Visualizing uncertainty in the weather forecast

A study focusing on wind, temperature, and precipitation

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OSLOMET

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A DISSERTATION

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Abstract

This project takes on the challenges of visualizing uncertainty in weather forecasts, aiming to create efficient, simple, and user-friendly solutions that present complex data. Specifically, it focuses on the visualization of precipitation, wind, and temperature. The preliminary research explored the field of data visualization, with the aim to find challenges and opportunities within the field. Uncertainty visualization became the chosen subject as the existing literature showed gaps open to explore further, and weather forecasts were specifically relevant due to the complexity of data and user comprehension. Literature and the project's qualitative research uncovers how uncertainty information can be helpful for decision-making and risk evaluation. When uncertainty is not presented, users frequently draw from their past experiences and knowledge to interpret forecasts, thereby forming their own mental models of uncertainty. New insights led to ideation and concept development, which resulted in new ways to visualize uncertainty in weather forecasting.

Keywords: Uncertainty, Weather Forecast, Data Visualization, User Experience, Visual design

Sammendrag

Prosjektet omhandler utfordringene rundt visualisering av usikkerhet i værvarslingen, med mål om å skape effektive, enkle og brukervennlige løsninger til å presentere komplekse data – med fokus på visualisering av nedbør, vind og temperatur. Det innledende forskningsspørsmålet utforsket datavisualisering, ved å søke etter muligheter og utfordringer innenfor feltet. Usikkerhet var et fokuspunkt ettersom eksisterende litteratur avdekket områder for videre utforskning, og værvarslingen var spesielt relevant på grunn av komplisert data og brukeres forståelse av det. Litteratur og prosjektets kvalitative forskning viste at informasjon om usikkerhet kan være nyttig for beslutningstaking og risikoevaluering. Når usikkerhet ikke blir kommunisert, må brukere belage seg på tidligere erfaringer og kunnskap for å tolke prognosene, som fører til utviklingen av egne mentale modeller i forbindelse med usikkerhet. Ny innsikt ledet til idégenerering og konseptutvikling, som resulterte i andre måter å visualisere usikkerheten i værvarslingen på.

Nøkkelord: Usikkerhet, Værvarsling, Datavisualisering, Brukeropplevelse, Visuelt design

Table of contents

1. Introduction

Introducing the master's thesis

1 Introduction

Data visualization is often used to make information more accessible and useful by visually representing information. It allows us to identify patterns, trends, and provides us with insight that otherwise would be hidden or incorporated in presentations difficult to grasp for lay people. Data visualization is a rapidly growing field that we are constantly exposed to; from news articles and books, to presentations and digital applications. When used correctly, it can be a valuable tool for democracy and education to empower individuals and organizations with insight to make informed decisions.

As the field of data visualization grows, challenges and opportunities within the field emerges. Often, information about uncertainty may be excluded, and user groups with visual impairments can be forgotten. Use of misleading information and manipulative methods are increasing. Furthermore, some visualizations lack a design perspective, failing to create both user friendly and visually engaging graphics, among other issues. To keep focus throughout the jungle of data visualization, a preliminary research question was defined as follows, *Which opportunities and challenges are found within the field of data visualization today?* The first phase of the master's project intended to explore the research question.

Uncertainty presents a challenge that lacks a standardized method of visualization. While certain approaches exist, such as the use of colors and patterns, these are existing solutions and do not necessarily represent a universal technique. Not all people find graphs and similar visualizations intuitive and accessible in their daily lives. This may impact people's ability for everyday decision-making and planning. Weather forecasts services exemplify one such domain, where a diverse group of users with different needs search for weather data which often contains significant uncertainty. Despite the relevance of uncertainty, there remain opportunities for exploration. Exploring this issue requires not only finding alternative ways to visualize, but ensuring that the information presented is engaging, understandable, and useful. With uncertainty in this domain comes additional challenges related to accessibility, aesthetics, and data literacy, all of which are significant in the field of data visualization. With these insights, the final research question formed into: *How can weather forecast predictions of temperature, wind, and precipitation be visualized to enhance users' comprehension of uncertainty?*

