomics. Therefore, installations of CRS are important to ensure correct system status, meaning that the products included are secured and properly placed in the car. The goal of the project was to develop a concept that ensured that the CRS recline angles were within a uniform range across a variety of car seat geometries, while enabling installation in a slope as well as communicating clear feedback and guidance to users handling the product.

The development of the concept followed the principles of the Double Diamond design process including the phases Discover, Define, Develop, and Deliver. The research included a questionnaire, observations, a benchmark, and stakeholder insights. The data collected was analyzed through a thematic analysis. This analysis, combined with design opportunities that aligned with stakeholder insights, was used to define customer needs, requirements, and the problem definition.

Based on the findings, an iterative concept development process followed where ideas as sketches, mock-ups, and prototypes were evaluated and iterated continuously until the final concept was discovered. The process had two phases, a mechanical- and a user experience concept development. The result was a 3D printed prototype on a scale of 1:1 of a tilt-adjustable child car seat base with sensory feedback as well as a prototype of an app, which guides the user to perform the installation. The systems were connected by electronics, which included an angle sensor, a microcontroller and LED lights.

Keywords: CRS, child car seat, car seat base, ISOFIX, recline, concept development, Thule

Sammanfattning

Det här examensarbetet utfördes i samarbete med Thule Group under våren 2026. Syftet var att utföra en konceptutvecklingsprocess för barnsäkerhetssystem, mer kända som bilbarnstolar. Produkter i den kategorin är strikt kopplade till krocksäkerhet och även barnergonomi. På grund av säkerhetskraven är installationer av systemen viktiga för att kunna säkerställa korrekt systemstatus, vilket innebär att de inkluderade produkterna är säkrade och korrekt placerade i bilen. Målet med projektet var att ta fram ett koncept som säkerställer att bilbarnstolens lutningsvinklar ligger inom ett uniformt spann hos varierande bilsätesgeometrier, samtidigt som den möjliggör installation i backe samt tydlig feedback och vägledning till användare som hanterar produkten.

Konceptutvecklingen följde designprocessen och principerna av Double Diamond, som innehåller faserna Discover, Define, Develop och Deliver. Användarstudien inkluderade ett frågeformulär, observationer, en marknadsanalys och insikter från företaget. Insamlade data analyserades i en tematisk analys. Analysen, kombinerad med designmöjligheter som låg i linje med företagets intressen användes för att definiera kundbehov, krav och problemdefinitionen.

Utifrån resultaten följde en iterativ konceptutvecklingsprocess där idéer i form av skisser och enkla prototyper utvärderades och förbättrades kontinuerligt tills att slutkonceptet var identifierat. Processen hade två faser, en mekanisk- och en användarcentrerad konceptutveckling. Resultatet var en 3D printad prototyp i skala 1:1 av en lutningsjusterbar bilbarnstolsbas med sensorer och en prototyp av en app som ska guida användaren under installationen. Systemen var sammankopplade via elektronik som innehöll en vinkelsensor, en mikrokontroll och LED lampor.

Nyckelord: CRS, bilbarnstol, bilstolsbas, ISOFIX, lutning, konceptutveckling, Thule

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1 Introduction

This chapter will introduce Child Restraint Systems, how they are used and what aspects affect the usage of them. It will also include the purpose of the project, the problem description, delimitations, ethical considerations, and relevance for sustainable development.

1.1 Background

An Enhanced Child Restraint System (ECRS) is a product commonly known as a child car seat. The system restrains the child from moving and reduces the risk of injury if an accident occurs, according to standard UN Regulation No. 129 (United Nations Economic Commission for Europe 2018). Children are more at risk than adults in car crashes. The heads of children younger than four years old are heavier in proportion to their bodies, and their neck is more fragile. In fact, one of the most common causes of death for children is car crashes (Brolin 2025). Therefore, development of these products handles more than child comfort, it is about crash safety where mechanisms and technologies need to be on their edge. In this report, ECRS will be referred to as CRS.

1.1.1 Thule Group

This project was executed at Thule Group, a Swedish company that develops and produces premium outdoor and transportation products, often car related. In general, the products have a neutral color palette and a Scandinavian aesthetic. CRS is one of their product categories, and they currently have three types of child car seats on the market, an infant seat, a toddler seat, and a booster seat. The infant and toddler seats are installed on a base. The initial focus of the project was on concept development for the toddler seat.

1.1.1.1 Thule Elm and Thule Alfi

The toddler seat, Thule Elm, is a car seat for children aged six months to four years. It has a recline system with three positions, allowing the child to be upright, leaned back or in between. The recline is adjusted by a lever located right beneath the front. The seat is mounted on a base, Thule Alfi, which is secured in the car by its ISOFIX

arms. ISOFIX is an international standard for attachment points for CRS in cars (ISO 13216-4:2020). The products can be seen below (Figure 1). The seat is attached to the base by a middle plate which it rotates around and is secured by two fastenings at the front and in the back. This system prevents the seat from moving in any direction. The load leg in the front of the base is folded out to stabilize the system in occasion of a crash. The leg has contact with the floor, which gives resistance and hinders a forward rotational movement.



Figure 1 Thule Elm and Thule Alfi (Thule n.d.a).

Thule Alfi has electronic sensors connected to LED lights to instruct the user during installation. The display is located on top of the load leg as seen below (Figure 2). The sensors activate when the load leg is detached from a magnet underneath the base. The lights turn from red to green when correct installation maneuvers are performed, and a beeping sound alarms the user until the installation is complete and all lights are green. A further developed version of the base is Thule Alfi Connect, which connects the base to a Thule-app where users can get real-time feedback of the system status.



Figure 2 Display of Thule Alfi (Thule n.d.b).

1.1.2 Crash safety, ergonomics, and installation

CRS products are heavily tested and must fulfil certain standards. One of the most respected consumer safety assessments in Europe is Allgemeiner Deutscher Automobil-Club (ADAC) (Thule n.d.c). The tests evaluate CRS based on safety, ergonomics, user experience and pollutants. Considering crash safety of children in car seats, the angle range is a factor with great significance.

A study showed how recline angles of rear-facing toddler seats affect spinal forces within the range from 35° to 55° measured from vertical, where 45° was the nominal angle (Tushak, Valdano, Kerrigan & Lopez-Valdes 2026). The study included a digital model of a 1.5-year-old child, called a PIPER model, where different types of spinal loads were analyzed. The results of the study indicated that the generally recommended recline angles (30° to 45°) were ideal for most of the spinal loads analyzed. Therefore, recline angles are strictly connected to safety and affect the result of a consumer safety test like ADAC.

In addition to crash safety, recline angles also affect child ergonomics. An experiment including 21 children aged two to four years old investigated how child ergonomics are affected by seat-back angles of 20°, 30°, and 40° (Lai, Chen, Chen, Yeh & Lai 2009). The study showed that a 30° reclined position, measured from vertical, was the most optimal position from a child comfort perspective. This was concluded using a grey relational analysis (GRA) of pressure points. The result also showed that the use of a soft mat design reduces peak pressure values (Lai et al. 2009).

Even though the person installing a CRS into a car has great responsibility for performing a correct installation, the system must provide sufficient guidance and feedback to support the person to do so. A study carried out in London, Ontario, evaluated parents' confidence when installing their CRS, which was compared to how they had performed (Britton et al. 2023). The study had two phases, community checks and an online survey. The results from the community checks were that only 29% of 96 CRS checked were correctly installed and therefore properly used, while 24% of the 96 had multiple errors. The greatest challenge faced with proper installation was getting the car seat at the correct angle in the car, according to the results of the online survey. In general, the parents had high self-perceived confidence regarding the CRS installation, which differentiated greatly from the actual performances.

1.2 Purpose and research questions

The purpose of the project is to develop a concept that improves the flexibility of the recline system of Thule Elm, with the goal of increasing child comfort without jeopardizing crash performance. Through research, one or more actual user experienced problems will be identified and further defined in a problem definition. The concept will be visualized through a prototype on a scale of 1:1.

The research questions of this project are related to the user experience of CRS. It is crucial to uncover why, when, and how the recline system of these products is adjusted. This supports the identification of development areas that are beneficial for the users. Other research questions are related to how recline angles affect crash safety and child ergonomics, as well as how users respond to feedback and guidance during installation of CRS.

If nothing else is stated, illustrations and figures in this report are the authors' own work.

1.3 Delimitations

Considering the timeframe of this master's thesis, delimitations help define the scope and outline of the project. The complex construction of a CRS product has led to the choice of a conceptual approach, ensuring focus on the user experience. This is also related to the crash performance of the product, for which demands are high and needs fully developed mechanisms meeting such requirements.

Another delimitation is to not include children in the user research because of the difficulty of interpreting their experience. A third delimitation is to only include data of rear-facing CRS due to Swedish governmental recommendations. In Sweden, rear-facing CRS are recommended for children up to four years old (Transportstyrelsen 2017).

1.4 Ethical considerations and relevance for sustainable development

Since this project includes a user study, it is ethically appropriate to protect the participants' identities (Muratovski 2022). The material of the user study aims to avoid words of value and a leading language. This allows participants to express their experiences freely, without guidance or prejudice. It is also important to consider informed consent, making sure that participants are informed about the

purpose of the study and that it is voluntary to participate, highlighting transparency. A third consideration is privacy and confidentiality. Participants' identity will be protected using ethical standards.

Traffic safety is a part of The Global Goals and the 2030 Agenda for Sustainable Development (Svenska FN-förbundet 2018). Target 3.6 of The Global Goals aimed to reduce traffic injuries and deaths by 2020, highlighting the importance of continuous development of safety products such as CRS. Furthermore, Target 12 of The Global Goals aims to support sustainable production and consumption, which will be considered during the concept development- and evaluation phase. In alignment with Thule's work with sustainability, the result of this project aims to have smart material use and avoid unnecessary details of the final concept (Thule n.d.d).

2 Methodology overview

The Methodology Overview presents the Double Diamond framework, which serves as the foundation for the concept development of the project. The method broadens and narrows the scope of the project in an iterative manner.

2.1 Double Diamond

The concept developed in this project used the Double Diamond design methodology, including the phases Discover, Define, Develop, and Deliver (Rogers, Sharp & Preece 2023). The process is illustrated in Figure 3. The first phase, Discover, is about understanding the problem and the users involved through divergent exploration, which sets a foundation for the next phase. The second phase, Define, narrows the project through convergent thinking and closes the first diamond with a clear idea of what to focus on ahead. The third phase, Develop, aims to broaden the view once again through divergent methods and focuses on the visualization and embodiment of ideas and concepts. Finally, the second diamond ends with the convergent phase, Deliver, which presents the result of the project.

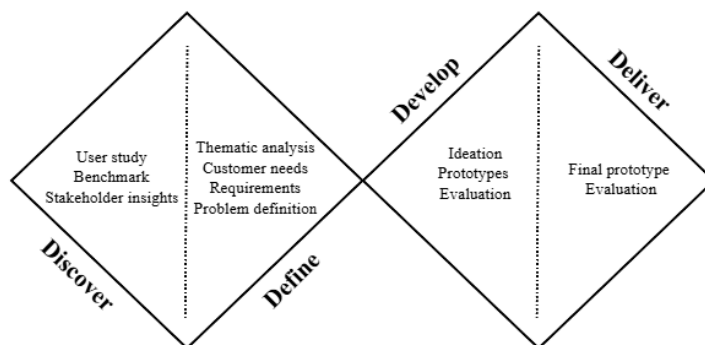


Figure 3 The Double Diamond methodology.

The project time plan and work distribution between the authors can be seen in Appendix A.

3 Discover

This chapter includes stakeholder insights and user research consisting of a feasibility study, a questionnaire, and an observation study. The user research aims to answer research questions and gain a deeper understanding of users handling CRS and will set a foundation for the problem definition. The chapter also includes a benchmark, which aims to analyze the current market of CRS.

3.1 Stakeholder insights

An ongoing dialogue was held with the supervisor at Thule to ensure that the project met the expectations and aspirations of the company. A recurring topic discussed was the market gap where no product considers different car seat geometries at the same time as installation can be made in a car standing in a slope. The geometry of the car seat affects the position of the base, which in turn affects the position of the seat due to variations in car seat angle and shape. The origin of the topic is that there already exist products that solve the car seat geometry issue, minimizing its impact on the CRS position and therefore also the recline, although with the condition that installation needs to be done while the car stands on a flat surface to ensure correct installation.

Data received from Thule research shows that different car models have a variation of seat inclinations. The variation of the car seat bench angle affects how the base Thule Alfi is positioned, furthermore affecting the recline angle range of Thule Elm. A larger seat bench inclination naturally gives a larger incline to the base. The car seat bench angle, measured from horizontal, shows a variation from 8° to 25° and can be seen as a diagram in Figure 4.

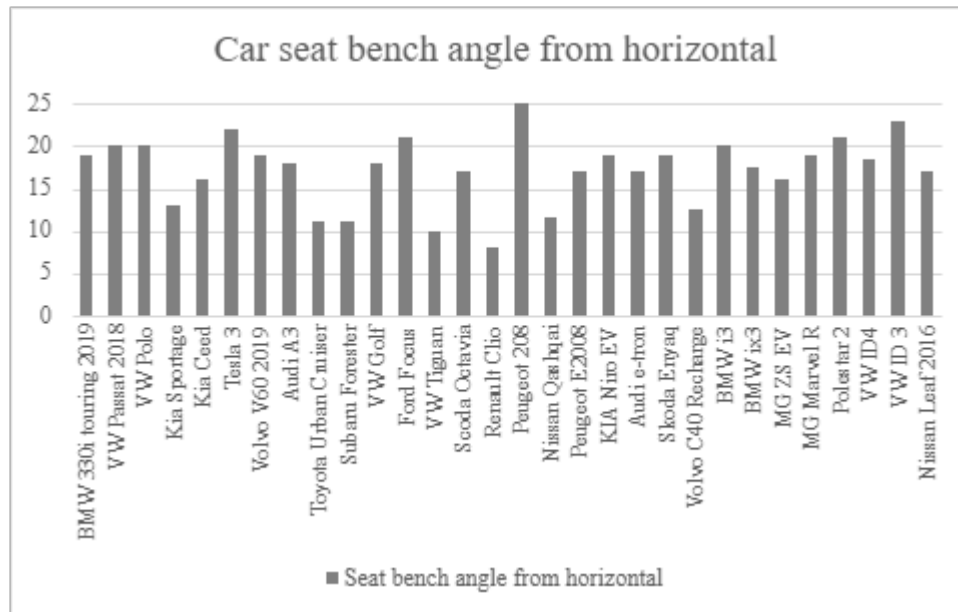


Figure 4 Data of seat bench angle, used with permission from Thule.

Another topic focused on what type of product should be developed, which in the given scope was the toddler seat, Thule Elm. While discussing car seat geometry and its impact, it arose that a possible solution could be beneficial for other products beyond Thule Elm, such as the infant seat, Thule Maple. From a production perspective there is an advantage for Thule if a potential solution could be applied to the base, since it serves as the base for both the infant and toddler seat.

3.2 User research

The user research includes a feasibility study, a questionnaire and observations. All material in the study, as well as the collected data, is in Swedish (the native language for participants and the authors) for participants to express themselves naturally and to avoid misunderstandings. All quotes and findings were translated into English by the authors. To prevent a loss of nuance, the raw data is presented in its original Swedish form in Appendix B.

3.2.1 Feasibility study

The feasibility study aimed at understanding the primary context and gaining an initial impression of the users consisted of a questionnaire and interviews. The questionnaire created in Microsoft Forms consisted mostly of open-ended questions designed to gather qualitative data. A semi-structured approach was chosen for the interviews, allowing the participants to share experiences and opinions spontaneously (Muratovski, 2022). This way the interviewer was also allowed to ask follow-up questions when necessary.

The target group for the questionnaire and interviews were individuals who handle child car seats in their everyday life. These were reached through social media and personal networks with the reason of collecting answers rapidly. The number of participants in the interviews were 2 and in the questionnaire 18, all anonymous. The material of the questionnaire for the feasibility study can be seen in Appendix B.1.

One insight gained from the feasibility study was that multiple choice-questions were preferred when analyzing the data rather than gather answers in free text, since these make comparison more difficult. Since the questionnaire included several questions of this nature, the open answers could later be used to create multiple choice questions for the upcoming questionnaire of the in-depth study. Another insight was that more narrow questions about the recline function itself allowed for a deeper understanding of the topic. The interviews generated an initial impression of the users, although not much was related to the recline function. This showed that users of CRS consider many different aspects of the product, such as belt functions, installing the seat and removing it from the car, and ergonomic aspects, including the ability of the seat to rotate on its base.

3.2.2 Questionnaire

The main questionnaire aimed to gather both qualitative and quantitative data, with an overall focus on the recline function. The ultimate questions to answer were how, when, and why the recline system is adjusted. Other questions were related to safety and recline, and if the users saw any potential development areas for their product. For the questionnaire to reach the right audience, a link or QR-code with description was published through posts in relevant groups on social media, given to four preschools in Lund and Malmö for parents to fill out, and sent to all of Thule's employees by email. The questionnaire was created in Microsoft Forms (see Appendix B.2.1).

The raw data from the questionnaire was then processed in Excel. During data cleaning, answers outside of the target group of the study were removed. This meant that the remaining participants were users who had a recline function of their CRS, used it in the back seat, and had children up to four years old. Quantitative data,

answers like yes or no and multiple-choice answers were translated into binary quantities to ease the analysis. Relevant connections were cross-checked using pivoted tables. Out of the 220 questionnaire participants, 129 remained relevant after data cleaning which can be seen in Appendix B.2.2.

Due to the importance of the safety factor, the users were asked how they perceive their own awareness regarding recline of CRS in relation to safety. These were divided into two groups, high awareness 68% (n=88) and low to neutral awareness 32% (n=41). For a clear comparison see following figure (Figure 5).

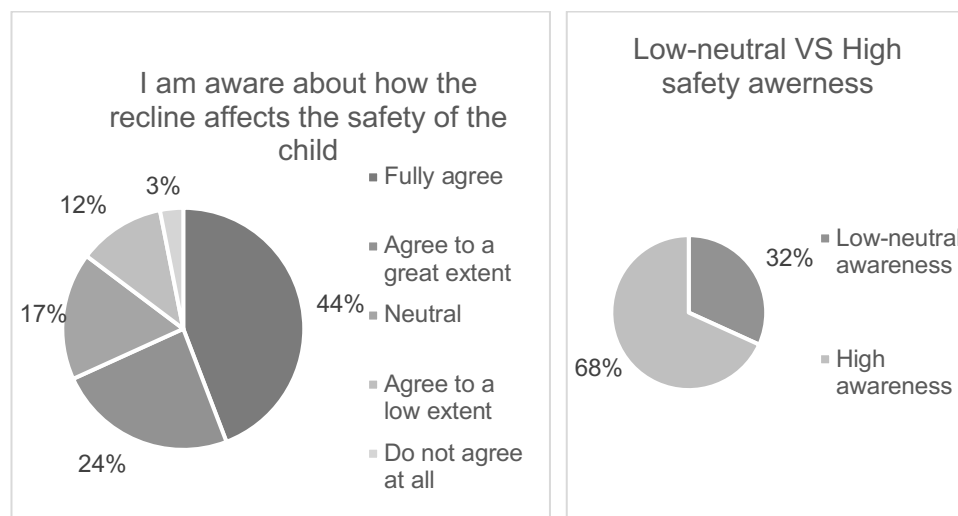


Figure 5 Perceived safety awareness.

To see how awareness and actual behavior is correlated, the respondents' reason for why they change recline was compared within the two safety awareness groups. Results show that recline adjustment due to sleep or rest were similar in both groups, where a slightly larger difference was seen when it comes to comfort (see Figure 6).

Considering crash safety, where the two groups differed the most, 7 % (n=3) of the low to neutral awareness group adjusted the recline because of this aspect, in comparison to the 34% (n=30) of the high awareness group (see Figure 6).

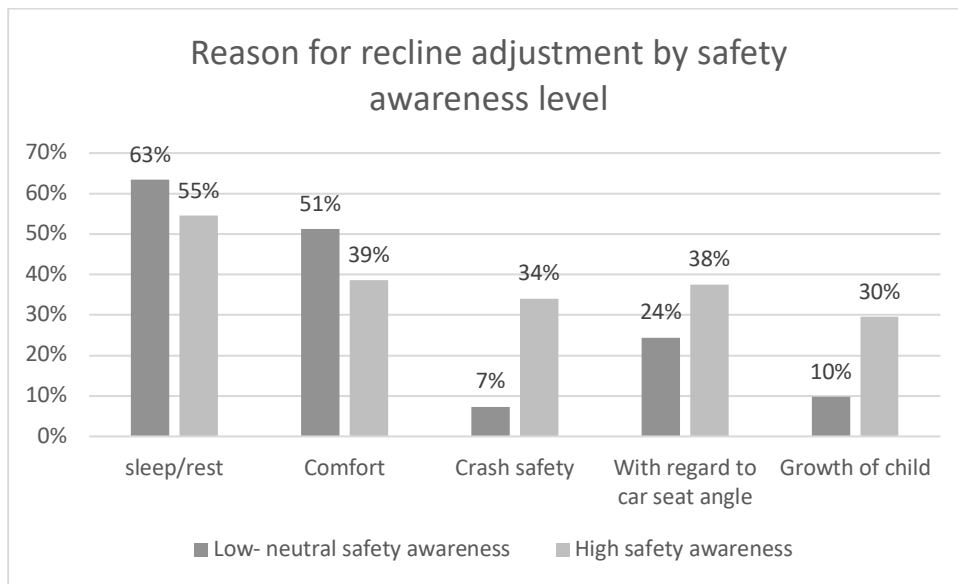


Figure 6 Comparison between awareness groups.

To investigate perceived difficulties with the user experience of the recline function, they were asked if it is clear how to adjust the recline. The result was that 90.7% (n=117) stated it was clear how to perform the adjustment. View result in following figure (Figure 7).

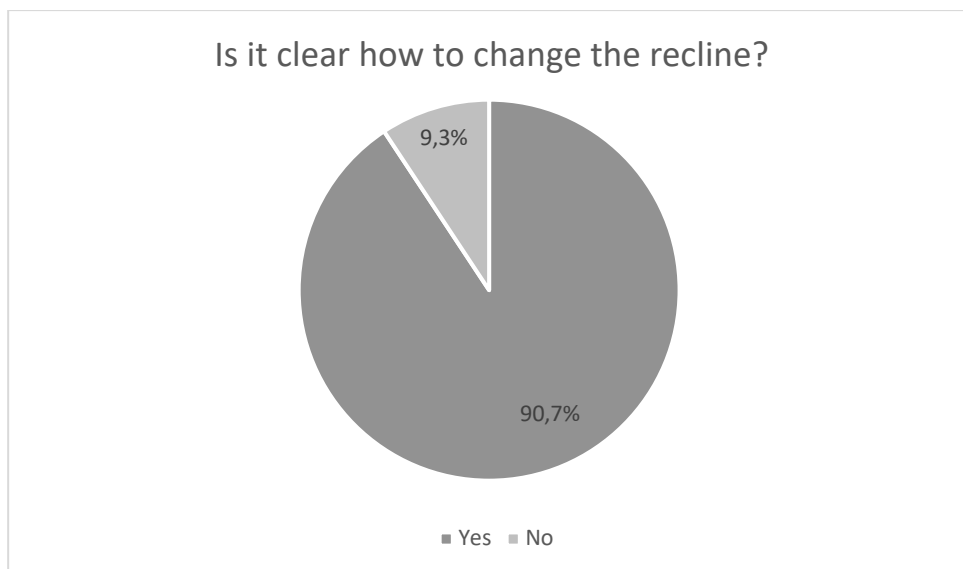


Figure 7 Clarity of how to change recline.