> "Of all methods for analyzing and communicating statistical information, well-designed data graphics are usually the simplest and at the same time the most powerful
>
> (Tufte, 2001, from Introduction)

1.1 Background

Previously conducted research in the field

Michael Florent Van Langren created in 1644 the first visualization of statistical data known to history (Friendly & Valero-Mora, 2010). Since then, the field of data visualization has developed over the course of centuries, particularly with the rise of digital communication and the access to the internet. The growth in data visualization has brought both notable challenges and exciting opportunities. Parallel with the development, research on cognition, perception, misinformation, accessibility, visual design, and more has emerged, leading to increased knowledge. This provides the field with more tools, which may be used to improve and create user friendly data visualizations. Data visualization plays a significant role in our everyday lives. Research shows that visualization helps people understand and perceive information much faster than reading (Einsenberg, 2014).

The communication of uncertainty in data visualization has been identified as a challenge and been a topic of discussion for decades (Brashers, 2008). Hullman (2019) studied why authors choose not to visualize uncertainty and outlines the challenges they typically faced, in addition to discussing common misconceptions about the impact of uncertainty.

Burgman (2015) has conducted research in fields of life sciences and psychology. His work discusses the concept of uncertainty, and provides definitions of uncertainty types. Burgman shares the challenges of decision-making processes when information is lacking, leading decision-makers to rely on and trust experts. Burgman's contribution does not only discuss the importance of communicating uncertainty, but also how such information is received by the audience. He explores the concept of probability in relation to an individual's data literacy and comprehension, highlighting how uncertainties can lead to different interpretations.

Various studies have been conducted on uncertainty in the context of weather forecasts, carried out by Seitter (2008), Fleischhut (2020), and Sivle (2016). These researches discuss the challenges of presenting uncertainty, while also arguing its benefit to users. For example, Sivle's research explores users' data literacy in relation to weather forecasts. He contributes with insights related to how the use of symbols, text, and color influences a user's perception of weather predictions and their certainty. Additionally, Toet and Tak (2014) investigated how specific colors could represent levels of uncertainty, along with the intuitiveness of these colors. Among others, the "traffic light" palette was explored.

Further studies have experimented with visual elements and their representation of uncertainty (MacEachren et al, 2012). The study explored not only which visual elements might represent uncertainty, but also their relation to intuitiveness. Kinkeldey et al (2014) analyzed 44 existing user studies on uncertainty visualization to evaluate how uncertainty can be displayed.

While substantial research has been conducted on the topic of uncertainty visualization, it remains a challenging field. There is no universal approach, and existing approaches may not be easily applied to all contexts.

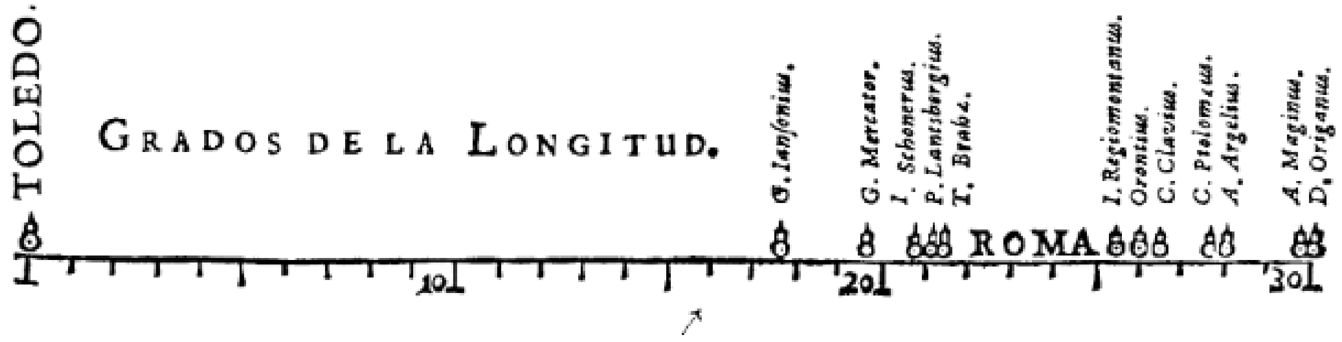


Fig 1.1. *The First (Known) Statistical Graph: Michael Florent van Langren and the "Secret" of Longitude,* 2010 by Friendly et al. The American Statistician. 64(2):174-184, p. 2.