To determine if recline adjustment is desirable while driving, the respondents were asked about their opinion on the matter. The question had multiple choice options and data showed that 50.4% (n=65) desired the possibility to adjust it while driving (Figure 8). Regarding who should have the possibility to adjust while driving, the breakdown was as follows: 20.0% (n=13) believed that both the driver and passenger should be able to do so, 69.2% (n=45) chose the passenger only, while 10.8% (n=7) chose the driver only (Figure 9). Inconsistent answers in Figure 8 represent respondents who indicated that it is both desirable and undesirable to change while driving.

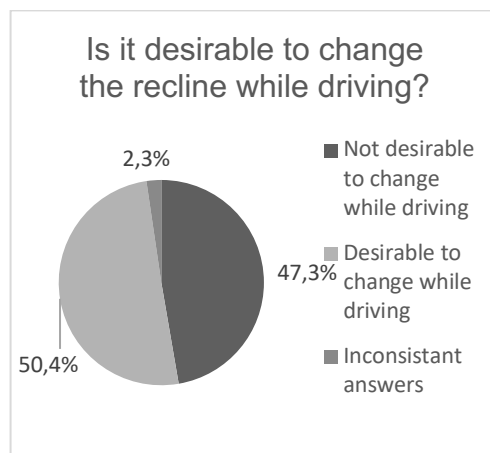


Figure 8 Desire to change recline while driving.

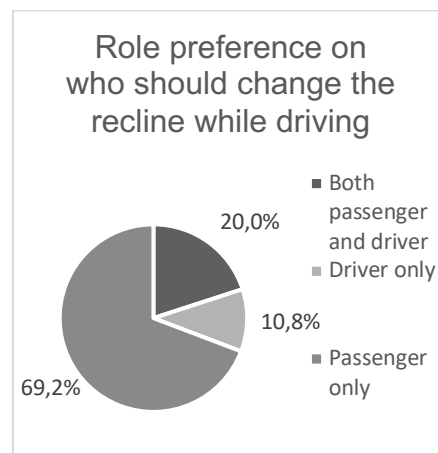


Figure 9 Role preference, recline adjustment while driving.

3.2.3 Observations

The purpose of the observations was to discover latent behaviors and needs of the user while installing Thule Elm in a car. Latent needs are referred to as unrevealed needs of the user (Ulrich & Eppinger 2016). To add structure to the study, an observation procedure proposed by Delft Design Guide was used (Van Boeijen, Daalhuizen & Zijlstra 2020).

The participants performed five tasks with identical settings while the observers filled in an observation checklist, see results in Appendix B.3. A pilot observation was performed to verify the method and identify unforeseen issues with the tasks as well as the checklist. The observations were video recorded with the participants' consent, and all participants filled out a consent form before starting the tasks. They were performed in Thule's test center. The car used during the study had ISOFIX only in the back seat, forcing the users to install the system there. The five tasks performed are presented in the following list:

1. Install the base in the car.
2. Install the car seat in the base.
3. Place the dummy in the seat and prepare for departure.
4. Test all recline positions and tell the observer how many there are.
5. Instruct the observer how you would wish to adjust the recline position of the system from the driver's seat.

Like the handling of data from the questionnaire, Excel was used to process raw data from the observations. Components of the checklist were translated into binary quantities to identify high success and failure rates, and relevant outputs were highlighted. The observations had six participants, all of whom were Thule employees with varying levels of prior experience with CRS, including two with specific experience with Thule Elm. Observation findings are presented with success rate of the different tasks in the following table (Table 1).

Table 1 Observational findings with success rate.

<i>Observation findings no.</i>	<i>Success rate (%)</i>
1. Ease of pressing buttons to extract ISOFIX arms.	17
2. Noted feedback (green/red light) from sensors during installation.	100
3. Noted click-sound during installation.	67
4. Looked at instructions on the base of the CRS.	83
5. Unfolded load leg before attaching ISOFIX to car.	50
6. Found the handle for recline adjustment.	100
7. Identified all three recline angle positions.	67

3.3 Benchmark

A benchmark was internally performed to discover existing products on the market with attention to recline adjustment as well as communication between product and user. The products were analyzed in a real-life setting and the data collection focused on market availability, recline angle communication, neutral position availability, safety information, and consideration of car seat geometry. The car seats and their bases were considered as one system. The benchmark included eight models, where three products were from the EU market; Beyond and iZi Modular i-

size from Besafe and Minikid 4 Max from Axkid, and five products were from the US market; RAVA Next and REVV from Nuna, Revolve360 from Evenflo, Fit360 from Chicco, and Knox from Uppababy. The result is presented in Table 2 and Table 3.

The reason for including products from the US market was because of the richness of features such as communication of the recline angle and safety information, in comparison to the EU market. In fact, products on the US market communicated the recline angle of the seat more frequently, while none of the products from the EU market did. The angle was communicated through a number or an arrow indicating current position, a spirit level or through a ball in a circular area which moved with gravity. Regarding indication to the user that the position of the system is correct, two products on the EU market and one on the US market used a spirit level as a communication to the user.

Safety information available on the product was identified on five out of eight products. This was through guiding the user with length and weight recommendations, and through colored zones guiding the user how to properly use the product. Safety information in product manuals was not looked for in this benchmark.

Car seat geometry was considered for half of the products analyzed, where all solutions used an adjustable load leg or foot to adapt to the variation of car models. Three of them had a spirit level to provide feedback to the user that the position was correct.

None of the models studied offered all four areas of interest combined, which were: recline angle communication, neutral position availability, safety information, and consideration of car seat geometry.

Table 2 Benchmark.

<i>Benchmarking</i>				
Brand	Besafe	Besafe	Axkid	Nuna
Model	Beyond	iZi Modular M i-size	Minikid 4 Max	RAVA Next
Market	EU	EU	EU	US
Recline angle is communicated	No	No	No	Yes
How?	N/A	N/A	N/A	Number indicating current recline position
Neutral position/angle is communicated	Yes	Yes	No	No
How?	Spirit level (base)	Spirit level (base)	N/A	N/A
Communicates safety information	Yes	No	No	Yes
How?	Length connected to recline positions	N/A	N/A	Blue/red zone for rear/forward facing.
Considers different car seat geometries	Yes	Yes	Yes	No
How?	Adjustable load leg	Adjustable load leg	2 adjustable load legs	N/A

Table 3 Benchmark.

<i>Benchmarking</i>				
Brand	Nuna	Evenflo	Chicco	Uppababy
Model	REVV	Revolve360	Fit360	Knox
Market	US	US	US	US
Recline angle is communicated	Yes	Yes	No	Yes
How?	Arrow pointing on current recline position	Spirit level (seat)	N/A	Ball moves in circular radius
Neutral position/angle is communicated	No	No	Yes	No
How?	N/A	N/A	Spirit level (base)	N/A
Communicates safety information	Yes	Yes	No	Yes
How?	Blue/red zone for rear/forward facing.	Weight (rear-facing only)	N/A	Several parameters (rear- and forward facing)
Considers different car seat geometries	No	No	Yes	No
How?	N/A	N/A	Level foot under back rest	N/A

4 Define

This chapter will clarify the aim of the project by presenting a thematic analysis, customer needs, design opportunities, the problem definition, and the product requirements.

4.1 Thematic analysis

Continuing with findings from the phase Discover, a triangulation of data sources was applied meaning that various data were analyzed to ensure reliability (Muratovski 2022). By synthesizing data from the questionnaire and the observations, a thematic analysis was conducted to identify patterns and recurring challenges with the user experience of CRS (Braun & Clarke 2023). Each raw statement was marked with an identification number and was color-coded according to the brand of the product. By categorizing quantitative and qualitative answers from the questionnaire and combining these with qualitative results from the observations, three main themes were identified: adjustability, guidance and feedback. These are presented below together with quotes and observations serving as a foundation for the following user need (see Table 4-6). In the study about parents' confidence during installation of CRS presented in 1.1 Background, it became clear that there is a gap between parent's self-perceived ability to install child car seats relative to how they perform (Britton et al. 2023). This supported the choice of including the themes guidance and feedback, since it indicates a need of improvement of the installation sequence. The complete thematic analysis can be seen in Appendix B.2.3.

4.1.1 Adjustability

The theme adjustability refers to the recline function and how the users perceive the angle range, accessibility, and how it affects comfort for their child. It also addresses observational insights regarding ease of use.

Looking at the data of the questionnaire regarding adjustment of recline while driving, the results showed that a slight majority (50.4%) desired the possibility to change while driving, and out of these, a majority (69.2%) said they preferred that

only the passengers would be able to change the recline (see Figure 8 and 9). During the observations, when the participants were asked to describe how they would wish to change the recline from the driver's seat, most leaned back and tried to reach the CRS. A quote from participant number two was "dangerous", and participant number three stated that you want to "keep your eyes on the road". This could indicate that the recline adjustment is not desirable for when the user themselves drives the car. Although it is important to note that the current CRS is not adapted to do this for safety reasons, and this may be the reason for the feeling of the action being unsafe. The function to adjust recline while driving could be desirable if done in a safe and accessible manner.

A few selected representative answers from the open question are stated from the questionnaire, see Table 4. These quotes indicate that the accessibility of changing the recline could be expanded to other locations in the car as well as on the CRS itself, for example on the control panel.

As explained in 3.1 Stakeholder insights, car seat geometry is a factor that affects how the CRS is positioned and thereby affects the recline angle range. This is also addressed in the answers to the questionnaire, where some users stated that they wished for more recline to better fit their car.

Regarding comfort of the child in relation to recline, the results from the questionnaire showed that the main reasons for changing the recline were due to sleep, rest, and comfort, within both safety awareness groups (see Figure 6). This indicates that comfort of the child is an important factor regarding recline. This theme is recurring when looking at quotes from respondents, stating that they wish for more adjustability in recline for when the child is going to sleep (see Table 4).

The observations showed that there was some difficulty in pressing the ISOFIX buttons (see Table 1). This is not directly associated with recline, even so, it generated insights that could be applied regarding ease-of-use. Participant number five stated "pain in thumbs" while pressing the buttons. This addressed that when performing necessary actions while handling CRS, it needs to be done without discomfort for the user.

Table 4 Answers regarding adjustability.

<i>Question/Statement/Task</i>	<i>Quote</i>	<i>Source</i>
Questionnaire		
1. What areas of improvement can you see in the recline function?	“More different reclines, to fit better in the car”	R68
	“Wish for more recline, primarily when the child is going to sleep”	R131
	“Adjustment from the side, or from above, instead of between the legs.”	R24
	“It would be fantastic if you could adjust the recline using an app on your phone or something similar, so you can do it when you’re alone in the car and can’t reach the child car seat”	R137
	“Would like more recline, primarily when the child is sleeping.”	R131
	“Better sleeping position without compromising safety.”	R8
1. Explain why it is clear to adjust the recline angle.	“I increase the recline in case the child falls asleep for the head not to fall forward”	R57
Observations		
Adjust recline from driver’s seat.	“dangerous”	O2
	“Keep their eyes on the road”.	O3
ISOFIX installation	“Pain in thumbs”	O5

Note: R - Respondent ID from questionnaire, O – Participant ID from observations.

4.1.2 Guidance

The theme guidance refers to how information regarding recline is communicated to the user, regarding when to recline, learnability of the function, and affordances. From the results of the questionnaire, it was clear that many respondents (90.7%) was certain of how to adjust the recline (see Figure 7). Although, answers to the open question showed that on the first use, it could be difficult to know where the control for the adjustment was located. After the first use it seems to be located logically and used effortlessly, showing a high learnability to the function in general. Observations showed that locating the handle for adjusting recline was not a problem (100%) (see Table 1). This implies that the functions discoverability could be improved to increase usability, but not necessarily.

While most of the respondents (68 %) perceived their safety awareness as high, it was discovered that safety is more of a passive rather than active consideration when analyzing the actual behavior. The data showed that in the group of high awareness, the primary drivers for adjusting recline was comfort and sleep, indicating that the safety perspective is not top of mind for the user when interacting with the recline function (see Figure 5 and 6). Qualitative insights highlighted insecurities regarding what the “correct” recline position is and what is considered safe. Others expressed a wish for more recline to enhance the comfort for the child.

Observations showed that having instructions available for installation is necessary since the majority (83%) of the participants looked at instructions while installing the base. A common mistake among the participants (50%), was that the load leg was not folded out at the right time, which indicates that instructions with a clear sequence are necessary.

Although these different views do necessarily not origin from the same individuals, together they point towards a need for improved guidance, communicating safety parameters effectively for the user to feel confident and secure in handling the CRS while the product itself is safe. A selection of representative quotes from respondents can be seen in Table 5.

Table 5 Answers regarding guidance.

<i>Question/Statement/Task</i>	<i>Quote</i>	<i>Source</i>
<i>Questionnaire</i>		
1. What areas of improvement can you see in the recline function?	“Only want to know what is the safest and hold on to that setting”.	R205
	“Clearer guide on when you should recline”.	R129
2. Explain why it is clear how to adjust the recline angle.	“It is clear HOW to adjust the recline but not WHEN you should change”.	R28
	“Well explained in manual and clear button”.	R141
	“Intuitive handle in a logical place”.	R12
	“Difficult to locate the first time but once you know you know”.	R5
3. Explain why it is not clear how to adjust the recline angle	” There is no information on the seat”.	R3
	“Don’t know which recline is correct”.	R154

Note: R - Respondent ID from questionnaire.

4.1.3 Feedback

The theme feedback includes what the user perceives as confirmation of actions and system status when handling the CRS. From the open questions of the questionnaire, several respondents commented that they would like to have feedback on what the recline angle is as well as better measurement of it. This could be related to safety awareness and be interpreted as a need for feedback on what the recline angle is, as well as knowing when the system is safe.

During the observations, a majority (67%) identified the three recline positions of Thule Elm. The positions were identified when releasing the handle, indicating that feedback is not given if the handle is not released, of which the need for clear sensory feedback could be derived from. The existing system rather relies on signals such as sound when the handle was released in one of the three positions. All participants noted the green and red LED light during installation which indicates that visual feedback was successful. Representative quotes are presented in Table 6 Answers regarding feedback.

Table 6 Answers regarding feedback.

<i>Question/Statement/Task/Findings</i>	<i>Quote</i>	<i>Id respondent</i>
<i>Questionnaire</i>		
4. What areas of improvement can you see in the recline function?	"To see or easily determine what the recline is."	R187
	"Better measurement of the recline"	R51
5. Explain why it is clear to adjust the recline angle.	"You pull on a lever and see on the side what position it is in"	R182
	"It clicks when it is in the "correct" position."	R174
	"There are measurements that show the recline"	R76

Note: R - Respondent ID from questionnaire, O – Participant ID from observations.

4.2 Need analysis

The identified themes of the thematic analysis adjustability, guidance and feedback, were used to group customer statements from the questionnaire and raw observations from the observation study. These were transferred into six interpreted customer needs (see Table 7).

Table 7 User Needs.

<i>Need no.</i>	<i>Need Statement</i>	<i>Theme</i>	<i>Based on data from</i>	<i>Priority</i>
1.	As a caretaker I need more adjustability for the CRS to fit my car better.	Adjustability	R68, R27, R99, R188.	***
2.	As a caretaker I need to have more adjustability for my child's sleep comfort and safety.	Adjustability	R131, R8, R15, R57.	**
3.	As a caretaker I need ergonomic and easy access to controls for usability.	Adjustability	R24, R137, R66, O5	*
4.	As a caretaker I need clarity on how and when recline should be used for it to feel safe.	Guidance	R129, R25, R173, R205	***
5.	As a caretaker I need to easily learn to locate the controls to increase discoverability.	Guidance	R5, R18, R119	**
6.	As a caretaker I need to get clear feedback on the recline angle to be sure that it is correctly adjusted.	Feedback	R187, R51, R182, R76, Success rate 2	***

Note: *** to * indicates level of importance, where *** indicates critical importance. R - Respondent ID from questionnaire, O – Participant ID from observations.

4.3 Design opportunities

Since the project is performed in collaboration with Thule, there are objectives to consider beyond the user perspective. Important insights from Thule, particularly the fact that their CRS consists of two main parts, a base and a car seat, led to the conclusion that the concept should be developed to conceptually function with existing products in the product category.

Looking at the benchmark, it revealed that there today exist solutions on the market that take car seat geometry into account, with the constraint that the car must be standing on horizontal ground, due to use of spirit level as feedback. This indicates a gap in the market where no solution enables installation in a slope while at the same time consider car seat geometry. This gap was seen as an opportunity for innovation and was therefore decided to be included. Both the study about crash safety as well as the study about child ergonomics presented in 1.1 Background indicated that it would be beneficial to have a uniform recline range of child car seats since the recommended angles from both perspectives pointed at similar numbers, 30 ° to 45° respectively 30° (Lai et al. 2009; Tushak et al. 2026). To consider car seat geometry, and the aim of eliminating that factor, companies like Thule could achieve increased control over the position of children in CRS, which is related to safety and comfortability.

Considering the chosen models of the benchmark, manufacturers prioritize feedback and guidance more frequently in the US market compared to the EU market. The guidance was communicated in various ways, and in some cases the information was confusing due to small text and a significant amount of instructions. This can be seen as an opportunity for the concept to be developed to be clear in communication to avoid misuse and misinterpretations.

As seen in 3.3 Benchmark, none of the models combined all four criteria which were looked for. However, it may not be necessary to incorporate all four of them. For example, either current recline angle or correct system position would be sufficient to communicate to the user, depending on the system's functions and the desired feedback.

Product aesthetics are important for concept development as well. The aim is to visualize the concept as a Thule product regarding colors and form language. This will be a guideline for the design process when choosing forms and colors.

4.4 Problem definition

The problem definition was outlined with a foundation in the previous thematic and need analysis combined with benchmark and stakeholder insights from the phase

Discover. The themes adjustability, guidance and feedback were broken down in a problem definition method called WWWWH (Van Boeijen, Daalhuizen & Zijlstra 2020). The problems were deconstructed, reviewed, prioritized, and rewritten into three problem areas:

1. Users lack feedback on which recline angle the CRS has.
2. Users seek increased recline adjustability.
3. Users lack clarity on what recline positions are approved.

These three problem areas were further analyzed by answering nine questions, with the goal of uncovering relations between them (see Table 8).

Table 8 Deconstruction of problem areas.

	<i>Users lack feedback on which recline angle the CRS has.</i>	<i>Users seek increased recline adjustability.</i>	<i>Users lack clarity on what recline positions are approved.</i>
Why is the problem?	Product does not communicate angle or position.	Increased comfort for the child.	Insufficient information.
For whom?	Caretakers.	Caretakers and children.	Caretakers.
When is the problem?	When installing or adjusting the CRS.	When child is asleep.	When installing or adjusting the CRS.
Where is the problem?	In the car and on the product.	In the car and on the product.	On the product and in product manual.
What are the relevant context factors?	Safety regulations, branding and manufacturing.	Car variations, safety and comfort conflict.	Safety and comfort conflict, regulations, and communications.
What is the desired solution?	Clarity for users.	Safe recline in all cars.	Clarity for users.
What are the possible side effects?	Increased danger and misuse.	Increased danger and misuse.	Adding responsibility to users.
What solutions exist on the market?	Spirit level, weight ball, weight- and age range recommendations.	Increased recline steps, ISOFIX base adjustment.	Information on products, in manuals, videos, and websites.
Why is there no solution?	Different car seat angles affecting angle range.	Crash safety factors and regulations.	No control of actual angle range.

To identify the problem definition, uncovering the main issues identified in research, correlations were searched for. The conclusion was that a universal solution would increase the control of the recline system, taking different car seat geometries into account. Using clear communication, applying user-centered design principles, could increase users' confidence while handling CRS products as well as taking design opportunities into consideration. User-centered design principles are about considering the user's needs and behaviors throughout the concept development process (Rogers, Sharp & Preece 2023). This resulted in the following question, reframed from the problem definition:

- Is there a way to ensure that the CRS recline angles are within a uniform range across a variety of car seat geometries, enabling installation in a slope while communicating clear feedback and guidance to users?

4.5 Requirements

The 11 projects design requirements were created with a foundation in user needs and in the objectives provided through consultations with Thule. The themes of the thematic analysis are represented as follows: feedback corresponds to one requirement, guidance to four, and adjustability to three (see Table 9). Three requirements with foundation in design opportunities were also identified.

Table 9 Prioritized requirements derived from needs and design opportunities.

Source	Requirement no.	Requirement	Theme	Priority
N6.	1.	The CRS provides sensory feedback indicating correct system status.	Feedback	***
N4.	2.	The product communicates safety information regarding recline angles.	Guidance	***
N4.	3.	The product communicates when the recline angle adjustment is needed.	Guidance	***
N4.	4.	The CRS clearly communicates how to perform correct installation	Guidance	***
N5.	5.	The controls of the system are easy to locate and identify.	Guidance	*
N1.	6.	The CRS considers different car seat geometries.	Adjustability	***
N2.	7.	The CRS offers sufficient recline angle.	Adjustability	**
N3.	8.	The CRS is easy to operate without causing physical discomfort.	Adjustability	*
Design opportunities	9.	The solution considers whether the ground is inclined	-	***
Design opportunities	10.	The solution uses the color scheme and form language of Thule.	-	*
Design opportunities	11.	The solution is adapted to function alongside existing relevant products.	-	**

Note: *** to * indicates level of importance, where *** indicates critical importance. N – Need no.

5 Develop

Following chapter presents the early concept development phase of the project, including an ideation phase, early prototypes, further developed prototypes, user experience development, and evaluation of all steps mentioned.

5.1 Mechanical and electronic concept

5.1.1 Ideation

Once the project outlines were defined, as presented in earlier chapter, the ideation phase began with a brainstorming session. The session had the aim of answering the question “How to neutralize the effect of different car seat geometries?” as well as “How to prevent recline angle adjustment beyond safe limits?”. These queries were requirements reframed to questions with origin in the theme adjustability. Initially, ideas were generated in text on sticky notes, which were grouped in subcategories within each question. Using ideas in text as inspiration, nine concepts were illustrated, all presented in Appendix C.1. The concepts were numbered and evaluated using the Six Thinking Hats method (Wikberg Nilsson, Ericson & Törlind 2015). Six Thinking Hats was chosen to look at the concept from different perspectives to gain a broader understanding of the concepts. The result of the evaluation is presented in Table 10 and the different perspectives used during the process are presented in the list below:

- White: Data, facts, and information.
- Black: Potential problems.
- Red: Intuition and insights.
- Green: Possibilities and innovative alternatives.

Table 10 Evaluation of initial ideas.

<i>Six thinking hats</i>				
Concept	Perspective (color)			
	White	Black	Red	Green
1	Angle range An extra part Covers handle and buttons Adjusted to existing system	Additional task Redundant	Feedback Uncertainty Already exists Disclaimer	Minimize material use All-in-one?
2	New base “Accordion” covering ISO	Function unclear to user	New possibility Smart material use	Framework
3	How to attach? New base	Clumsiness Will get in the way	Circumstantial Bulky	A brake on the hatch Fixed in ISO
4	Conceptual – new base or an extra part	Need further development	Need further development	Need further development
5	New seat	Instability	Smart material use Flexible	Can be hidden
6	Additional part Rail	Additional task How to adjust recline?	Impractical	Do not need to be solid Could be part of the seat or base
7	Motorized PLC	Requires a heavy battery	Technical Future	Connect to app
8	Part of the seat Rails	Safety impact	Interference	Small adjustment needed Additional steps
9	Reclines around axis Part of the seat	Risk of mixing with existing recline Stability	Use of space	Make in separate color Axis in the middle

The second brainstorming session focused on further developing the existing concepts based on the results of the earlier evaluation. The new concepts were numbered from 10 to 28, presented in Appendix C.2. These were later evaluated using a C-box method to uncover which solutions were innovative and easy to implement (Wikberg Nilsson, Ericson & Törlind 2015). Concepts numbered 1-9 were also included in the evaluation. The C-box is presented in Figure 10.

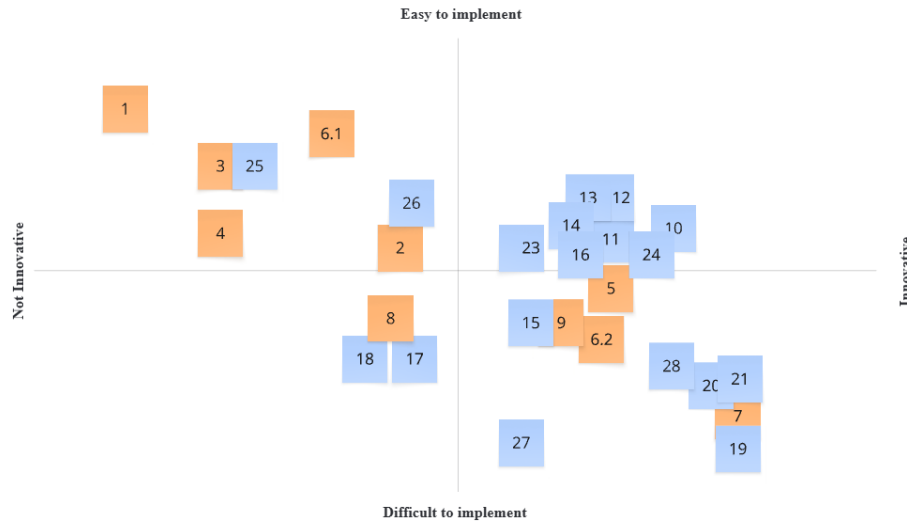


Figure 10 Evaluation of further developed concepts in a C-box.

The concepts placed on the right side of the C-box, the more innovative ones, were decided to be further developed. This was done in a final sketching round, where ten new concepts were created, numbered 15.1, 20.1, 23.1, and 29-36, presented in Appendix C.3. The concepts 15.1, 20.1, and 23.1 focused on transferring 15, 20, and 23 from difficult to easy to implement, while the concepts 29-36 focused on finding a solution which was both easy to implement and innovative.

To be able to embody the ideas and test the concepts through prototyping, a final evaluation took place. This was through a discussion between the authors, with the goal of sorting concepts within identified principles that stood out. The sorting of concepts resulted in ten different conceptual principles, presented with motivation in Table 11. As seen in Table 10, ideas at this stage were still considering a new base, seat, and an additional part. It was decided to move on with concept development of a base since it can be considered as an installation of the system, and the aim was to only perform the installation once. It was also to avoid conflict with the existing recline system of the seat as well as to avoid a third additional part of the system for the users to handle. The latter was also due to the aim of developing a concept with smart material use, aligned with Thule's work with sustainability (Thule n.d.d). Regarding the first requirement, to provide sensory feedback, sensors were already implemented for existing Thule bases such as LED lights, however not for the seats, further strengthening the decision.

Table 11 List of conceptual principles.

<i>Conceptual principles for a base concept</i>			
No.	Corresponding sketch	Principle	Motivation
1	20.1, 23, 23.1, 24, 26, 33	Rotary knob	To control small adjustments.
2	20.1	Snap fit	Plastic parts, mechanical locking mechanism.
3	4, 5, 15.1, 20, 24, 34, 36	Height adjustment vertically	Minimal gravity point movement.
4	9, 10, 11, 32	Adjustment around center	Minimal height adjustment.
5	2, 9, 16, 20, 21, 24	Hidden mechanisms	Clamp risk and aesthetics.
6	2, 12, 14, 15, 15.1, 24, 34	Telescopic cover	Clamp risk and aesthetics.
7	29, 34	Gravity	Cheaper solution compared to electronics.
8	7, 23.1, 31, 32, 33	Angle sensors	To be precise.
9	10, 20, 21	Attaching points follow mechanism	To adapt to existing solution.
10	15, 26	Smart material use	Sustainability.

With the identified areas for the base concept to be developed, named conceptual principles, the project was mature enough to move from sketching to prototyping. The corresponding sketches sorted within each principle in Table 11 were used as inspiration during the next phase.

5.1.2 Early prototypes

To visualize the selected conceptual principles presented in Table 11, a rapid prototyping process was applied using accessible materials such as carton, MDF sheets, wooden pins, tape, and screws. The early developed prototypes aimed to test the mechanisms of the concepts, and to evaluate them in a real-life setting. Initially, the prototypes named X-Z in Figure 11, were created to test the principles 3, 4, 7, 9, and 10. Prototype X and Y explored the idea of splitting the base into two parts, where one part moved around an axis. Prototype Z tested a concept of using gravity to install the base in a neutral position but did not meet expectations. The concept included a weight that would force a slot to rotate; hence the concept was not successful because of trigonometric functions. To utilize physical gravity was excluded hereinafter.

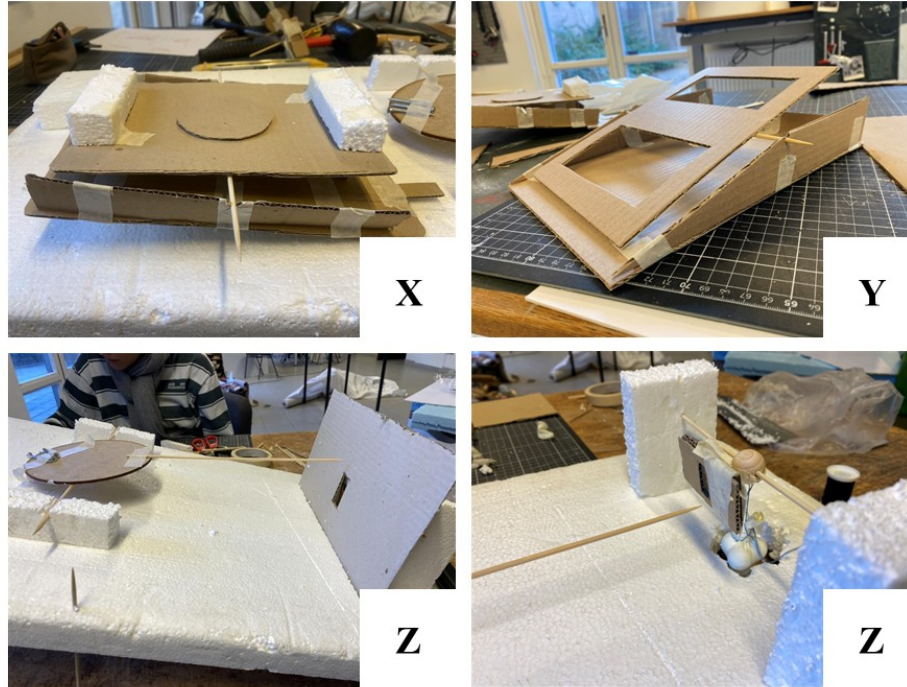


Figure 11 Prototype X-Z.

Continuing the rapid prototyping process, five new concepts named prototype A-E were created which are presented in Figure 12-Figure 14. Prototype A tested the use of a sensor to install the base in a neutral position, while B-E discovered different ways of tilting a plane where the seat was to be installed. Since the concept with the sensor was tested for one prototype, it was not needed to implement electronics for all.

5.1.2.1 Prototype A

Prototype A explored the conceptual principles 1, 3, 4, 8 and 9. It had a threaded rod with a nut at one edge and a central axis where the mounting for the seat was imagined following the movement of the tilting plane. Angle measurement was tested using an MPU6050, a sensor connected to a microcontroller, Arduino nano. The sensor had a built-in accelerometer and gyroscope, which allowed live tracking of the angle the tilting plane had, relative to a horizontal plane. The code controlling the microcontroller was written in C++ (Appendix D). The code was generated and optimized iteratively using Microsoft Copilot (Microsoft 2026). The microcontroller had a pre-set target angle, 0° with a tolerance of -1° , creating a goal angle range for the plane to reach. The system had two LED lights, a green and a

red, to serve as feedback and guidance, and a button to trigger the measurement. If the tilting plane started at an angle outside the goal range, the red LED lighted up. When the nut was rotated, the plane slowly got closer to being horizontal, and the green LED lighted as the plane reached the reference angle range.

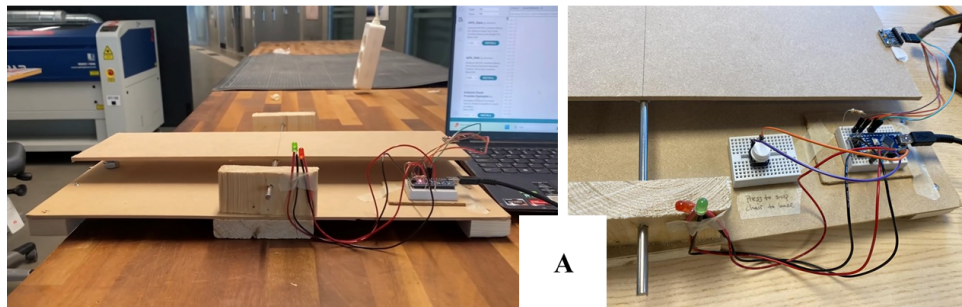


Figure 12 Prototype A.

5.1.2.2 Prototype B-E

Prototype B and C explore principles 3 and 9. The mechanical concept of prototype B was that the tilting plane was on top of the bottom. It had an axis in the front, leading to the front fastening being fixed, and the back fastening for the seat followed the movement of the tilting plane. It had a hollowed space to reach the ISOFIX tightening handle and buttons, as well as an intended spring-loaded pin mechanism to lock the plane's position in pre-set holes which were built on top of the bottom. Prototype C used the principle of a rack and pinion, where a wedge moved horizontally to raise the tilting plane by pushing from underneath. The rack and pinion were hidden in the back of the base.

Prototype D tested the principles 3, 5, 6, 9, and 10. The concept was similar to B, except for the top part being recessed into the bottom part, so that the fixed holes were placed on the side of the bottom instead of on top. Finally, Prototype E included the principles 1, 5, 9, and 10 and used a wedge, pushing the back mounting in a vertical movement which, in turn, maintained the same distance between the front and back mounting of the seat.

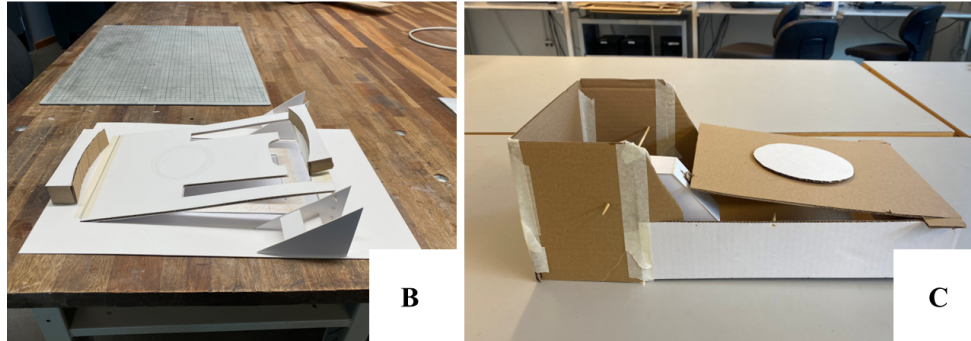


Figure 13 Prototype B and C.

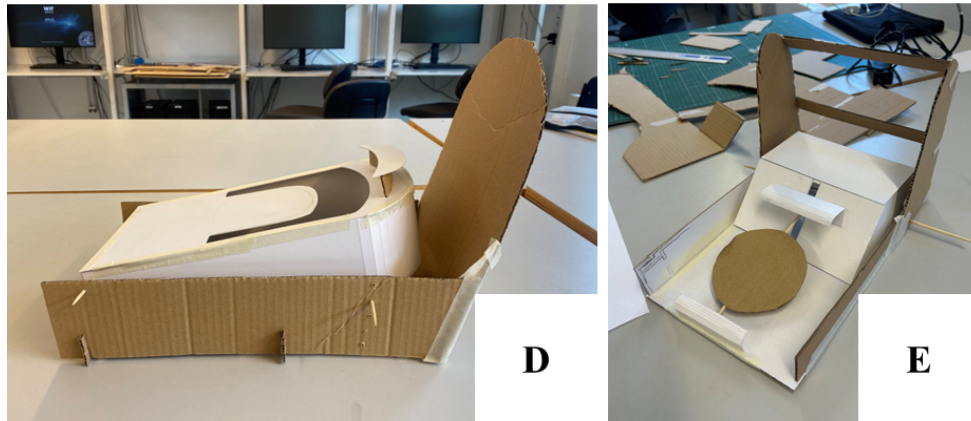


Figure 14 Prototype D and E.

5.1.2.3 Evaluation of Prototype A-E

To evaluate the prototypes A-E, a group of three experts from the research and development team at Thule were consulted to generate valuable insights to take into consideration in concept scoring. The session involved a discussion of the concepts with the mechanisms in focus, where the experts' opinions were noted (Wikberg Nilsson, Ericson & Törlind 2015). The group collectively preferred the sensor concept with continuous height adjustment in prototype A. The motivation was that the continuous adjustment added value to the sensor by achieving precision to the adjustment. One highlighted the implementation aspect of where the level of complexity should be matched with how much the function is used, therefore the mechanical function of A was pointed out to be best from that perspective. The same expert pointed out a challenge with C and E due to friction and tolerance stack-up due to the complexity of the functions. A, B and D were considered more robust from that point of view. Prototype D was experienced as intuitive from the same expert. Another pointed out that the diameter of the axis in B and D will affect the

number of steps which give less precision. Additionally, the same expert gave input on that the control should be hidden after placement of seat or have a two-step activation to prevent accidental adjustment.

After the discussion, a concept scoring matrix (see Table 12) was performed with the criteria: angle precision, robustness, innovativeness, minimal position movement, and simple mechanisms, which were areas discussed during the expert session. The concepts were scored on a scale 1-5 based on each criterion, with 5 as the highest score.

Table 12 Concept scoring matrix.

<i>Evaluation of prototypes A-E</i>					
Criteria	Concepts				
	A	B	C	D	E
Angle precision	3	1	3	1	3
Robustness	1	3	1	3	2
Innovativeness	1	1	2	1	2
Minimal position movement	3	2	2	2	2
Simple mechanisms	3	2	1	2	1
Sum	11	9	9	9	10

The result of the scoring matrix was that prototype A had the highest score of 11, even though the scores were quite similar. None of the concept A-E stood out particularly, which can be assumed to be a result of the similarity between them. Looking at criteria level, what stood out were the angle precision in concept A, C, and E, robustness from B and D, and finally minimal position movement as well as simple mechanisms from A.

5.1.3 Further developed prototypes

Moving forward, it was decided to combine concept A and E, achieving the highest score in the scoring matrix, with inspiration from criterion that stood out with high scores from the other concepts. Prototype F and G (see Figure 15) shared the same base where the back fastening for the seat was connected to a threaded rod and was adjusted vertically by a screw mechanism. The front fastening would allow rotation of the connected part of the seat. Hence, what differentiated them was that F had a pivot mechanism for the plate, movable around a central axis to match the position of the fastening at the back, and G used a framework with the middle plate attached

which followed the movement of the back mounting. The framework of G was fixed in the front and back fastening.

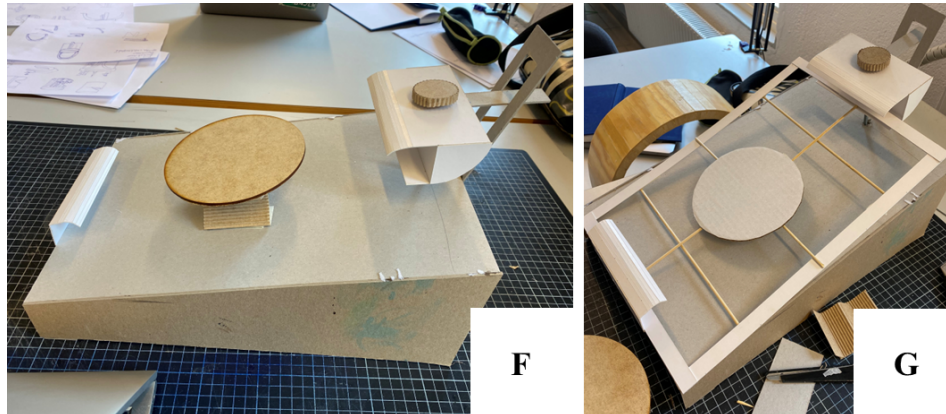


Figure 15 Prototype F and G.

Another evaluation was performed along with supervisor at Thule to discuss the concept and make eventual alterations. Feedback on the concept was that significant forces are absorbed by the surface, not only the attaching points. Therefore, the concept of Prototype F and G needed further development to become more rigid.

A final rapid prototyping session followed, resulting in Prototype H (Figure 16). The concept was a base consisting of two main parts, referred to as bottom and top, linked together with a frontal axis to enable the top move with the height adjustment. The height adjustment consisted of a screw mechanism, where a threaded rod rotated in a fixed nut inside of the bottom part. The plate, front-, and back fastening were all systems part of the top. The electronics were implemented to test the concept of the sensor and LED lights, and the angle sensor was placed on top of the moving part.

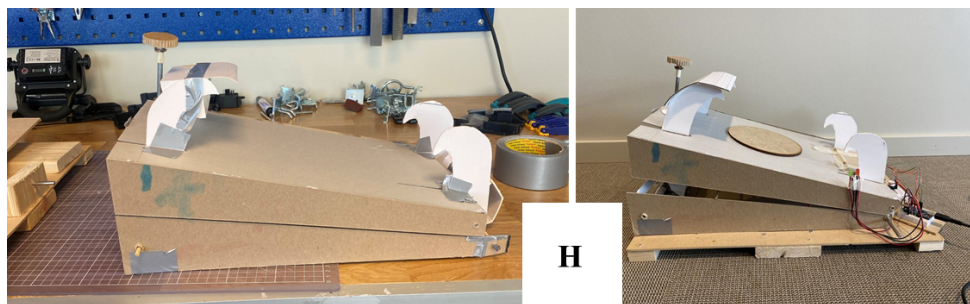


Figure 16 Prototype H.

The electronic system was further developed by implementing the external component of a smart phone. An app that can track live data of a smartphone, which has a built-in accelerometer, gyroscope, and magnetometer, was used to measure a reference angle for the microcontroller. The app was connected to a computer which stored the information and sent it to the microcontroller. As seen in Figure 17, the smartphone was placed flat on a surface. When the button, activating the electronic system on the prototype, was pressed, a reference angle was applied to the sensor. The system of the sensor and LED lights then worked as explained in 5.1.2.1 Prototype A. The procedure also worked when the system was tested on a non-flat surface, mimicking an imaginary scenario where a car would be parked in a slope.

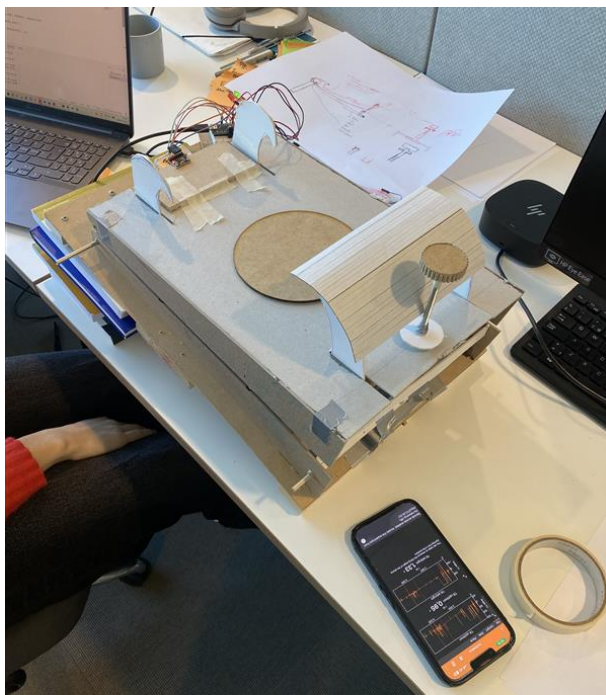


Figure 17 Test with Prototype H, electronics, and smart phone.

Given the time plan of the project, it was decided that no further development of construction or mechanisms should be made. With the rapid prototyping process completed, focus was on deciding on details before creating a 3-dimensional computer-aided design (CAD) model. The details included how the top and bottom part should look and fit together, and how to integrate existing components such as ISOFIX arms and load leg. This was done through detailed illustrations presented below (Figure 18-Figure 20). The illustrations present three design alternatives. The first had the top part lying on top of the bottom, creating a hollowed space between them when adjusting the height. In the second alternative the top was recessed into the bottom part so that the edges of the bottom surround the top part. The third

alternative was an inverted version of the second, where the top's edges surrounded the bottom.

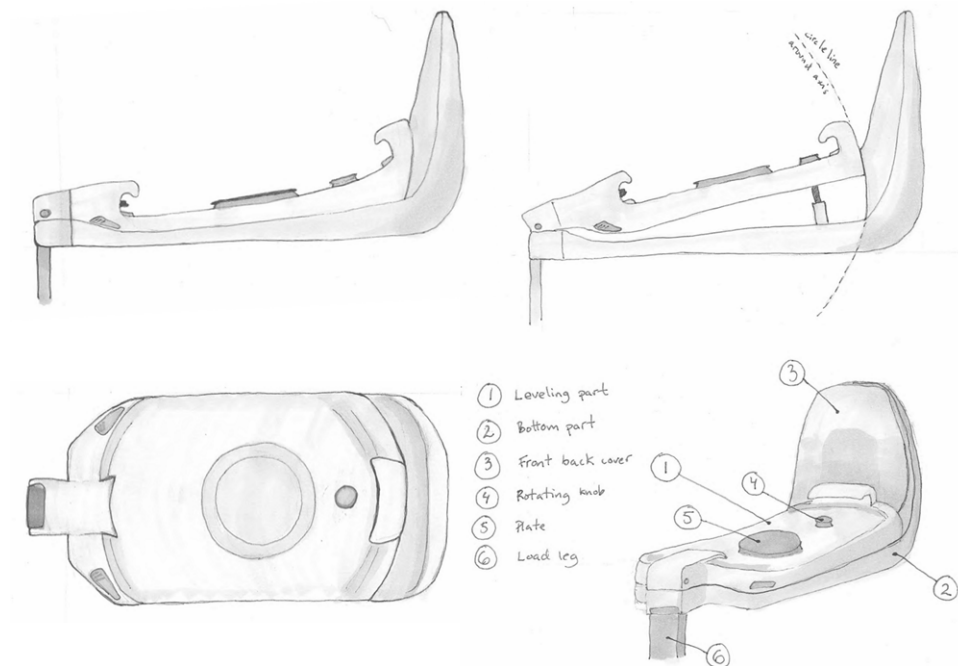


Figure 18 First design alternative.