1.2 Personal motivation

Selecting a research topic for a master's thesis can be both inspiring and overwhelming. I recognized that having little to no knowledge of a topic could serve as the ideal foundation for a master's thesis, leading me to data visualization. The multidisciplinary nature of data visualization is intriguing, and the desire to explore how design, combined with data, could lead to effective communication with the audience ignited my initial interest. I sought to use this opportunity to also learn and become a better visual and UX designer. Additionally, I was motivated to learn about uncertainty visualizations and the user experience associated with them, as well as how to transform data into useful information. The knowledge acquired from a project of this nature could potentially be applied to other projects involving uncertainty, communication, visualization, diverse users with various needs, and more. This ensures that, even though the subject might appear narrow, it holds significant relevance.

1.3 Methodology

Qualitative research and participatory design will be significant methodologies for this study. A qualitative approach provides in-depth understanding, and supplemented with quantitative studies could create a holistic perspective on the topic. Participatory design is known to be helpful for enhancing understanding and ideation of needs and possibilities within a project's scope. This methodology will be applied in this study. Several resource persons will be contacted from an early stage, having the opportunity to offer insight, ideas and share their opinions throughout the process.

Participatory design builds upon collaboration and co-creation. It allows users to contribute to the design process through feedback, decision-making, ideation, validation, reflections, and sharing of experiences (Interaction Design Foundation, N.D-a). Insights from participants will be essential for the project to understand needs, preferences, behaviors, and more, thereby informing design decisions.

The use of participatory design influences the project to intuitively follow the five steps of the design methodology, Design Thinking: emphasize, define, ideate, prototype, and test (Interaction Design Foundation, N.D-b). It will be essential to understand users, define the challenge, ideate possible solutions and concepts, and finally prototyping before testing on users. The process does not necessarily happen linearly, as some steps naturally repeat themselves.

Lastly, the project draws inspiration from the methodology developed by Microsoft (2016), namely Inclusive design. This is a design methodology focusing on human diversity. Creating designs that allow for diverse ways of participation is important. This project aims to incorporate Inclusive design methodology. Being aware of one's own biases and reminding oneself of possible limitations will be crucial during decision-making and creative sessions.

Fig 1.2. Illustration of methodologies.

1.4 Ethical considerations

Ethical considerations have been made and followed throughout the master's project. The guidelines and principles on privacy by General Data Protection Regulation (GDPR) have been adhered to. GDPR is part of Norwegian law from 2018 (Personopplysningsloven, 2018). To ensure safe data processing and sharing, a registration form containing the project's data collection and management plan was sent to the Norwegian Agency for Shared Services in Education and Research (SIKT) in January 2023 for approval and was approved shortly after.

All participants involved in interviews and workshops have given consent to take part in this master's project. With the consent form, the participants were informed about the opportunity to receive access to the interview summaries and option to provide feedback and corrections. Personal information such as name, educational background, position, and workplace has been shared only when relevant to the project, for example, to enhance the person's credibility in relation to their expertise. Anonymization has been implemented when personal information is not relevant.

The APA 7th edition citation style has been used in this project. The complete reference list is placed in Chapter 8. Unless otherwise cited, all images and illustrations are created or taken by the author. Certain photos have been used from the free photo license webpage, Unsplash.com, which requires no attribution. However, the photographer's name will be credited under photos from this service.

1.5 Project process

The process of this master thesis has been inspired by the evolved version of the double diamond (Design Council, 2019). This is a well-known design process in which the phases of the process are diverging and converging, meaning each phase starts with an open approach before narrowing the scope down. The double diamond uses Design Thinking (Interaction Design Foundation, N.D-b) methodology to achieve a creative, innovative process.

The beginning of the project led to identifying one or several problems. The initial goal was to search for opportunities and challenges within data visualization before delving deeper into one selected challenge. The project, through exploration, used insights and findings to lead and define the project further. The research question continued to evolve during the project, as the divergent phases shaped the project further.

As challenges were uncovered, the project continued from the open start by narrowing down to the challenge of uncertainty. After finding a collaborative partner, the project explored how to visualize uncertainty in weather forecasts. Exploring research and the field further, the project narrowed its focus to three weather elements: precipitation, temperature, and wind. Interviews with users provided important insights which shaped the concept development phase. The project's planning and structure were also influenced by participants' involvement.

The final phase of the process focused on choosing final concepts for presentation. While a design process feels or usually is not finished, the continued journey is unknown. Several suggestions for further work have been presented.

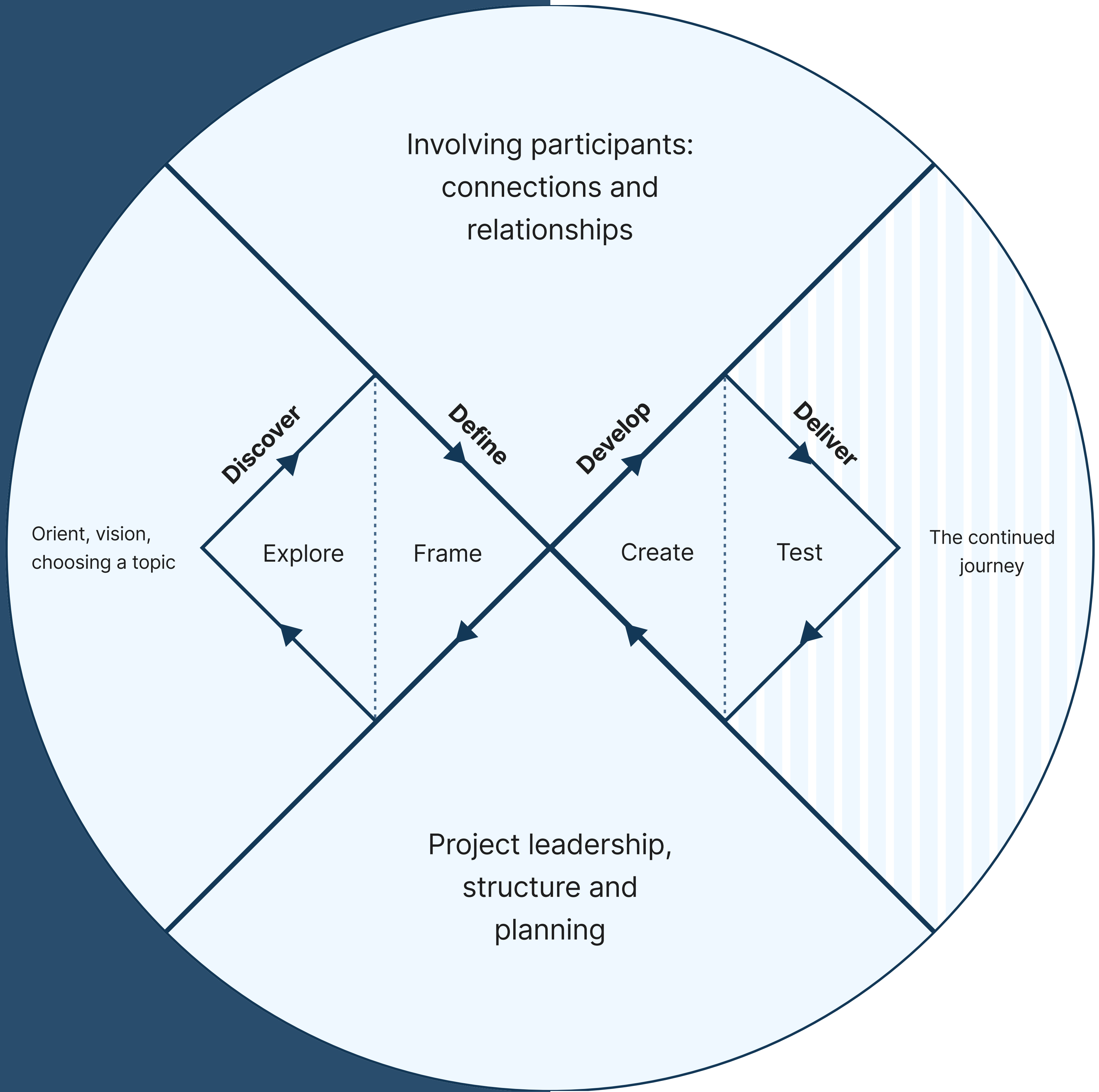


Fig 1.3. Illustration of the project's process.

1.6 What is data?

As my partner, our dog and I went on our evening hour walk in January, we conversed as always about ongoing projects, news, and relevant topics of life. Halfway through the walk, the three of us passed a map, leading me to question, “Is a map data visualization?”. Despite knowing the answer to be yes, I was still a bit hung up by the thought of data visualization to merely be a presentation of hard numbers. My partner, an engineer by profession, eagerly confirmed the question, elaborating on how the map communicated data about our nearby community, from the landscape, contours of hills to other relevant information.

Delving deeper into the subject, he playfully challenged me, “A picture can be data visualization”. Confused, I asked, “Not a picture of two people holding hands?”. The question had obviously raised his interest as he asked, “What do you think data is?” I paused for a moment before explaining my view of data as values and numerics. He confidently responded: “Everything is data,” further describing how every pixel in a photo represents data, how the display of light reveals information, and how the position of elements can reveal size, volume, or even location. Gradually, I started to understand his perspective of data, and we continued our conversation by examining surrounding elements, such as footprints in the snow.