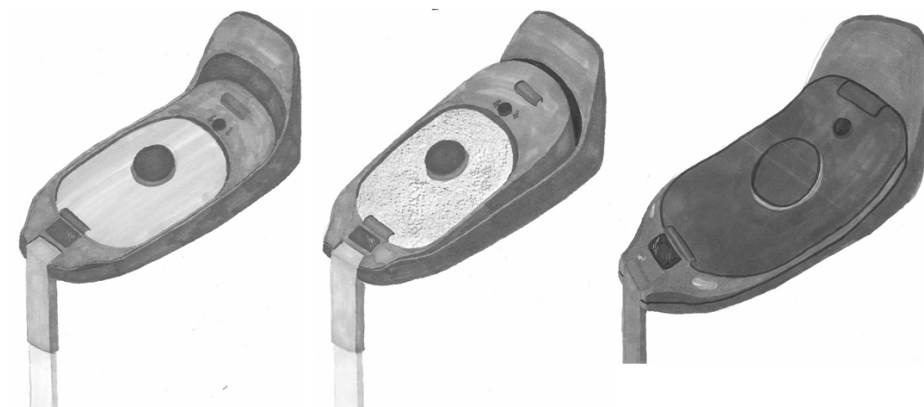


Figure 19 Second design alternative.

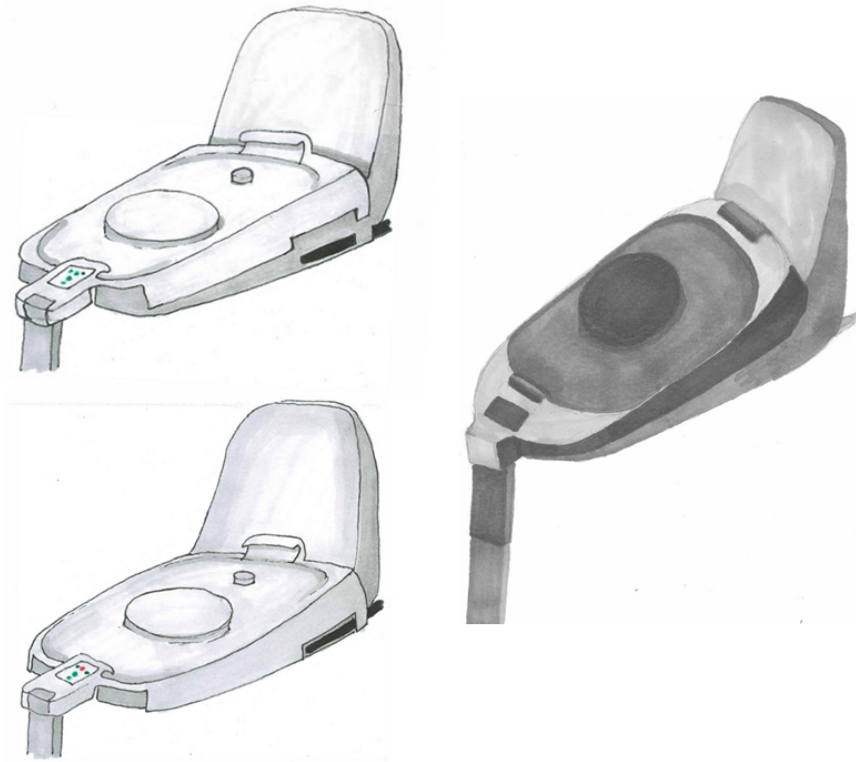


Figure 20 Third design alternative.

A discussion of the detailed concepts led to design decisions presented in the list below:

- The parts should be shells and therefore not include structural components since the project focuses on generating a concept rather than a fully developed product.
- To avoid gaps where dirt can gather, the top part should enclose the bottom as in Figure 20.
- The rotating knob should be placed between the plate and the back fastening and is thereby hidden when the seat is installed to prevent accidental adjustment by child.
- The frontal axis assembles the bottom, top and load leg to allow a stable structure.
- LED lights connected to the sensor are placed on top of the load leg, which also is where the LED light-display on Thule Alfi is placed. This is to consider spatial mapping.

5.2 User experience concept

Once the mechanical and electronic concept was decided, the project moved on with a user experience (UX) concept development. The focus was on user-centered design principles which are about understanding a user's needs and experiences (Rogers, Sharp, & Preece 2023). It began with discovering different ways of interacting with the concept including a sensor.

5.2.1 Conceptual ideas

5.2.1.1 App concept

The first alternative was called the app concept and had the purpose of using an app to measure the incline of the ground as a reference angle for the system in the base. The user measures the incline of the ground, and the angle is communicated to the microcontroller mounted on the base. It sets the angle of the ground as a reference angle to then register the angle of the accelerometer in MPU6050. The target angle for the base is now the reference angle, given by the measurement of the ground.

After the ground inclination measurement, there are three scenarios of user actions depending on the angle position of the base. One is that the position of the base is reclined too little and needs to be raised to match the reference angle, while another is that the base has a too steep angle and therefore needs to be lowered. The third scenario is that no adjustment is needed since the position of the sensor in the base matches the reference angle.

Guidance or feedback will be given to the user on what actions to take. Depending on which adjustment is needed, the guidance will differ. If a raise of the base is needed, the app will instruct the user to rotate the control clockwise, whereas if it needs to be lowered the instruction will be to rotate it counterclockwise. When no adjustment is needed, or when adjustment is sufficient, feedback will be given on whether the system status is correct and the installation is complete.

5.2.1.2 Condition of level ground

The second alternative had a condition that the car was parked on level ground. The concept would use the MPU6050 alone and with a ground inclination of 0°, it would become the pre-set reference angle for the base to achieve. Alike the app concept, the angle sensor is mounted on the top of the base to measure the recline position and the scenarios of user actions are likewise to the app concept. The main difference is that level ground will be the reference angle as well as it is a requirement for the concept. Feedback and guidance would need to be communicated to the user through light and sound integrated into the base. Lights could be located around the rotating control indicating clock- or counter wise rotation of knob, and sound would be used to strengthen the communication.

5.2.1.3 Additional wireless sensor

The third concept consists of an additional wireless sensor placed in a portable part of the base. Through instruction labels, the user is guided to measure the inclination of the ground with the portable part, the inclination angle is then registered, and the part is put back into the base. Following actions for adjustment of the base would be as the ones described in the condition of level ground. Like the previous concept, feedback and guidance would have to be implemented on the product.

5.2.2 Chosen concept and use case

To fully meet the problem definition regarding installation in a slope, as well as aligning with Thule's direction of digitalization such as Thule Alfi Connect, the concept chosen was the app concept. The concept would develop the already existing Thule-App. Contributing to the selection was also the feedback and guidance benefits derived from utilization of a smartphone, allowing for more detailed and dynamic guidance than can be communicated through instruction labels.

The interaction between the user and the product is presented as a use case in Table 13. A use case is a step-by-step explanation of how a user interacts with a system to achieve a specific goal (Rogers, Sharp, & Preece 2023). The order of sequence includes eight steps where steps five, six, and seven have alternative courses which means that the following step can be carried out in various ways.

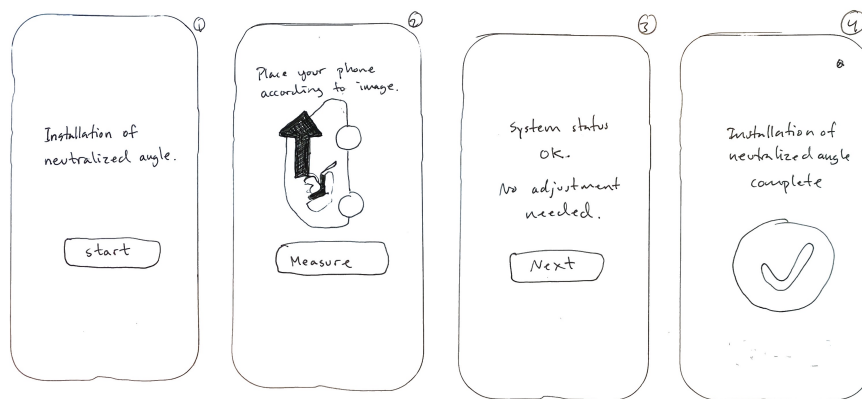
Table 13 Course and alternative course of system interference.

<i>Use case of app concept</i>	
<i>Order of sequence</i>	<i>Course and alternative course</i>
1.	User installs the ISOFIX and load leg in a parked car.
2.	The user gets indication to measure the angle of the ground.
3.	The system waits for reference angle.
4.	User measures the ground on signal.
5.	The system registers reference angle:
5.1	System registers correct state.
5.2	System registers incorrect state.
6.	The user receives information about system state:
6.1	The user gets feedback and guidance that no adjustment is needed.
6.2	The user gets feedback and guidance on how to perform the adjustment needed.
7.	Depending on the system state:
7.1	User proceeds to step 8.
7.2	User adjusts the inclination of base.
8.	System gives feedback that the installation is complete.

5.2.3 Low-fidelity prototypes

With the use case and requirements of the UX concept as a foundation, low-fidelity prototypes were made to illustrate the sequence of the app. A low-fidelity prototype is a mock-up of a digital interface and is used to quickly visualize how a digital system can work (Rogers, Sharp & Preece 2023). Two versions were made, where one explains the installation sequence in two courses and the other, both courses are included (see Figure 22-Figure 24). The first version (course one) had the following sequence:

1. A start page to begin the installation.
2. An illustration of a car from the side with a large arrow pointing in the driving direction. A square to be pressed to measure reference angle was at the bottom of the page.
3. Text explaining that the system status is correct and that no adjustment is needed.
4. Installation is complete and an illustration of a checkmark.



Feedback

- Vartför behöver jag inte göra ut? ③ → Mätning klar
- Info saknas om vartför ok. ③
- Trycka på "measure" → bra, så att den inte väntar om man lagt den rjustats. ②

System status ok

Figure 21 The first version (course one) of the low-fidelity prototypes.

The first version (course two) had the following sequence:

1. A start page to begin the installation.
2. An illustration of a car from above with a large arrow pointing in the driving direction and a smartphone on its side. A square to be pressed to measure reference angle was at the bottom of the page.
3. An illustration of a knob with arrows indicating rotation to left and instructions to rotate until green light shows on the product.
4. Same as 3 but rotation to right.
5. Text explaining that the system status is correct and that adjustment is completed.
6. Installation is complete and an illustration of the display on the product including all green LED lights.

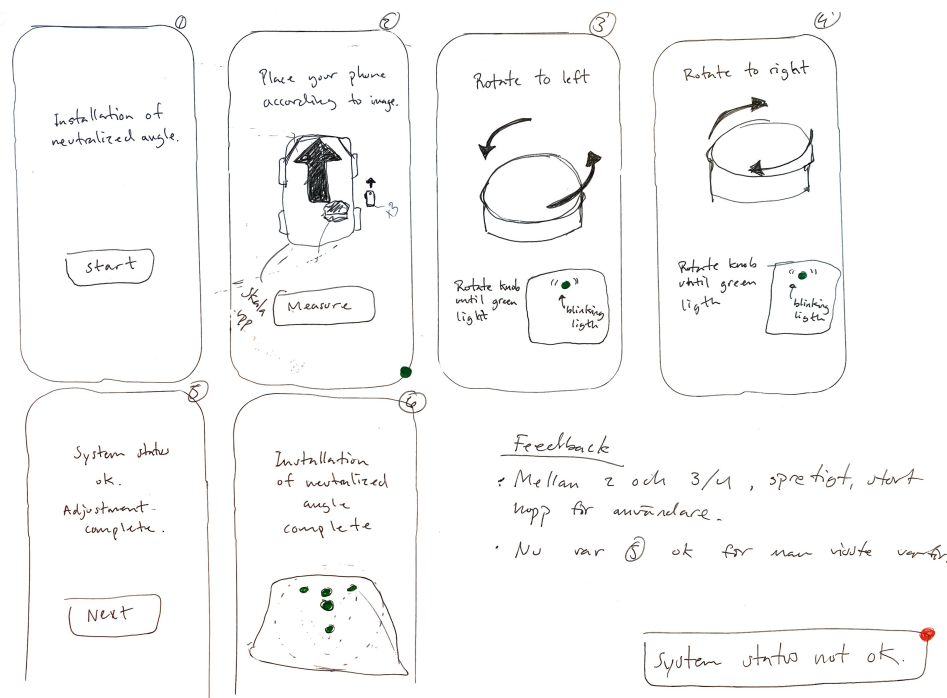


Figure 22 The first version (course two) of low-fidelity prototypes.

The second version included a demonstration of which step of the installation the user was on. The sequence starts with step four out of seven because previous steps such as installation of ISOFIX and load leg were considered complete. It had the following sequence (course one and two included):

1. Step 4/7 with an illustration of the base with an arrow indicating where movement applies. A square to be pressed to proceed to the next step.
2. Step 5/7 with an illustration of a car from its side with a large arrow pointing in the driving direction and a smartphone under the car. A square to be pressed to measure at the bottom of the page.
3. No adjustment vs adjustment:
 1. Step 6/7 with a text explaining that the measurement is complete and that no adjustment is needed. An information icon to press to be informed why.
 2. Step 6/7 with text explaining that the measurement is complete and that adjustment of recline is needed. An information icon to be informed of why as well as an illustration of the base from above with arrows indicating rotation of the knob to right.
 3. Same as 3.2 but rotation to left.
4. Step 7/7 with a text explaining that the installation is complete and an illustration of a checkmark.

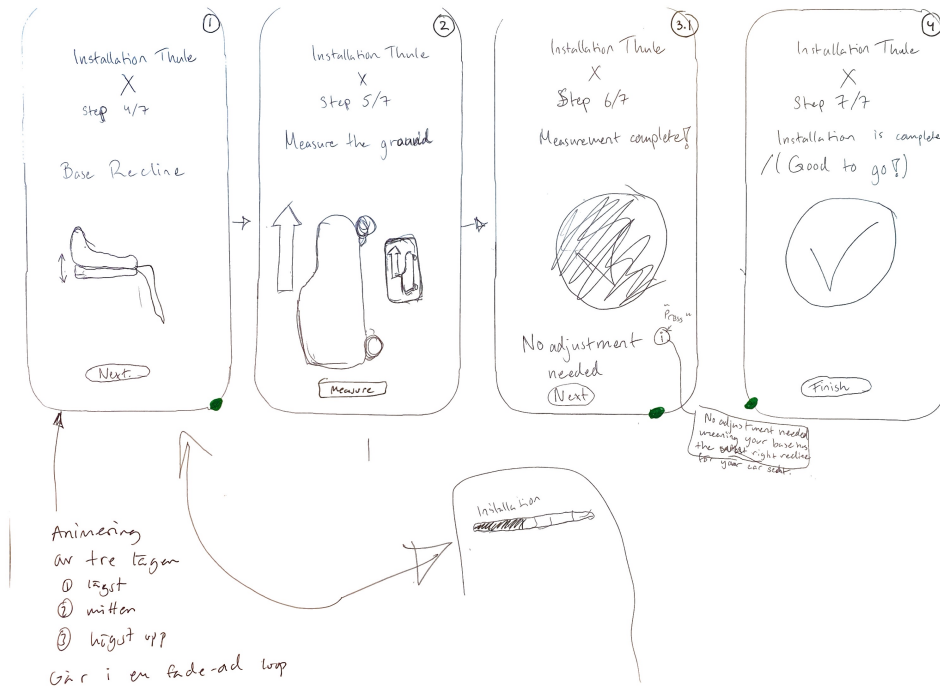


Figure 23 The second version of low-fidelity prototypes (1/2).

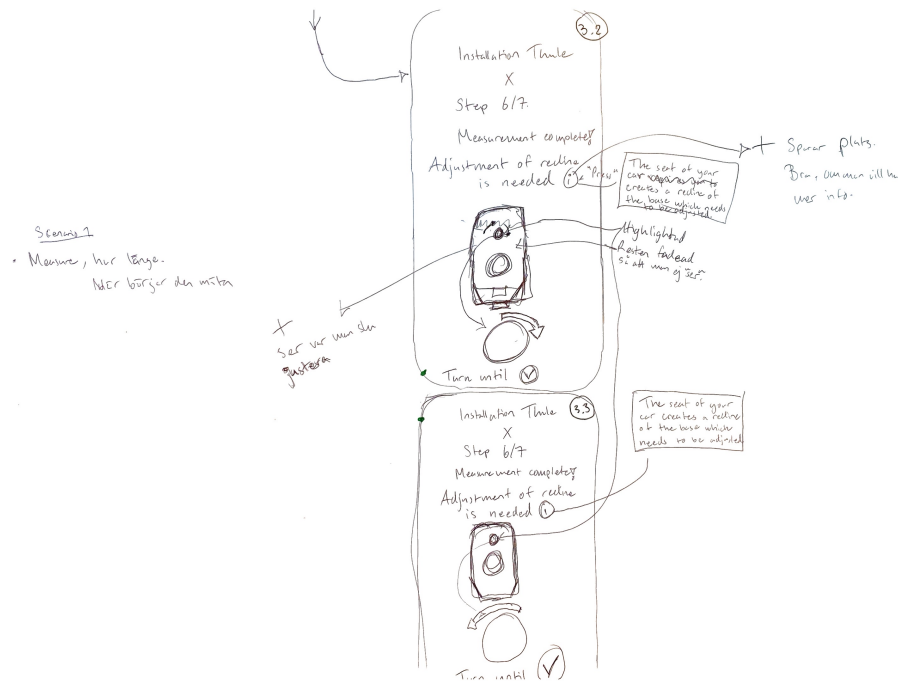


Figure 24 The second version of low-fidelity prototypes (2/2).

The low-fidelity prototypes were evaluated using the principle of Wizard of Oz which is a method that allows people to interact with the system as it was software-based (Rogers, Sharp & Preece 2023). The authors went through each page with a blockage of the rest of the sequence, allowing one another to interact with their ideas such as pressing on illustrations of buttons. The sequences were similar, but a merged result was agreed upon to create a better flow for the user.

5.2.4 High-fidelity prototype

The merged result of the low-fidelity prototypes was created as a high-fidelity prototype in Figma. A high-fidelity prototype appears more like the final product and supplies more functionality compared to a low-fidelity prototype because the user can interfere with the system (Rogers, Sharp & Preece 2023). The sequence with five steps is presented with snapshots below and is as follows (Figure 25-Figure 34):

1. Start page giving feedback to the user on how far the installation process has proceeded, an animation of the base inclination, and a button to start.

2. An animation of a smartphone being put down on the ground beside a car with an arrow illustrating driving direction. A button to measure.
3. Measuring button and an arrow pointing to the left, as well as feedback to the user to hold.
4. No adjustment vs adjustment:
 1. Feedback to the user that no adjustment is needed and an information icon explaining why. A button to proceed to next.
 2. Feedback to the user that adjustment is needed and an information icon explaining why. An animation of the knob rotating either to right or left.
5. Feedback to the user that the installation is complete. An illustration of the base where green dots indicate completed installation steps. A button to finish.



Figure 25 High-fidelity prototype step 1.

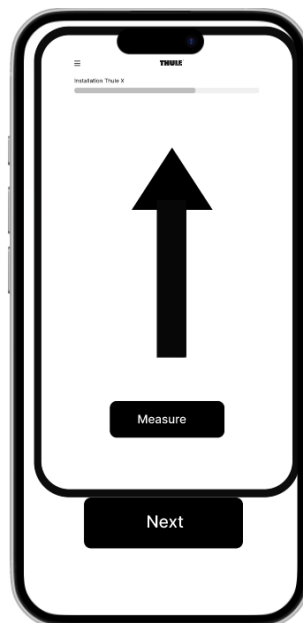


Figure 26 High-fidelity prototype step 2.

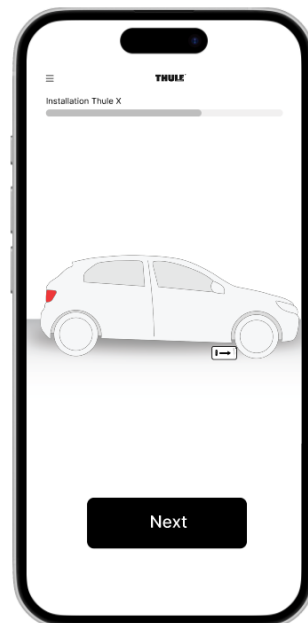


Figure 27 High-fidelity prototype step 2.

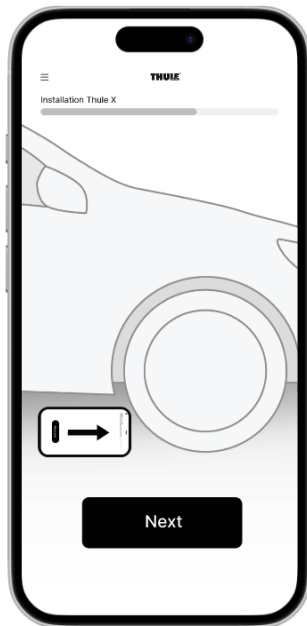


Figure 28 High-fidelity prototype step 2.



Figure 29 High-fidelity prototype step 2.

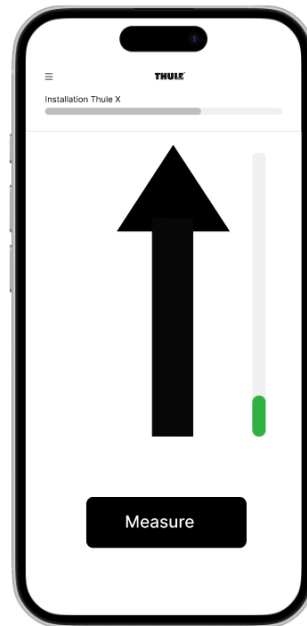


Figure 30 High-fidelity prototype step 3.

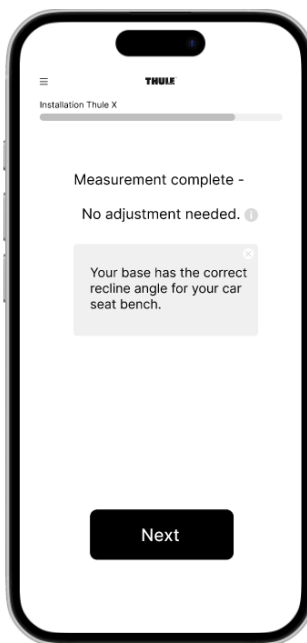


Figure 31 High-fidelity prototype step 4.1.

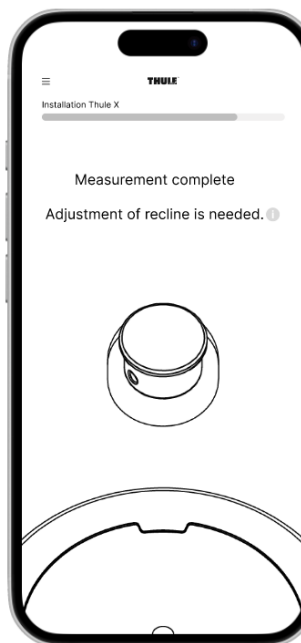


Figure 32 High-fidelity prototype step 4.2.

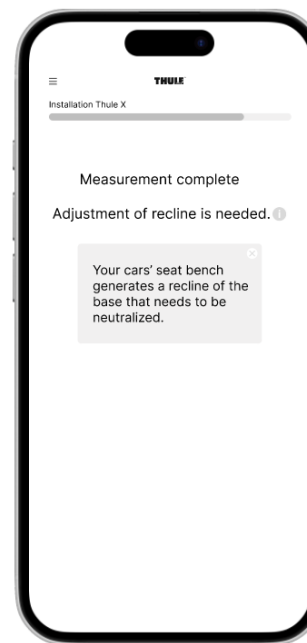


Figure 33 High-fidelity prototype step 4.2.



Figure 34 High-fidelity prototype step 5.

The evaluation of the high-fidelity prototype can be seen in the following chapter, Deliver.

6 Deliver

This chapter will present the result of the project in form of a physical prototype including electronic parts and the application interface used to guide the installation.

6.1 Final concept and evaluation

The result of the project is a concept of a sensor-based child car seat base with leveling system, installed using an app as guidance and tool. The system enables the user to achieve the same starting point when installing a child car seat on the base independent of car model or ground inclination. The existing base Thule Alfi has three installation steps: ISOFIX, load leg, and child car seat. This solution adds an additional step before installing the seat, a base inclination.

6.1.1 Final prototype of mechanical and electronic concept

6.1.1.1 Leveled prototype

The 3D-printed prototype consists of two main shelled parts, a top containing the fastening of the car seat and a bottom. The parts are put together with an axis at the front. The top part can be inclined with a continuous screw mechanism, and the inclination is performed by rotating a control. Rotation to the left will raise the top and rotation to the right will lower it. The top has slightly larger dimensions than the bottom and therefore enclose it. Existing parts of Thule Alfi installed in the prototype are load leg for stabilization and a metal and plastic plate for where the seat connects. 3D printed replicas of ISOFIX arms are also implemented, provided by Thule. The lowest, middle, and highest inclination stage of the base as well as the toddler seat Thule Elm installed are presented below (Figure 35-Figure 38). For the seat frame to fit the base, a groove was milled as seen below (Figure 39). This was done because the control of the height adjustment interfered with the seat otherwise.



Figure 35 Lowest inclination of the base.



Figure 36 Middle inclination of the base.



Figure 37 Maximal inclination of the base.



Figure 38 Toddler seat mounted on the prototype.



Figure 39 Milled seat frame installed on the prototype.

6.1.1.2 Screw mechanism

The screw mechanism consists of a threaded rod with 2.5 mm pitch, a mount which is attached to the bottom part, a nut, a hat of which the top part rest on, and a knob. The threaded rod, hat, and knob are put together by two screws. The screw mechanism allows an inclination adjustment of 8 degrees. The parts and how they are implemented in the prototype are presented in the following figures (Figure 40 and Figure 41).

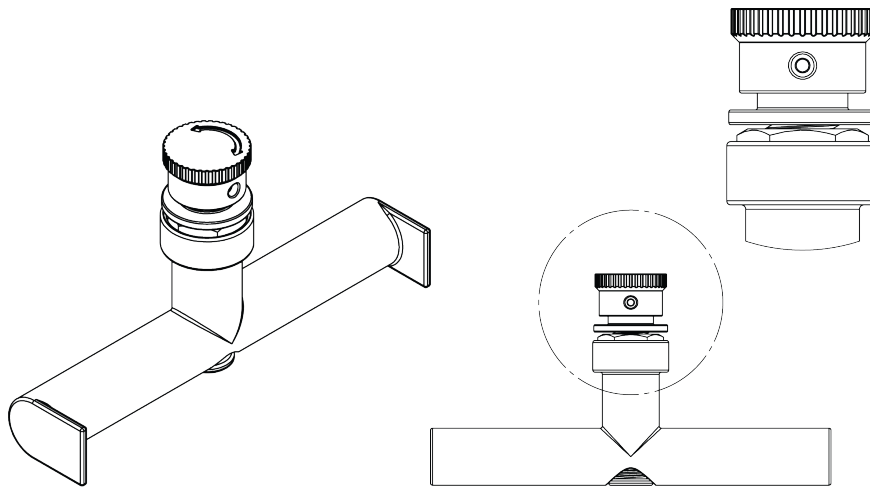


Figure 40 Screw mechanism.

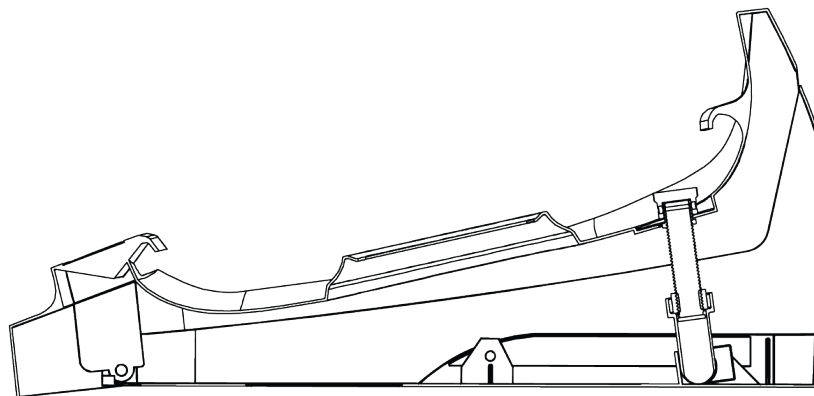


Figure 41 Cross-section of prototype in maximal inclination.

6.1.1.3 Guidance and feedback

The rotating knob has an arrow pointing in both directions to instruct the user that it can rotate both ways. The symbol also avoids the interaction to be a push or pull, for example. The LED-display both guides and supports the user with feedback since a red or green light instructs the system status of base inclination, and when the light changes the user gets feedback of correct or incorrect installation. The rotating knob with its arrow and the LED-display are presented in the following figure (Figure 42).

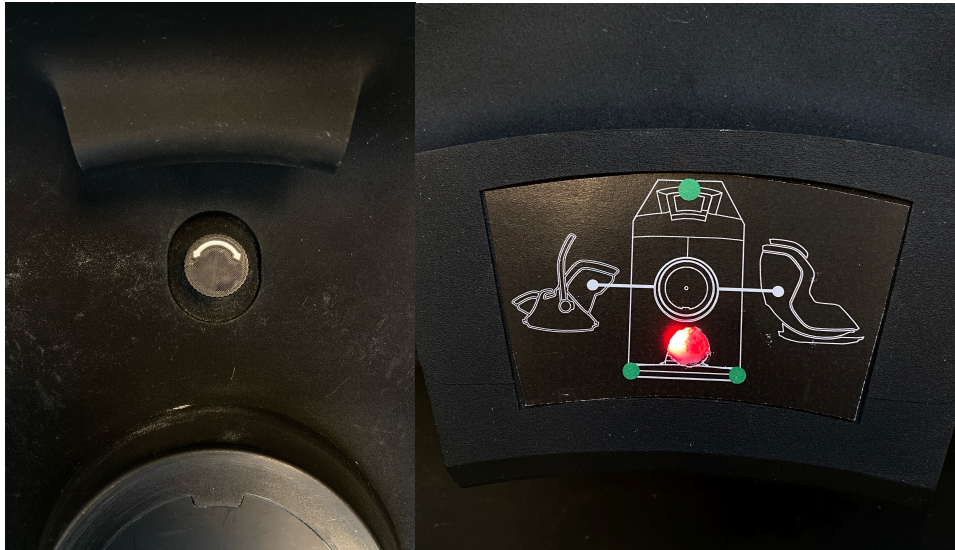


Figure 42 Guidance and feedback on the prototype.

6.1.1.4 Electronics

The electronics installed are an MPU6050 sensor including an accelerometer, a micro controller, LED lights, resistors, and cords. An electronics schedule of how the system is intended to communicate is presented below (Figure 43). A reference angle is measured with a smart phone and delivered to the microcontroller via wireless connection. A green LED light lights up if the accelerometer matches the value of the reference angle, and a red LED light if it does not. The angle reference measurement with the smartphone is supported by an app. Since the smartphone also has an accelerometer as well as a gyroscope and a magnetometer installed, it enables installation when the car is parked in a slope, since the goal always is to match the ground inclination.

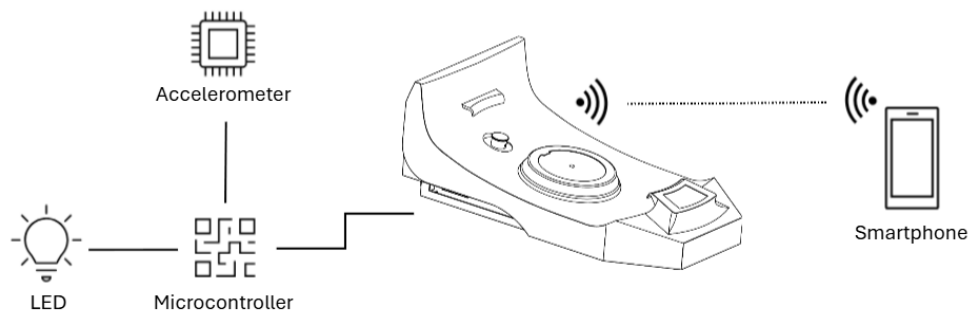


Figure 43 Electronics schedule.

6.1.1.5 Test in car

The prototype was tested in a car parked in a garage, and therefore the reference angle of the microcontroller was zero degrees. The condition of correct installed system was satisfied for a maximal inclined position, and when the base was not inclined, in its lowest position, the top surface had an offset angle of eight degrees (See Figure 44 and Figure 45). A smartphone's spirit level function was used to illustrate the inclination.



Figure 44 The base in a car in a non-inclined position.



Figure 45 The base in a car in its maximal inclined position.

6.1.2 Evaluation of mechanical concept with high-fidelity app prototype

To test the sequence and the design of the high-fidelity app prototype, an evaluation was performed with inspiration from a method called usability testing (Rogers, Sharp & Preece 2023). The goal of usability testing is to evaluate whether the app is used the way it is intended to and if the user can complete the tasks of the installation sequence. Therefore, the participants performed an installation of the physical prototype's inclination using the high-fidelity prototype as their tool. The setup was in a temporarily controlled environment including a car seat placed as if the car was parked on a slope, an inclined surface next to the seat with identical angle representing the ground, the prototype placed in the car seat, and a smartphone with the app. The participants were four people working at Thule with various knowledge of CRS products. The participants were told to think out loud while performing the installation and their thoughts and expressions were compared to six of the 11 requirements presented in Table 9. These six requirements were the only ones selected for user evaluation. It was noted whether the requirements were met or not met, along with a comment.

The result was that five of six requirements were met, see Table 14. A step the participants struggled with was the measurement of the ground inclination, which corresponds to requirement number four. Step two and three of the app sequence was not clear enough, which showed a preview of the measurement and the actual measurement. It was not clear where to place the smartphone, whether it should be by the front wheel or not. The preview was in two cases mistaken of being the actual measurement. It was also not clear that the smartphone must be placed on the ground. However, one interpreted the preview as an instruction, which was the idea of step 2. In addition, all participants located the control and rotated in the given direction without any discomfort, although with comments on that the animation of the step could be clearer, for example by adjusting the animation so that the control rotated smoothly and not bit by bit. Two of the participants also pressed the information icon to understand why adjustment was necessary and all noted the LED lights on the physical prototype.

Table 14 Evaluation of high-fidelity prototype and physical prototype.

<i>Evaluation of high-fidelity and physical base prototype.</i>		
<i>Requirement</i>	<i>Met / Not met</i>	<i>Comments or raw participant statements</i>
1	Met	Noted LED on prototype. “There is the green light”.
2	Met	Pressed information icon.
3	Met	Sequence was clear.
4	Not met	“I was confused by the front deck of the car”. “Have I measured the ground inclination two times?”. “On its edge, forward, and in driving direction”. Interpreted the preview as instructions.
5	Met	Located knob without any trouble.
8	Met	Rotated knob smoothly.

Regarding the requirements not included in the user evaluation: 6, 7, 9, 10, 11, they were evaluated by the authors. Requirement six was met due to the eight-degree adjustability of the base’s inclination as confirmed in 6.1.1.5 Test in car. The seventh can be motivated as met because the manufacturer can gain control over the recline range, making sure it offers sufficient recline range. The ninth is met because the concept includes that the user measures the inclination of the ground. Furthermore, the tenth is met because the color scheme of Thule was used in the development of the app and their form language was considered in the creation of the final prototype. Finally, the eleventh is met because the prototype is adapted to function alongside existing products such as Thule Elm (see Figure 38).

6.1.3 Final application interface

The final application interface was iterated from the findings in the user evaluation. One adjustment was to move the horizon so that it aligned with the wheels of the car, to clarify that the placement of the phone should be on the ground. The phone in the preview was also moved away from the front wheel, closer to the center of the car, to avoid confusion with the front wheel. The text on the button “Measure” was altered to “Measure slope”, to remove any ambiguity what should be measured. An additional information icon was added to the measurement preview, with the steps as written instructions, in case the user needs more guidance than provided by the animation. The animation of the rotation of the knob was also altered to a smoother rotational movement to clarify the step.

All steps are explained in the following list, and the application interface pages are presented in the following pages (Figure 46 Application start page.-Figure 59). The application interface includes the Thule logotype (Thule, n.d.e).

- Application start page, press Thule X to begin installation.
- Step 1: An animation of base inclination. The progress bar is halfway through due to already completed installation steps (ISOFIX and load leg). A start button to begin installation.
- Step 2: An animated preview of how ground inclination, the reference angle, is to be measured. It displays car direction and smartphone placement. An information icon that provides the user with text explaining how to perform the measurement and a button to finish the preview.
- Step 3: A button to measure ground inclination and a green bar to instruct the user to hold.
- Step 4.1: Feedback that the measurement is complete and no further adjustment is needed. An information icon to explain why and a button to finish. The following step will be step 7.
- Step 4.2: Feedback that the measurement is complete and that adjustment of base inclination is needed. An information icon to explain why and a button to proceed to the next step.
- Step 5: An animated preview of how the adjustment is performed. The knob is rotated to the right or left until red light turns green. A button to finish preview.
- Step 6: An animation showing rotation direction.
- Step 7: An image of the LED-display with green lights indicating that installation is complete. A button to finish.

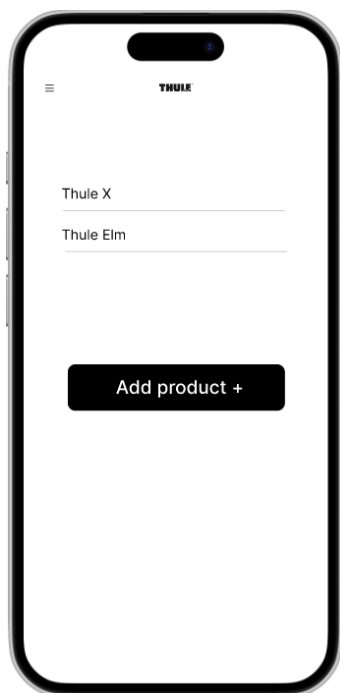


Figure 46 Application start page.

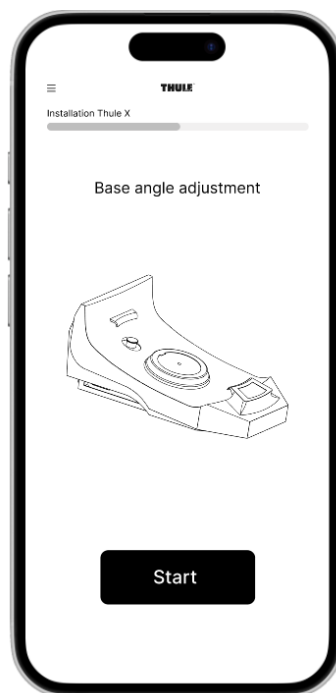


Figure 47 Application interface step 1.



Figure 48 Application interface step 2.

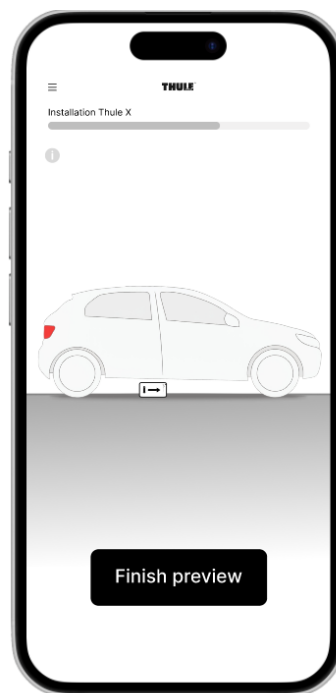


Figure 49 Application interface step 2.

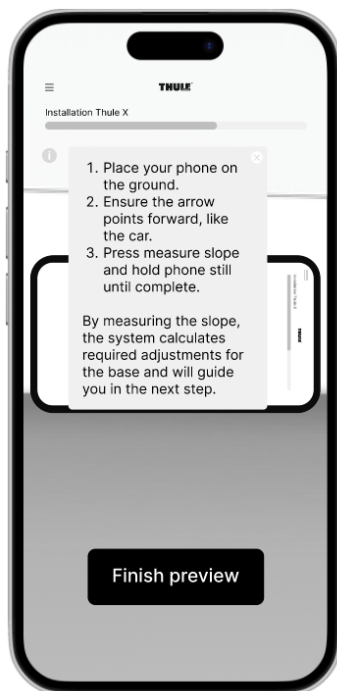


Figure 50 Application interface step 2.

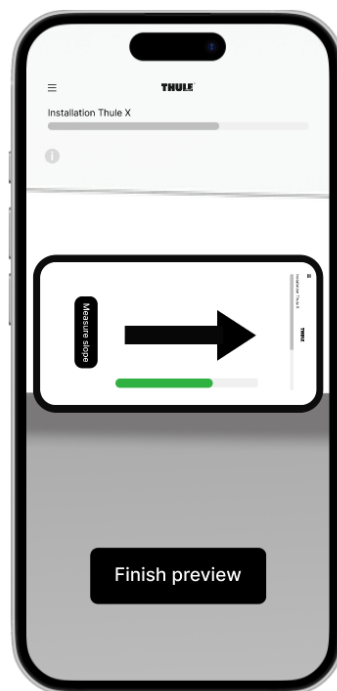


Figure 51 Application interface step 2.

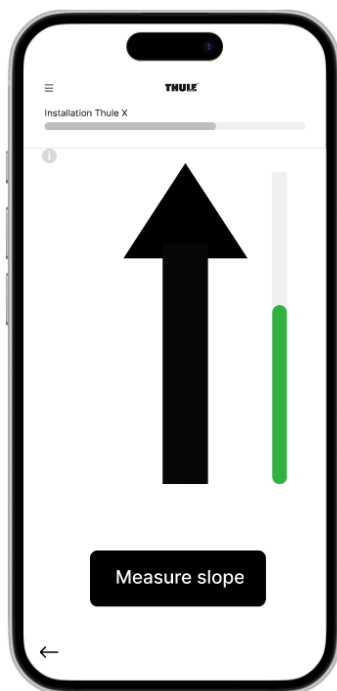


Figure 52 Application interface step 3.

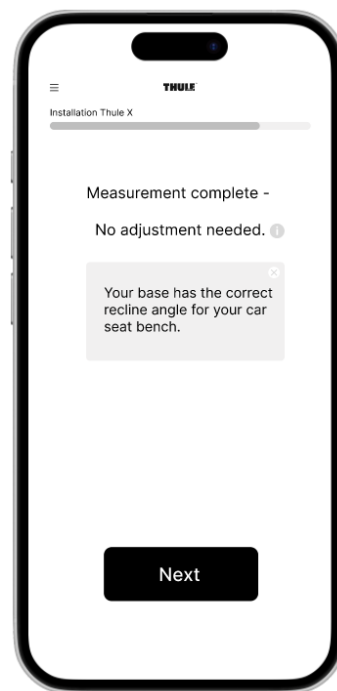


Figure 53 Application interface step 4.1.

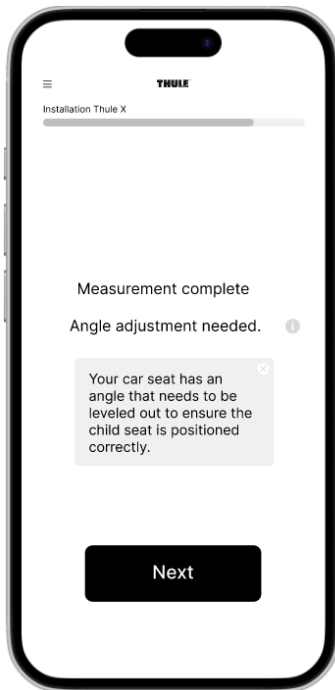


Figure 54 Application interface step 4.2.

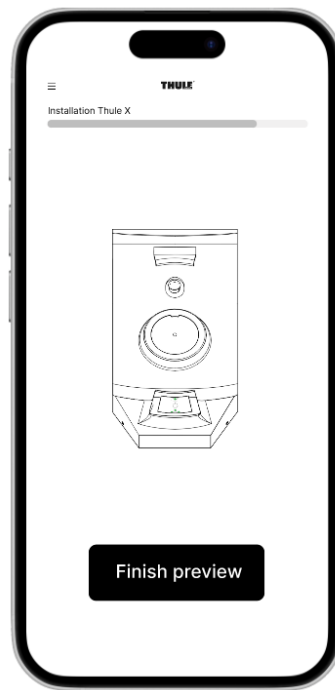


Figure 55 Application interface step 5.

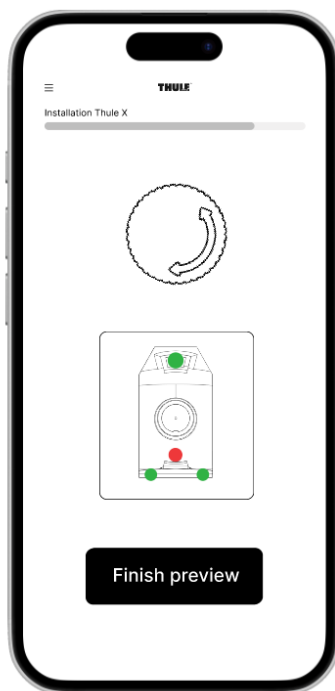


Figure 56 Application interface step 5.

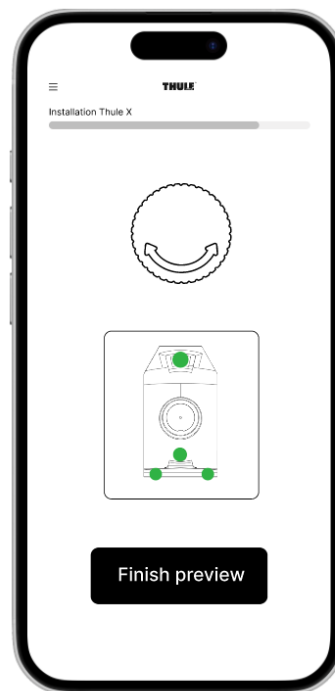


Figure 57 Application interface step 5.

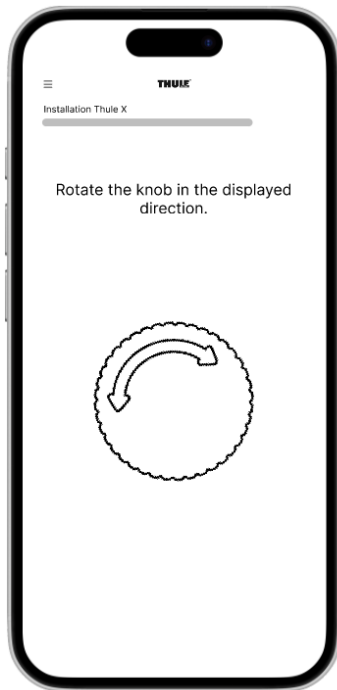


Figure 58 Application interface step 6.

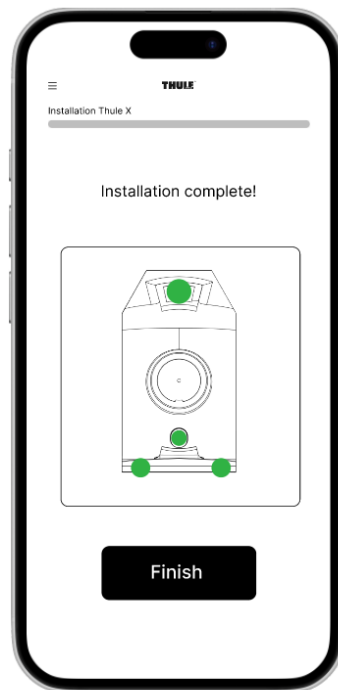


Figure 59 Application interface step 7.

7 Overall discussion

The final chapter consists of an overall discussion of the project. The discussion topics are reflections of methodology, user research, the result, and future development opportunities.

7.1 Reflection of methodology and time plan

The Double Diamond process allowed the scope of the project to alternate between being broad and narrowed. This was beneficial because it enriched the concept development by considering different perspectives throughout the process. However, the working procedure could have looked different. Quicker decisions during the phases ideation and early prototypes would have allowed more time spent on improving and refining the result such as further development of mechanisms or the design of both the physical prototype and the app. On the other hand, the quantity of ideas generated during these early phases helped form the result which would probably turn out differently otherwise.

7.2 Reflection of user research

The user study generated numerous insights directly affecting results such as the product requirement and customer needs, and thereby the final concept. To allow users to have such a central role of concept development was beneficial because the solution therefore reflects a legitimate need. However, it is important to reflect on the results of a user study. The questionnaire was designed to generate data on user behavior based on self-reporting. Answers reflect perceived information which means that they do not necessarily accurately reflect reality. Looking at the nature of the questionnaire, the respondents themselves reported on their perceived experience. This may not always match actual usage, in particular, the reported safety awareness may be affected by the social desirability to be aware of the safety of their child. On the other hand, the observations caught behaviors of users seen by the authors and the results can therefore be trusted to a greater extent, even though it can be difficult to interpret the participants' actions while observing them.

While analyzing the data gathered, insights were gained into how the procedure could have been performed differently. Two questions in the questionnaire had errors in reference. For instance, the quantitative focused question “Why do you change the recline angle of the CRS?” had the alternative “To provide more legroom”. This option can refer to more legroom for the child, a fellow passenger, or the driver. If such question had been specified, the response could have been analyzed. A qualitative data generative question was “Is it clear how to adjust the recline angle?” with the follow-up question “Why is it clear?”. This opened for interpretation and could have been clarified to “Why is it clear to adjust the recline angle?”. On the other hand, it generated a wide range of answers which gained knowledge of areas which would otherwise not be discovered.

While the majority perceived their safety awareness as high, recline adjustments were motivated more often by comfort for the child rather than by safety. This suggests that perceived safety awareness is not aligned with user behavior. Among the group of low to neutral safety awareness, a lower percentage said that they change recline motivated by safety, reflecting a logical correlation. For both cases, it could imply that users generally do not understand the correlation between recline angles and safety, which are strictly connected.

From the answers regarding improvements in the recline function, several mentioned that they would like to know or see the angle. Absence of feedback suggests that these users rely solely on their visual perception or measuring with other methods.

The thematic analysis includes interpretative categorization of the gathered qualitative data, which introduces some degree of subjectivity difficult to completely avoid. Even though the themes were grounded in recurring patterns, they reflect the interpretation of the authors. The fact that the analysis was conducted from two individual perspectives, a discussion was held and themes iteratively reviewed to reduce the risk.

The question regarding the desire to adjust recline while driving, was decided not to go forward with due to the safety aspect of the user keeping focus on the road, even if it for some of the users was considered desirable. While analyzing the results of the observations, where task five was to demonstrate how the user wished to adjust recline from the driver’s seat, it became clear that such function would have been difficult to implement while the system and situation remained safe.

While post reviewing the data, it was discovered that two of the 129 respondents of the questionnaire were not in the target group and had been overlooked during the initial filtering of the total 220 responses. These two respondents stated that they use their CRS in forward-facing position only, whereas the study targeted rear-facing users. However, representing less than 1.6% of the responses analyzed, their impact on the analysis and concept development was considered negligible.

7.3 Reflection of result

The result met all project requirements, and the development was done with inspiration from user statements gathered during the phase Discover. With the concept, it is possible for Thule to gain full control of the recline functionality of child car seats by accomplishing a standardized recline range, while users can use the system solely from a comfort perspective, which were discovered as part of users focus during user research. The controlled recline system enables the angle range to match the recommended angles of 30° to 45°, measured from vertical, which resulted in reduced spinal loads and increased comfort according to studies presented in Background (Lai et al. 2009; Tushak et al. 2026).

The system also provides clarity for users with the guidance of the app. Getting the child car seat at a correct angle in the car was one of the greatest challenges faced during installation of CRS products according to a study in Ontario (Britton et al. 2023). This concept solves the problem of getting the seat at a correct angle for each installation; however, it is crucial that the app gives sufficient support to the users to do so. By using as few steps as possible, focusing on a clear message with animations and icons, it simplifies the impression of the user.

Since CRS products are heavily tested and must fulfill certain standards regarding crash safety performances, the focus was not to implement a solid structure inside the two main parts of the prototype. For the time invested to be well spent, the concept should have been analyzed considering aspects like force flow, which the time plan of the project was judged not to be sufficient for. Instead, the project focused on the user experience that came with the digitalization of the installation sequence and implementation of electronics.

7.4 Future development opportunities

Since the result of the project is a concept, further development opportunities have been discovered along the working procedure. First, it could be beneficial to include a beeping sound connected to the angle sensor to give further feedback to the user while performing the installation. This feature is already implemented in Thule Alfı, and users of Thule products would be familiar with the sound.

Another development opportunity could be to implement a locking mechanism on the rotating control. Even though the knob is hidden when the child car seat is installed, further securement could be developed to ensure that it stays in place when the installation is complete, and to avoid interference with the seat when it rotates in place.

A third opportunity is to offer pre-settings in the app before starting the installation, such as if the system will be placed rear- or forward facing as well as installed in the back- or front seat. These settings would impact the installation sequence, and different settings would lead to different sequences. For example, if the user prefers to install the base in the front seat, they could be instructed to adjust the car seat to a neutral position before starting the inclination installation of the base.

Finally, the measurement of reference angle could be improved. This step of the installation is crucial for the base to be properly installed. Therefore, multiple measurement points could be added to the third step of the installation sequence, the measurement of ground inclination, and an average of these angles could be used as reference. This would add steps to the user activity, however, with the consequence of a more reliable result. Further research on where to measure the ground's inclination could also be of relevance since the smartphone could be exposed to moisture or dirt when measuring the ground incline. If possible, the measurement could take place in the car, with the condition that all car models have a surface parallel to the ground. Another opportunity to investigate further is whether it is possible to control the orientation of the smartphone, so that it matches the driving direction and thereby the direction of the accelerometer.

8 Conclusion

The result of this master's thesis project was a concept of a leveled child car seat base installed by the guidance of an app. The concept consists of a 3D printed prototype in a scale of 1:1 including electronics as well as a high-fidelity prototype of the user experience interface. The concept proved that it is possible to ensure that a CRS's recline angles are within a uniform range across a variety of car seat geometries as well as installing the system with a car parked on a non-level ground. This was because the base could be inclined to match the inclination of the ground by matching a reference angle measured with a smartphone. An angle sensor attached to the moving part of the base gave feedback to the user by LED lights whether the system status was correct or not.

The concept development process followed a Double Diamond process which alternated the focus between being broad and narrowed while performing the phases Discover, Define, Develop, and Deliver. The overall objective of the project was to demonstrate how the installation of this capability would be performed and therefore did not involve development of structures or mechanisms suitable for further analysis, such as force flow. The focus was instead on the user experience involving user-centered design principles and ergonomics.

The master thesis students responsible for the project see an opportunity to digitalize the installation process of CRS products with the final concept. They also believe the concept is an opportunity for users to gain increased control over such installations, leading to greater confidence regarding recline angles contrary to crash safety.

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Appendix A Work distribution and time plan

A.1 Work distribution

Table 15 Work distribution

<i>Discover</i>	<i>Define</i>	<i>Develop</i>	<i>Deliver</i>
50/50	50/50	50/50	50/50

A.2 Project plan and outcome

The project plan included the phases Research, Concept, Prototypes, and Deliverables. The initial project plan differentiates from the effective project plan of time spent on the prototype phase (Figure A.1 and A.2). The concept development iterated between sketches and prototypes.

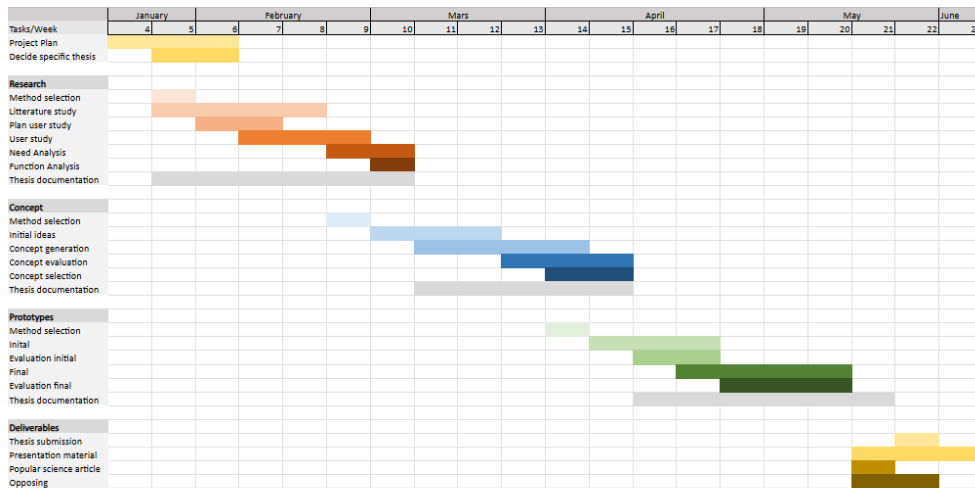


Figure A.1 Initial project plan.

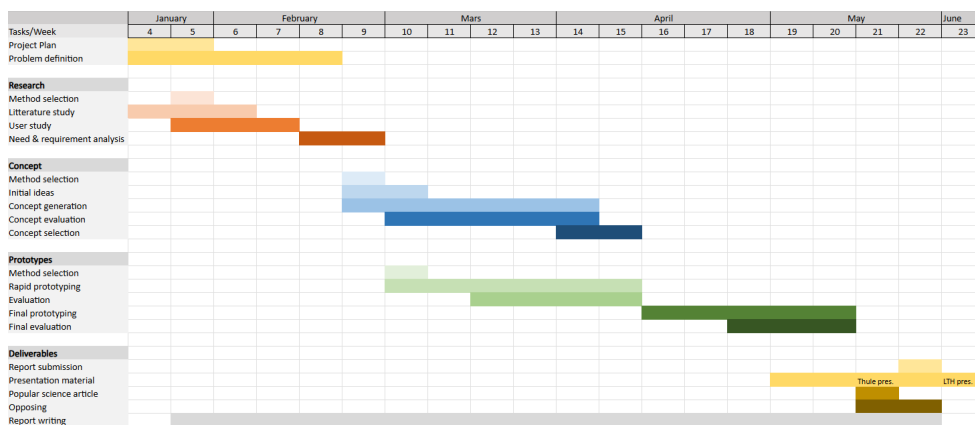


Figure A.2 Effective project plan.

Appendix B User research data

B.1 Feasibility questionnaire

Id	Email	Använder du / har du använt en bilbarnstol?	Vilket märke och vilken modell är/var det på den?	Vilken ålder är bilbarnstolen för?	Vilka problem har du upplevt med bilbarnstolen?	Hur ofta ändrar du lutning på stolen, om det finns en sådan funktion?	Varför ändrar du lutningen?	Har du upplevt några problem med lutningen eller dess funktion? Ge gärna ett konkret exempel.
1	anonymous	Ja	Be safe	0-1 år	Lite stor till spädbarn trots att det stor 0-1 år	Finns ej sådan funktion		
2	anonymous	Ja	Besafe	Från nyfödd till 5-6 åring	Inget problem	Aldrig ändrat	-	Inget problem
3	anonymous	Ja	Cybex Sirona	1-4 år	Hade velat ha en för upp till 7 år direkt	Massor när han va 1 men inte nu vid 4 år	När han sov eller skulle sova	Nej
4	anonymous	Ja	Cybex	0-2	Inga	Aldrig		
5	anonymous	Ja	Cybex	0-18 månader	Saknar upphängning för remar.	Finns ej		
6	anonymous	Ja	Be safe	4mån-4 år	Önska att den gick att vrida åt sidan för att underlätta insättning, den är bred så den går inte att ha i framsätet för då ser man inte ut alls typ	På helger när vi åker biltur på en timme, 6 dagar/månad	För att ändra läge så att hon kan sova bättre. Ibland åker vi bilturer på ca 4 timmar och då är det säkert skönt med lägesändring	Nej

7	anonymous	Ja	Thule Maple	0-9 månader	Inga	Ibland	Om han sover när vi kommer fram efter biltur	Nej
8	anonymous	Ja	Emmaljunga Besafe	0-1	Att den extra krockskyddsbiten som sitter på sidan och kan flyttas mellan sidorna, lätt kan ramla av, hade behövt något mer som man kan klicka i så att den satt fast bättre.	Varje dag	Antingen för att mitt barn har somnat och då lutar man stolen så hon ligger ned, annars för att hon inte ska försöka reda sig upp då hon gärna vill sitta i nyläget.	Nej.
9	anonymous	Ja	Cybox Cloud T i-size	0-1 år	Inga, superbra stol som går att snurra 360 grader med isofix-basen	Ej möjligt med denna stol, men snurrade den varje gång vi satte i och tog ut den på bra ergonomi		
10	anonymous	Ja	Cybox Sirona T i-size	1-4 år	Inga	När barnet skulle sova i bilen lutade vi den bakåt	För barnet skulle sova	Nej. Den kan också snurra 360 grader på isofix-basen. Väldigt bra när barnet ska sitta i och ur stolen och när man ska knäppa bältet.
11	anonymous	Ja	Maxi cosy	2024	Lite svärmöblerad	Sällan, nu är barnet såpass stort att det främst går att använda ett läge, som ger tillräckligt utrymme för benen	Om barnet behöver vila	Utrymmesbrist
12	anonymous	Ja	Britax swing och britax kidfix PRO	9 månader upp till 22 kg samt från 3,5 år		Ja	Sova	Vill kunna lura mer i vissa bilar.
13	anonymous	Ja	BeSafe stretch	4	Att den inre går att rotera	Aldrig		
14	anonymous	Ja	Britax	2-6 år	Fastnar i bland i sving fix läget	1 gång i månaden, mer när vitt barn var yngre	Kunna sova eller sitta upp mer rakt	Se ovan
15	anonymous	Ja	BeSafe Stretch	Upp till 7 år	Den är för stor och otymplig.	Aldrig		Svårt att få till och svårt att förstå hur man ändrar lutningen och behåller stolen fast
16	anonymous	Ja	Britax	3	Nej	Nej	Nej	Nej
17	anonymous	Ja	Britax	Upp till 5 år, ca 25kg	Inga	Jag roterar barnstolen vid varje användning	Roterar för att sätta i barnet lättare	Nej
18	anonymous	Ja	Cybox	2-4 ca	Hade önskat att straps va längre, svårt att få plats med overall	Varje gång	Skönare för barnet	Nej

Figure B.1.1 Feasibility questionnaire.

B.2 Main questionnaire

B.2.1 Questions in Microsoft Forms

...

Användning av bilbarnstolar och dess lutningsfunktion

Den här enkäten är en del av ett examensarbete vid Lunds Tekniska Högskola. Syftet är att undersöka användning av lutningen hos bilbarnstolar och kartlägga användarbehoven. Enkäten är frivillig, anonym och tar cirka fem minuter att genomföra.

Vid frågor, kontakta Linn Gabrielsson (li7273ga-s@student.lu.se) eller Victoria Simonson (vi2754si-s@student.lu.se).

When you submit this form, it will not automatically collect your details like name and email address unless you provide it yourself.

* Required

1. Hur gammalt är barnet som använder bilbarnstolen? *

☐ 0-11 månader

☐ 1-2 år

☐ 3-4 år

☐ 5 år eller äldre

2. Vilket märke och vilken modell är bilbarnstolen? *

Enter your answer

3. Används den framåtvänd eller bakåtvänd? (Fler alternativ möjliga) *

☐ Framåtvänd

☐ Bakåtvänd

4. Används stolen i framsätet eller baksätet? (Fler alternativ möjliga) *

☐ Framsätet

☐ Baksätet

5. Hur ofta åker barnet bil? *

- ☐ Dagligen
- ☐ Flera gånger i veckan
- ☐ Någon gång i veckan
- ☐ Mer sällan
- ☐ Aldrig

6. Går det att ändra lutningen på stolen? *

- ☐ Ja
- ☐ Nej

7. Varför ändrar du lutningen på bilbarnstolen? (Fler alternativ möjliga) *

- ☐ För vila/sömn
- ☐ För barnets komfort
- ☐ För att ge mer benutrymme
- ☐ För att barnet ska äta
- ☐ För att anpassa till bilsätets lutning
- ☐ För att ta hänsyn till krocksäkerhet
- ☐ För att barnet växer
- ☐ Other

8. När ändrar du lutningen på bilbarnstolen? (Fler alternativ möjliga) *

☐ Under färd

☐ När bilen står still

☐ Vid installation

☐ Vid längre resor

☐ Vid kortare resor

☐ Other

9. Om du ändrar lutningen vid resor, vid vilka tillfällen gör du detta? (Fler alternativ möjliga)

☐ Innan avfärd

☐ Under resan, stannar bilen

☐ Under resan, när bilen körs (av förare)

☐ Under resan, när bilen körs (av passagerare)

☐ Ändrar inte vid resor

☐ Other

10. Är det tydligt hur du ska ändra lutningen? *

☐ Ja

☐ Nej

10. Är det tydligt hur du ska ändra lutningen? *

☒ Ja

☐ Nej

11. Förklara varför det är tydligt. *

Enter your answer

10. Är det tydligt hur du ska ändra lutningen? *

☐ Ja

☒ Nej

11. Förklara varför det är otydligt. *

Enter your answer

12. Hur väl stämmer påståendet in på dig? *

	Stämmer inte alls	Stämmer i låg grad	Neutral	Stämmer i hög grad	Stämmer helt
Jag är medveten kring hur lutningen påverkar barnets säkerhet.	☐	☐	☐	☐	☐

13. Är det önskvärt att kunna ändra lutningen när bilen körs? (Fler alternativ möjliga) *

☐ Ja (av förare)

☐ Ja (av passagerare)

☐ Nej

14. Vilka förbättringsområden kan du se hos lutningsfunktionen?

Enter your answer

15. Har du intresse av att delta i en observationsstudie? Fyll i din mail nedan så kontaktar vi dig.

Enter your answer

Figure B.2.1 Questions in Microsoft forms questionnaire.

B.2.2 Answers from questionnaire (raw data)

Table B.2.2.1

Age distribution of the respondents' children (N=129)

Original question: *Hur gammalt är barnet som använder bilbarnstolen?*

<i>Age group</i>	<i>Frequency (n)</i>	<i>Percentage (%)</i>
0-11 månader	23	18%
1-2 år	54	42%
3-4 år	52	40%
Total	129	100%

Table B.2.2.2

Brand distribution of the brand of the respondents' CRS (N=129)

Original question: *Vilket märke och vilken modell är bilbarnstolen?*

<i>Brand</i>	<i>Frequency (n)</i>	<i>Percentage (%)</i>
Thule	12	9%
Axkid	45	35%
Britax	16	12%
BeSafe	50	39%
Cybex	7	5%
Maxi-cosi	4	3%
Chicco	1	1%
Silver Cross	1	1%
jOIE pRODIGI	1	1%
Total number of seats	137	
Total number of respondents	129	

Note: ^aNumber of seats exceed the number of respondents since some respondents reported owning multiple seats.

Table B.2.2.3*Orientation of the CRS, front- or rear facing (N=129)*Original question: *Används den framåtvänd eller bakåtvänd? (Fler alternativ möjliga)*

<i>Seat Orientation</i>	<i>Frequency (n)</i>	<i>Percentage (%)</i>
Framåtvänd	2	2%
Bakåtvänd	123	95%
Både fram- och bakåtvänd	4	3%
Total	129	100%

Table B.2.2.4*Placement of CRS in car, front- or back seat (N=129)*Original question: *Används stolen i framsätet eller baksätet? (Fler alternativ möjliga)*

<i>Placement in car</i>	<i>Frequency (n)</i>	<i>Percentage (%)</i>
Framsätet	12	9%
Baksätet	105	81%
Både fram- och baksätet	12	9%
Total	129	100%

*Note: Percentages may not be 100% due to rounding.***Table B.2.2.5***Frequency of usage of CRS (N=129)*Original question: *Hur ofta åker barnet bil?*

<i>Usage frequency</i>	<i>Frequency (n)</i>	<i>Percentage (%)</i>
Någon gång i veckan	25	19%
Flera gånger i veckan	40	31%
Dagligen	63	49%
Mer sällan	1	1%
Total	129	100%

Table B.2.2.6*Reasons for adjusting the recline (N=129)*Original question: *Varför ändrar du lutningen på bilbarnstolen? (Fler alternativ möjliga)*

<i>Reason for adjustment</i>	<i>Frequency (n)</i>	<i>Percentage (%)</i>
För vila/sömn	74	57%
För barnets komfort	55	43%
För att ge mer benutrymme	12	9%
För att barnet ska äta	1	1%
För att anpassa till bilsätets lutning	43	33%
För att ta hänsyn till krocksäkerhet	33	26%
För att barnet växer	30	23%
Other	9	7%
<i>Total number of responses</i>	257	
<i>Total number of respondents</i>	129	

Note: Multiple choice question.**Table B.2.2.7***Occasions for recline adjustment among respondents (N=129)*Original question: *När ändrar du lutningen på bilbarnstolen? (Fler alternativ möjliga)*

<i>When recline is adjusted</i>	<i>Frequency (n)</i>	<i>Percentage (%)</i>
Under färd	43	33%
När bilen står still	71	55%
Vid installation	53	41%
Vid längre resor	31	24%
Vid kortare resor	3	2%
Other	5	4%
<i>Total number of responses</i>	206	
<i>Total number of respondents</i>	129	

Note: Multiple choice question.

Table B.2.2.8*Occasions for recline adjustment while driving among respondents (N=126)*Original question: *Om du ändrar lutningen vid resor, vid vilka tillfällen gör du detta? (Fler alternativ möjliga)*

<i>Occasion</i>	<i>Frequency (n)</i>	<i>Percentage (%)</i>
Innan avfärd	49	39%
Under resan, stannar bilen	29	23%
Under resan, när bilen körs (av förare)	9	7%
Under resan, när bilen körs (av passagerare)	44	35%
Ändrar inte vid resor	40	32%
Other	3	2%
Total number of responses	174	
Total number of respondents	126	

Note: Multiple choice question.**Table B.2.2.9***Whether it is clear or not for the respondents regarding how to adjust the recline (N=129)*Original question: *Är det tydligt hur du ska ändra lutningen?*

<i>Response</i>	<i>Frequency (n)</i>	<i>Percentage (%)</i>
Ja	117	91%
Nej	12	9%
Total	129	100%

Table B.2.2.10*Likert scale regarding the perceived awareness on how recline affects safety (N=129)*Original question: *Jag är medveten kring hur lutningen påverkar barnets säkerhet.*

<i>Level of agreement</i>	<i>Frequency (n)</i>	<i>Percentage (%)</i>
Stämmer inte alls	4	3%
Stämmer i låg grad	15	12%

Neutral	22	17%
Stämmer i hög grad	31	24%
Stämmer helt	57	44%
Total	129	100%

Table B.2.2.11

Desirability of adjusting recline while driving (N=129)

Original question: *Är det önskvärt att kunna ändra lutningen när bilen körs? (Fler alternativ möjliga)*

Preference	Frequency (n)	Percentage (%)
Ja (av förare)	20	16%
Ja (av passagerare)	61	47%
Nej	64	50%
Total number of responses	145	
Total number of respondents	129	

Note: Multiple choice question.

B.2.3 Thematic analysis of open-ended questions

B.2.3.1 Question 14 “What areas of improvement can you see within the recline function?”

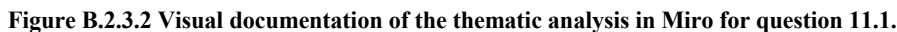




Figure B2.3.1 Visual documentation of the thematic analysis in Miro for question 14.

B.2.3.2 Question 11.1 “Explain why it is clear”

If respondents answered “yes” on question 10 “Is it clear how to adjust the recline?” they were presented with this following question 11.



If respondents answered “no” on question 10 “Is it clear how to adjust the recline?” they were presented with this following question 11.

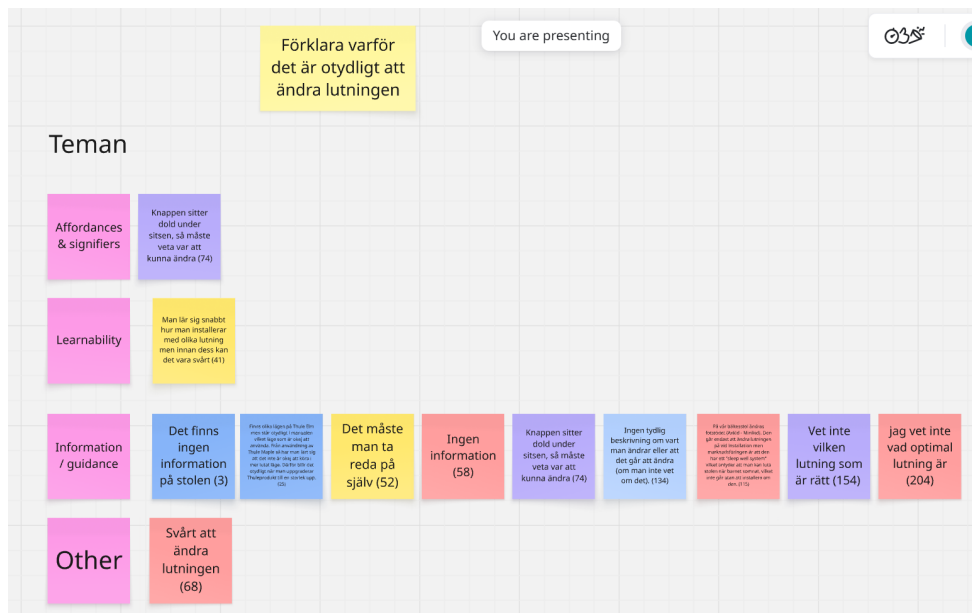


Figure B.2.3.3 Visual documentation of the thematic analysis in Miro for question 11.2.

B.3 Observations forms

Observation form Date: 11/2

Participant information

Signed consent form: ☒

Participant number: 1

Previous Experience: None ☐ With Thule Elm ☒ With other CRS ☐

Actions	YES/NO	Notes
TASK 1		
Placement of chair (Note front seat/back seat, left/right)	N/A	Back seat
Notes feedback from installation, eg. green lights, click	✓	Click E3 lampor
Correct installation	✓	
Other notes Task 1 Expressions, emotions, help, looks for info, struggles etc.		Tittar på installation på både iso-baser, Missade fälla ut bänst → Fick lossa och sedan fästa Iso igen
TASK 2		
Adjusts the recline as part of the installation	-	
Finds the handle for recline	✓	
Placement of hands when reclining (describe in note)	N/A	
Correct installation	2✓	Like walking. Långsamt
Other notes Task 2 Expressions, emotions, help, looks for info, struggles etc.		

TASK 3		
Adjusts the recline	—	
Finds the handle for recline	—	
Placement of hands when reclining (describe in note)	N/A	Sluggo
Other notes Task 3 Expressions, emotions, help, looks for info, struggles etc.	Tar bort babyvagnen. Svinner stol för att se till i - ut mot sig Där ligger vid ben först Noterar nackstöd.	
TASK 4		
Finds the different recline positions (note how many)	✓	3 st. (har problem med)
Other notes Task 4 Expressions, emotions, help, looks for info, struggles etc.	Valde mest lämpliga	
TASK 5		
Describes and shows thoughts on changing recline from driver seat (note)	✓	Upp e vid nackstödet. Känns naturligt.
Other notes Task 5 Expressions, emotions, help, looks for info, struggles etc.	Testar som det är - inte rimligt. Tar bort stol	

Figure B.3.1 Observation participant 1.

Observation form

Date: 11/2

Participant information

Signed consent form: ☒

Participant number: 2 (Spontaneous)

Previous Experience: None ☐

With Thule Elm ☐

With other CRS ☒ Semi
Installation en gång.
Thule Maple.

Actions	YES/NO	Notes
TASK 1		
Placement of chair (Note front seat/back seat, left/right)	N/A	Backseat
Notes feedback from installation, eg. green lights, click	✓	Kollade på lampor. Inget grönt.
Correct installation	✓	
Other notes Task 1 Expressions, emotions, help, looks for info, struggles etc.	Nej. Går inte in i click? Kolla mer på	
TASK 2		
Adjusts the recline as part of the installation	✓	
Finds the handle for recline	✓	
Placement of hands when reclining (describe in note)	N/A	-
Correct installation	✓	Click-ljud
Other notes Task 2 Expressions, emotions, help, looks for info, struggles etc.	Smidigt	

TASK 3		
Adjusts the recline	☒	
Finds the handle for recline	☒	
Placement of hands when reclining (describe in note)	N/A	
Other notes Task 3 Expressions, emotions, help, looks for info, struggles etc.	Rolens stoll. Lite svårt att hitta. Vad är 2. Bad om instruktionsmanual. (För bättet) → Gick bra. "Otydligt" med bätte	
TASK 4		
Finds the different recline positions (note how many)	☒	Svårt att hitta 3 Fick hitta i manual. 3
Adjusts recline	☒	Hand placement ☒ Håller video
Finds handles	☒	
Other notes Task 4 Expressions, emotions, help, looks for info, struggles etc.	"Lite så lätt" "Bara två" → Ändrade till "Ty 3" "Käns inte konstigt"	
TASK 5		
Describes and shows thoughts on changing recline from driver seat (note)		Knappe där fanns. Elverknapp att ändra på stolens bakstygg. Kan ändra i förarsätet när bilen står still.
Other notes Task 5 Expressions, emotions, help, looks for info, struggles etc.	När ej. "Färdighet"	

Figure B.3.2 Observation participant 2.

Observation form Date: 11/2

Participant information

Signed consent form: ☒

Participant number: 3

Previous Experience: None ☐ With Thule Elm ☐ With other CRS ☒

Actions	YES/NO	Notes
TASK 1		
Placement of chair (Note front seat/back seat, left/right)	N/A	Backseat
Notes feedback from installation, eg. green lights, click	✓	Tillade på lampene. Click noteras → Versteke for at riktig "click" sound på riktig hjørlet.
Correct installation	✓	
Other notes Task 1 Expressions, emotions, help, looks for info, struggles etc.		Like svært att få ut ISO-fetene. Tillade i instruksjonsmanual. Cattunde ta ut benet → Gjør om

TASK 2		
Adjusts the recline as part of the installation	✓	
Finds the handle for recline	✓	
Placement of hands when reclining (describe in note)	N/A	
Correct installation	✓	
Other notes Task 2 Expressions, emotions, help, looks for info, struggles etc.	Godt uttrykk bryta problem	
TASK 3		
Adjusts the recline	✓	
Finds the handle for recline	✓	
Placement of hands when reclining (describe in note)	N/A	
Other notes Task 3 Expressions, emotions, help, looks for info, struggles etc.	Tog ut belysninga Vend stol utst/mot sig for å sitte i boret.	

TASK 4		
Finds the different recline positions (note how many)	✓	2 lågen noteras.
Finds handle. Adjusts handle Other notes Task 4 Expressions, emotions, help, looks for info, struggles etc.		
TASK 5		
Describes and shows thoughts on changing recline from driver seat (note)	✓	
Other notes Task 5 Expressions, emotions, help, looks for info, struggles etc.		Aldrig berört på ryggstödet. Något man håller mest - bryr sig på vägen.

Figure B.3.3 Observation participant 3.

1 Observation form Date: 11/2

Participant information

Signed consent form: ☒ ~~✗~~

Participant number: 4

Previous Experience: None ☐ With Thule Elm ☒ With other CRS ☐

*jämn på stötgjods
har en Elm*

Actions	YES/NO	Notes
TASK 1		
Placement of chair (Note front seat/back seat, left/right)	N/A	Backseat
Notes feedback from installation, eg. green lights, click	✓	Tittade på lampor & insåg att beret.
Correct installation	✓	
Other notes Task 1 Expressions, emotions, help, looks for info, struggles etc.		Osäker på om Iso-kommer ut. & Beret var det. Faller inte ut beret Tog steg in i bilen för att få till Iso fix Beskriv: Rens som att den kan sitta tightare i setet & gör ej på telefon Vard

TASK 2		
Adjusts the recline as part of the installation	✓	
Finds the handle for recline	✓	
Placement of hands when reclining <i>(describe in note)</i>	N/A	
Correct installation	✓	
Other notes Task 2 Expressions, emotions, help, looks for info, struggles etc.		
TASK 3		
Adjusts the recline	✓	
Finds the handle for recline	✓	
Placement of hands when reclining <i>(describe in note)</i>	N/A	
Other notes Task 3 Expressions, emotions, help, looks for info, struggles etc. Arvände magnet.		
TASK 4		
Finds the different recline positions <i>(note how many)</i>	✓	2 lägen
Finds handle Adjusts recline Other notes Task 4 Expressions, emotions, help, looks for info, struggles etc.	✓ ✓	
TASK 5		
Describes and shows thoughts on changing recline from driver seat <i>(note)</i>	✓	Någonting på ryggen Både sidor. Det uppe. Skärn till.

Figure B.3.4 Observation participant 4.

Observation form

Date: 11/2

Participant information

Signed consent form: ☒

Participant number: 5

Previous Experience: None ☐

With Thule Elm ☐

With other CRS ☒

Actions	YES/NO	Notes
TASK 1		
Placement of chair (Note front seat/back seat, left/right)	N/A	Backseat.
Notes feedback from installation, eg. green lights, click	☒	Tittade på lamporna. "lyses grönt"
Correct installation	☒	Vi lade cykeln in.
Other notes Task 1 Expressions, emotions, help, looks for info, struggles etc.		Får mer hjälp först. Tar det steg in i bilen. "Hörda att cykeln var i 150-längderna." "Ost i tummarna." "Går bra" ironiskt ton.
TASK 2		
Adjusts the recline as part of the installation	☒	
Finds the handle for recline	☒	
Placement of hands when reclining (describe in note)	N/A	
Correct installation	☒	

TASK 3		
Adjusts the recline		
Finds the handle for recline		
Placement of hands when reclining (describe in note)	N/A	
Other notes Task 3 Expressions, emotions, help, looks for info, struggles etc.	Vred mot stolen mot. Tar ut bryggedel. <u>Erbudet:</u> Har bryggarna svängt lutar längre ut. Lättare lutar till stelen. Baser på en	
TASK 4		
Finds the different recline positions (note how many)	✓	3. Hand positioning
Finds handle Adjusts recline	✓ ✓	
Other notes Task 4 Expressions, emotions, help, looks for info, struggles etc.		
TASK 5		
Describes and shows thoughts on changing recline from driver seat (note)	✓	Tryckknapp över delaren ryggs känna med en hand. Grepp om.

Figure B.3.5 Observation participant 5.

Observation form

Date: 11/2

Participant information

Signed consent form: ☒

Participant number: 6

Previous Experience: None ☐

With Thule Elm ☐

With other CRS ☒

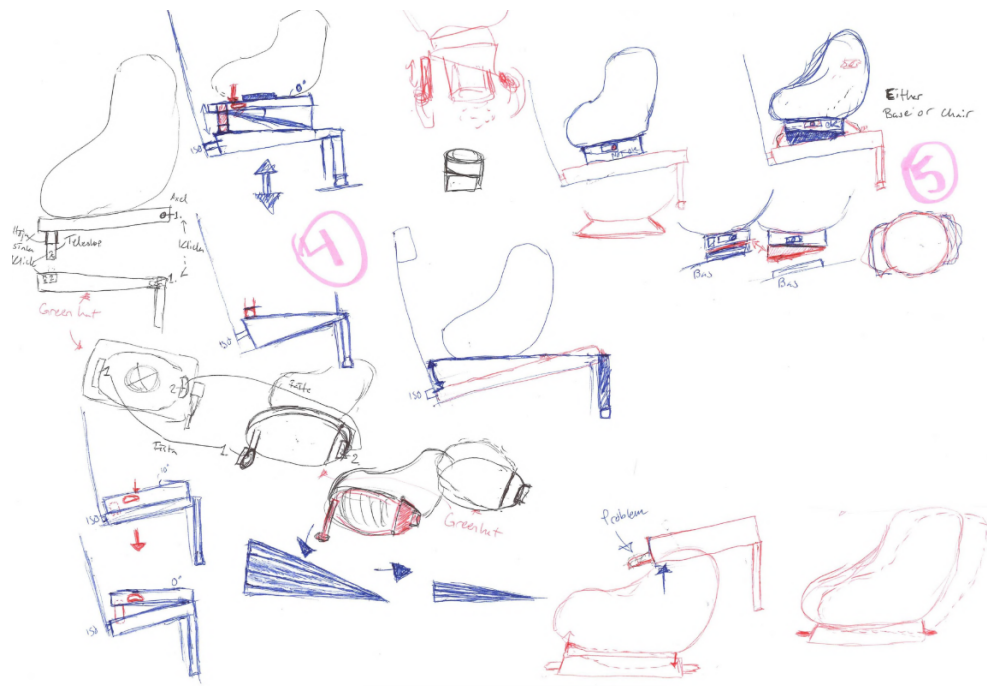
Med Testet Thule Palen.
Har barn så høft line olide
stiller.

Actions	YES/NO	Notes
TASK 1		
Placement of chair (Note front seat/back seat, left/right)	N/A	Backseat Kolla om det finns Iso-fix.
Notes feedback from installation, eg. green lights, click	☒	"Klickar" "lyser grönt"
Correct installation	☒	
Other notes Task 1 Expressions, emotions, help, looks for info, struggles etc.		Barnet talar på ett Sjukt barn stolar. Tittar på instruktionerna på stolar. Håller ner kroppen vid "Tycker det är kringligt." Barnet försöker vika ut benet. "Inne så håller lätt." + Läser instruktionsboken Mister isofixen. Kommer under. Pilen.

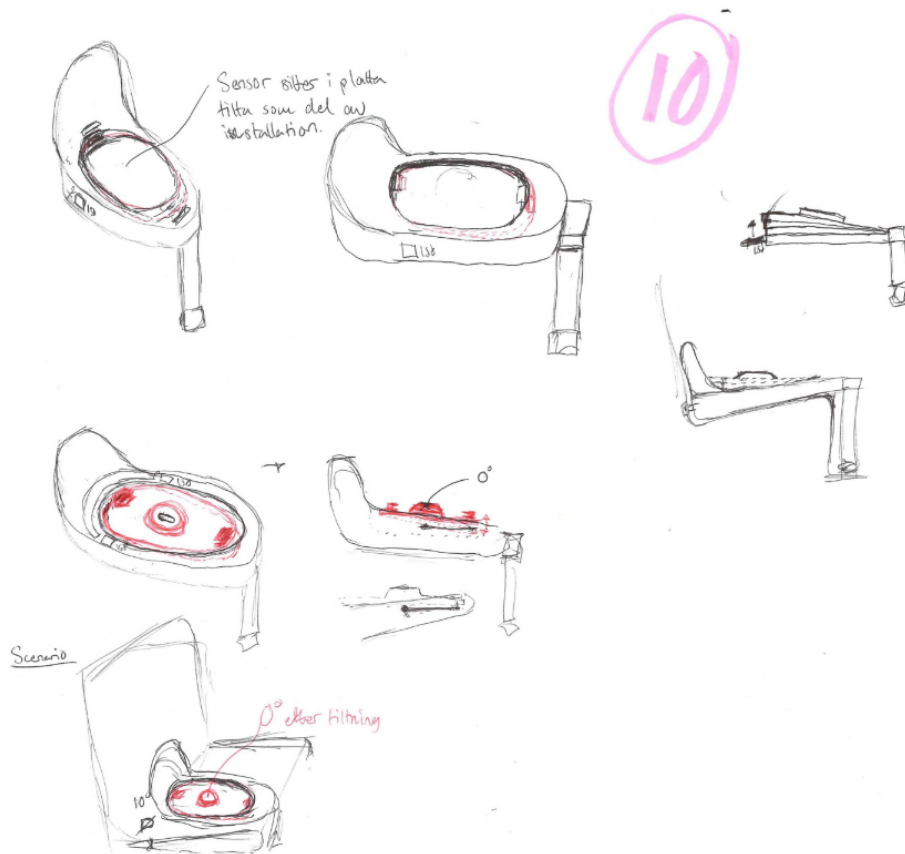
TASK 2		
Adjusts the recline as part of the installation	✓	
Finds the handle for recline	✓	
Placement of hands when reclining (describe in note)	N/A	
Correct installation	✓	
Other notes Task 2 Expressions, emotions, help, looks for info, struggles etc.	Tittar på installation på stolen "Väldigt lätt" "Känns väldigt"	
TASK 3		
Adjusts the recline	✓	Ger det först med hög annat syfte. Ville ändra bältes rummen
Finds the handle for recline	✓	Med annat syfte → 
Placement of hands when reclining (describe in note)	N/A	
Other notes Task 3 Expressions, emotions, help, looks for info, struggles etc.	Böjer ryggen och rummen. → Rör ändra reeline ett Tittar : installation. Testar sig fram "Ingen feedback", Vet ej om man tagit på knapp. Tar bort och bältes skydd. Där upp ruckstöd. Där ett hött → Där sedan, åt bältet.	

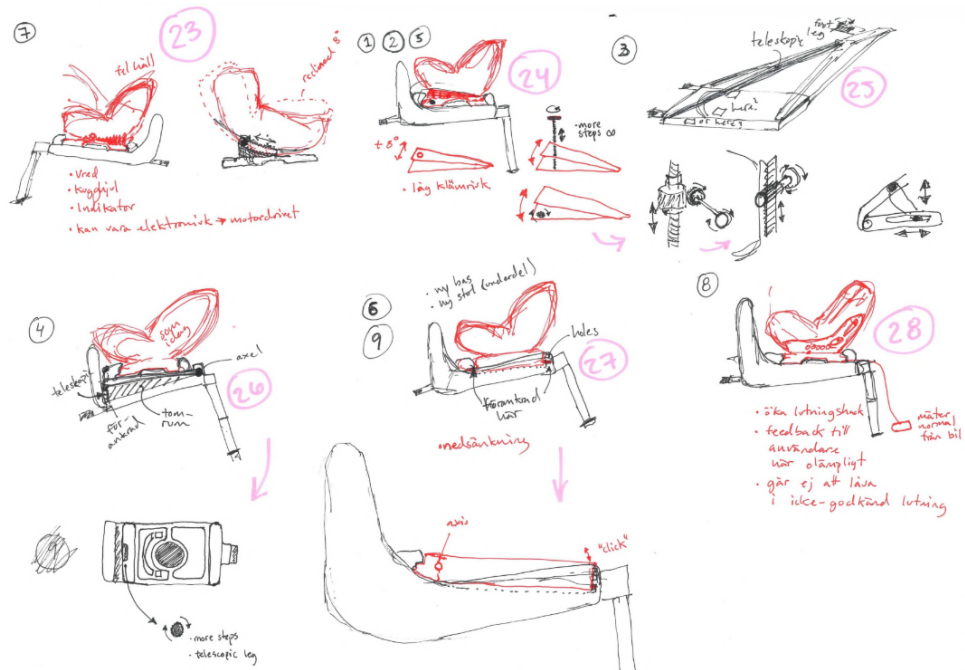
TASK 4		
Finds the different recline positions (note how many)	✓	3 læger.
Se bil 3.		
Other notes Task 4 Expressions, emotions, help, looks for info, struggles etc.		
TASK 5		
Describes and shows thoughts on changing recline from driver seat (note)	✓	Indikation → villet nuværende læge. Ej vurderes.
		Naturligt at han slapper. Ture rydd.
Other notes Task 5 Expressions, emotions, help, looks for info, struggles etc.		

Figure B.3.6 Observation participant 6.

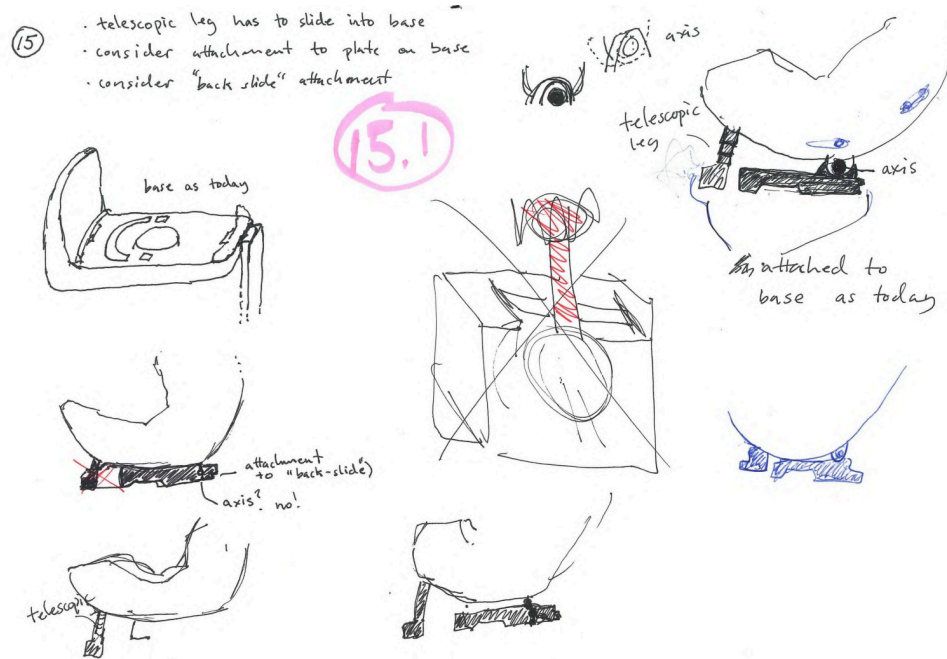


C.2 Sketches numbered 10-28



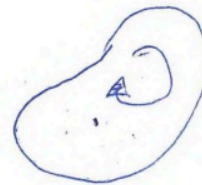
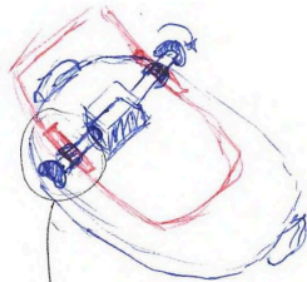


C.3 Sketches numbered 15.1, 20.1, 23.1, and 29-36

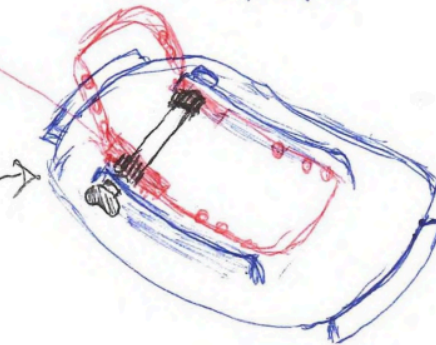
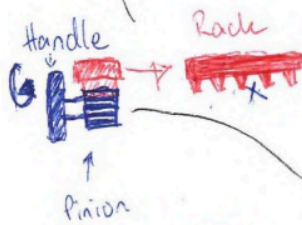


23.1

23.1



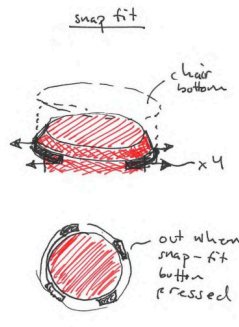
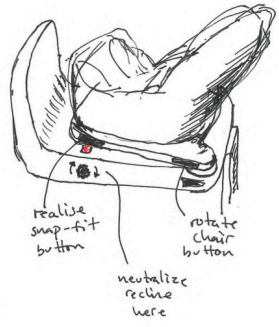
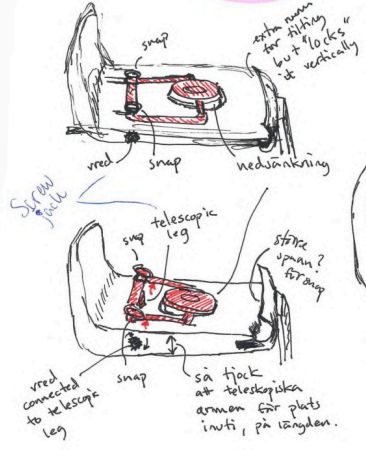
Elektronisk
sensor sign. 0°
→ Spärr.



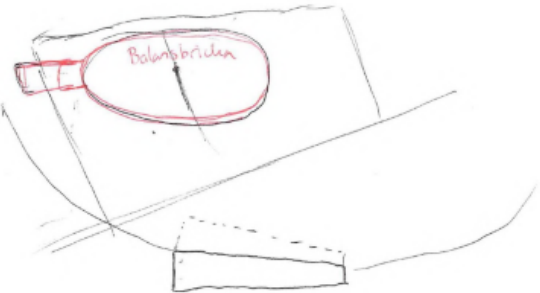
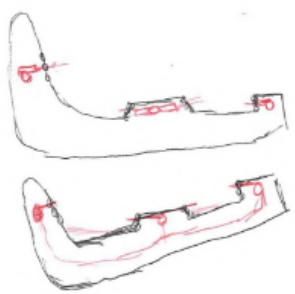
20 snap-
axis

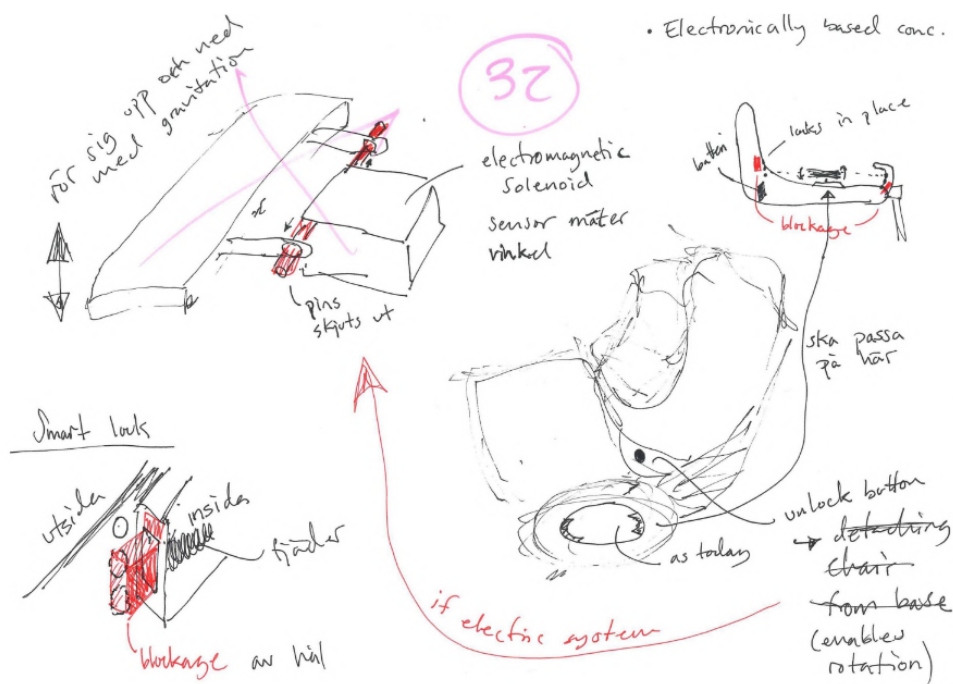
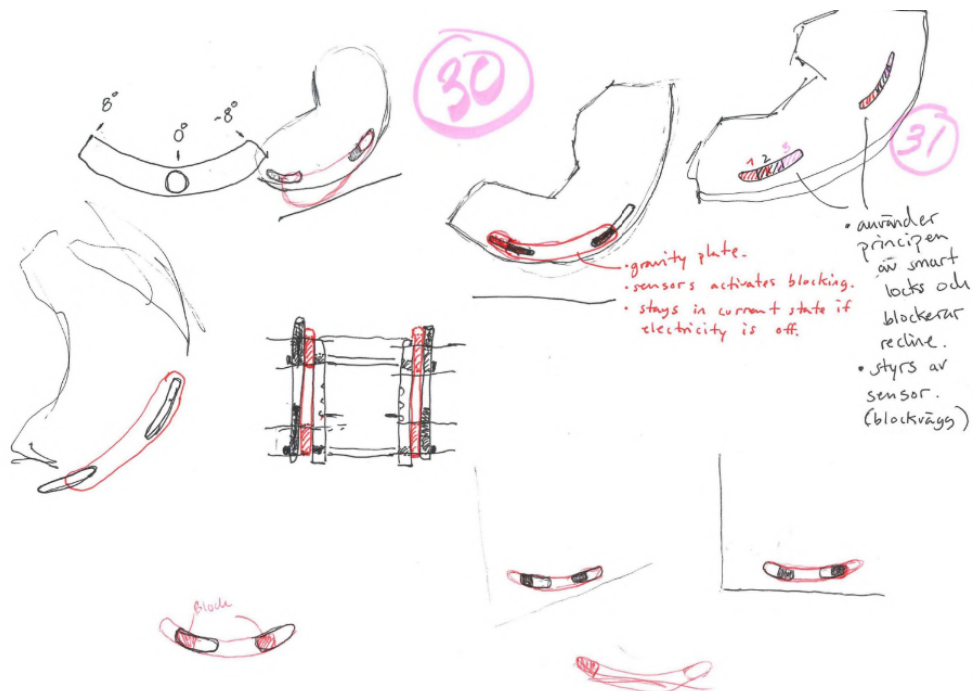
20.1

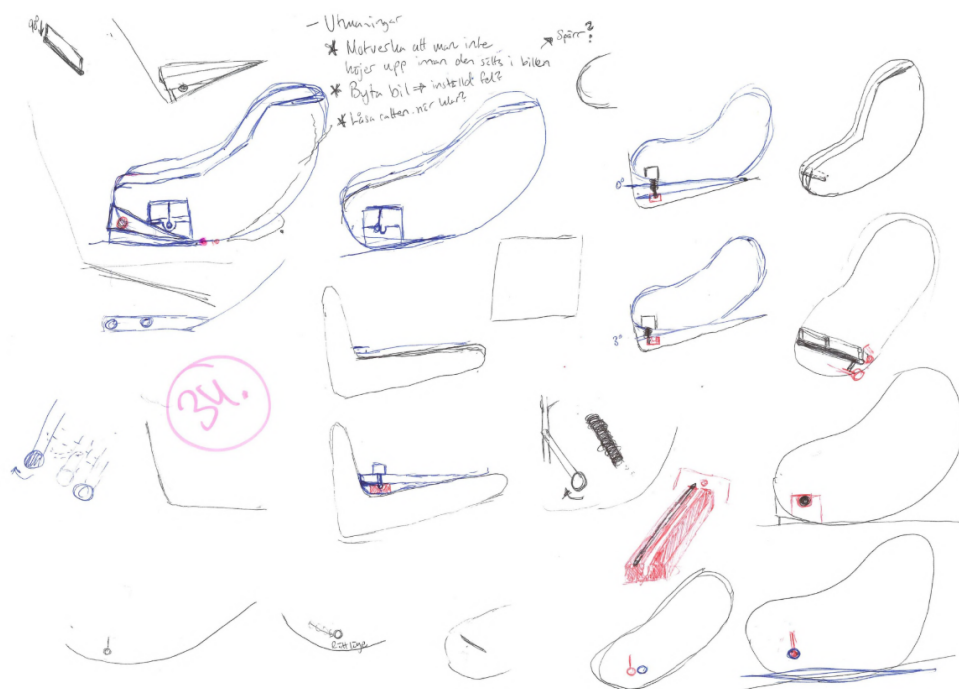
- new base
- new chair (bottom)



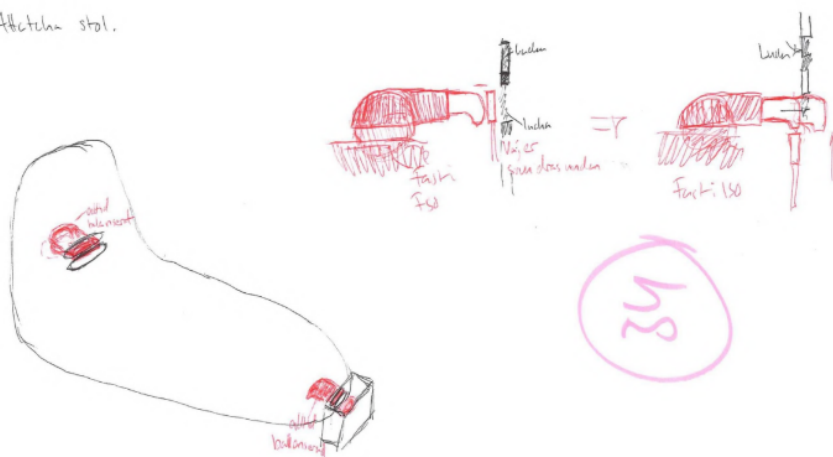
29

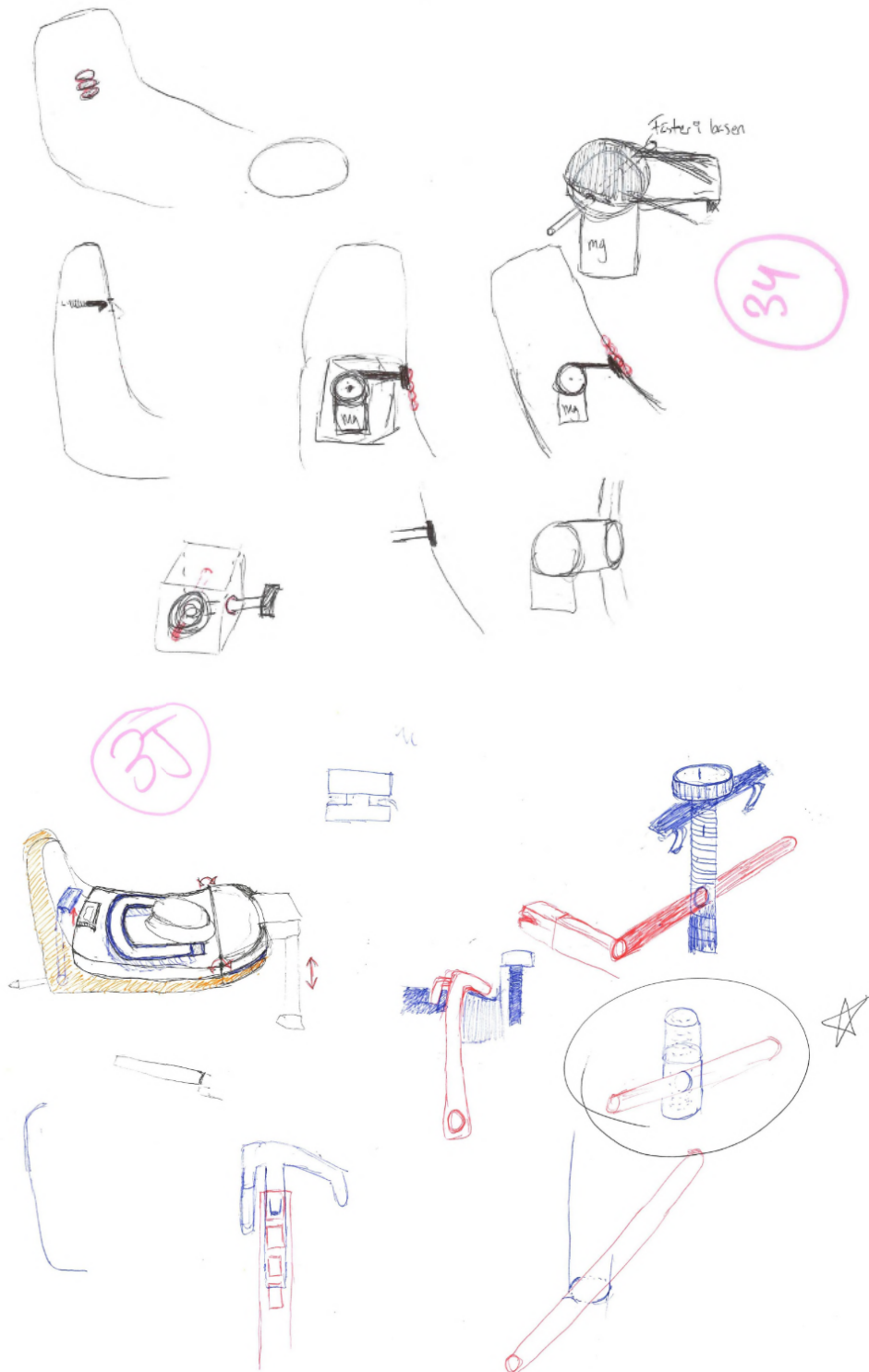






1. Installation av bus som det ser ut idag
2. Load leg + ISO grönt $\rightarrow$ OK signal Alternativt när stolen fästs på mitt $\rightarrow$ armer skjuts ut.
3. OK signal $\rightarrow$ Skjuter ut armer/festen i hål som matchar armens neutral
4. Attatcha stol.



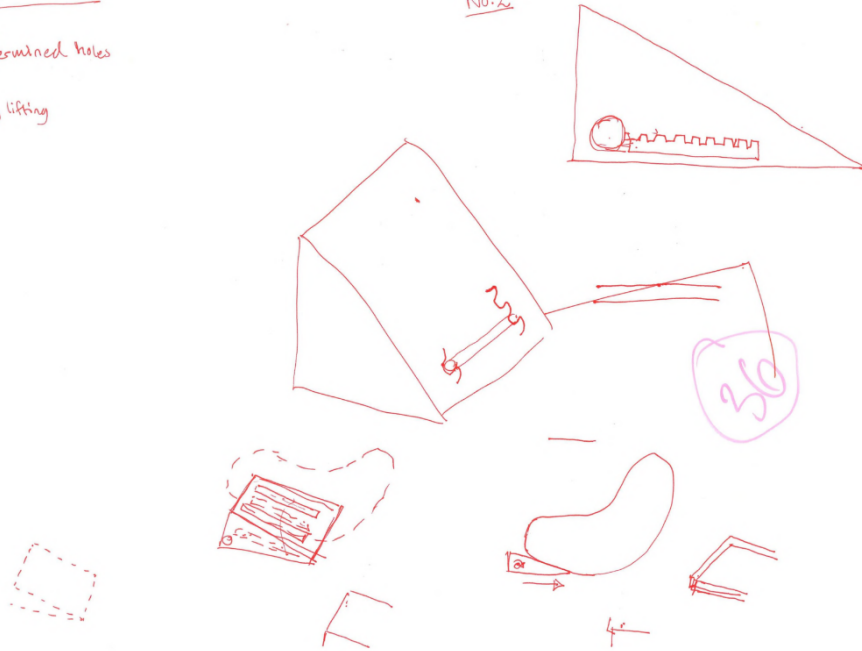


Prototypes W.12

No.1

- Pre-determined holes
- Bases
- Manually lifting

No.2



Appendix D Arduino code

```
#include <Wire.h>
#include <MPU6050.h>

MPU6050 mpu;

// LED
const int greenLED = 3;
const int redLED = 5;

// Justerbara värden via Serial
float refAngle = 1;
float angleOffset = 0;

// Buffertinställningar
const int samples = 10;
float pitchBuffer[samples];
int bufferIndex = 0;

bool startMeasurement = false;

// Funktionsprototyper
float getFilteredPitchRaw();
float getFilteredPitch();
void handleSerialCommands();

void setup() {
  Serial.begin(9600);
```

```

Wire.begin();

pinMode(greenLED, OUTPUT);
pinMode(redLED, OUTPUT);

mpu.initialize();
if (!mpu.testConnection()) {
    Serial.println("MPU6050 hittas inte!");
    while (1);
}

digitalWrite(greenLED, LOW);
digitalWrite(redLED, LOW);

Serial.println("Kommandon:");
Serial.println("start / stop");
Serial.println("setref X");
Serial.println("setoffset X");
Serial.println("calibrate");
Serial.println("status");
}

// Pitch runt X-axeln (positiv)
float getFilteredPitchRaw() {
    int16_t ax, ay, az, gx, gy, gz;
    mpu.getMotion6(&ax, &ay, &az, &gx, &gy, &gz);

    float axg = ax / 16384.0;
    float ayg = ay / 16384.0;
    float azg = az / 16384.0;

    // Pitch runt X, positiv
    float pitch = atan2(axg, sqrt(ayg * ayg + azg * azg)) * 57.2958;

```

```

    return pitch;
}

float getFilteredPitch() {
    float raw = getFilteredPitchRaw();

    // Vänd relationen så pitch går mot 0 när mekanismen går mot noll-läget
    // +1.0 för att sensorn sitter lite snett
    float pitch = (angleOffset - raw) + 9;

    // Buffring
    pitchBuffer[bufferIndex] = pitch;
    bufferIndex = (bufferIndex + 1) % samples;

    float sum = 0;
    for (int i = 0; i < samples; i++) sum += pitchBuffer[i];
    return sum / samples;
}

void handleSerialCommands() {
    if (!Serial.available()) return;

    String cmd = Serial.readStringUntil('\n');
    cmd.trim();

    if (cmd.equalsIgnoreCase("start")) {
        startMeasurement = true;
        Serial.println("Startar mätning...");
    }

    else if (cmd.equalsIgnoreCase("stop")) {
        startMeasurement = false;
        Serial.println("Stoppar mätning...");
        digitalWrite(greenLED, LOW);
    }
}

```

```

    digitalWrite(redLED, LOW);
}

else if (cmd.startsWith("setref")) {
    float val = cmd.substring(6).toFloat();
    refAngle = val;
    Serial.print("Ny refAngle: ");
    Serial.println(refAngle);
}

else if (cmd.startsWith("setoffset")) {
    float val = cmd.substring(9).toFloat();
    angleOffset = val;
    Serial.print("Ny offset: ");
    Serial.println(angleOffset);
}

else if (cmd.equalsIgnoreCase("calibrate")) {
    float rawPitch = getFilteredPitchRaw();
    angleOffset = rawPitch;
    Serial.print("Offset satt till: ");
    Serial.println(angleOffset);
    Serial.println("Pitch kommer nu visa 0.0° i detta läge");
}

else if (cmd.equalsIgnoreCase("status")) {
    Serial.print("refAngle = ");
    Serial.println(refAngle);
    Serial.print("offset = ");
    Serial.println(angleOffset);
}
}

void loop() {

```



```

handleSerialCommands();

if (!startMeasurement) return;

unsigned long greenStart = 0;
bool greenActive = false;

while (startMeasurement) {

    handleSerialCommands();

    float pitch = getFilteredPitch();

    Serial.print("Pitch (filtered): ");
    Serial.println(pitch);

    bool inRange = (pitch > refAngle && pitch < refAngle + 1);

    if (inRange) {
        digitalWrite(greenLED, HIGH);
        digitalWrite(redLED, LOW);

        if (!greenActive) {
            greenActive = true;
            greenStart = millis();
            Serial.println("Rätt vinkel - startar 10 sek timer");
        }

        if (millis() - greenStart >= 10000) {
            Serial.println("Grönt i 10 sek - avslutar");
            break;
        }
    }
}

```

```

    } else {
        digitalWrite(greenLED, LOW);
        digitalWrite(redLED, HIGH);

        if (greenActive) {
            Serial.println("Lämnade intervallet - timer nollställd");
        }
        greenActive = false;
    }

    delay(50);
}

digitalWrite(greenLED, LOW);
digitalWrite(redLED, LOW);
startMeasurement = false;

Serial.println("Klar - skriv 'start' för att börja igen");
}

```