I realized that a footprint reveals some data. It can inform about species, movement, and even the weight of its maker. However, the story is incomplete; colors, age, materials, and other details are left to the imagination. The observer’s personal experiences and knowledge influences how the data is perceived and interpreted. Without any context or familiarity with dogs or snow, one might struggle to comprehend the data or even recognize it as a dog’s footprint. This is especially transparent in situations like ordering a chair or clothing online, only to receive an item no bigger than a finger. The conveyor fails to visualize sufficient data.

This challenge extends to graphs and charts, where the audience’s knowledge and experiences define how easily they understand the information. The designer, automatically biased, must make critical decisions about what to include, exclude, and how to present the data. We must learn how data can be leveraged to design visualizations that present information while considering users’ backgrounds and comprehensions. Furthermore, recognizing one’s power and responsibility when using specific data will be just as important.

So, what is really data? Data in its widest term, represents information or facts, such as numbers, text, images, and videos (Cambridge University Press, n.d). It serves as the foundation of information, with the power to turn into knowledge through accessible communication, possibly simplifying decision-making, and facilitating democracy.

Fig 1.4. Winter evening walk in January

2.

Initial theory

Literature and data visualization theory

2.1 History

Delving into the history of data visualization (abbreviated to dataviz from here on) was seen as a natural starting point. It was important to build a foundation with a bit of historical overview to understand the development of the subject.

The most common types of dataviz prior to the 17th century were maps and other visualizations of cities, roads, and resources (Friendly et al, 2010). There has been massive research on the history of dataviz, but with the number of developments and inventions that have been made, it is hard to tell which one can be considered "the first". Michael Florent Van Langren is believed to have created the first graph within statistical data in 1644, as shown in Chapter 1.1. From the 18th century, William Playfair is considered to have invented many of the commonly used graphs today, such as the line graph, bar- and pie chart (Friendly et al, 2010). Furthermore, during the 19th century, several classic visualizations were created. These include the figurative geographic flow map by Minard, showing the French army's loss during Napoleon's war (Brinch, 2019), and the rose diagram by Nightingale for social and political advocacy (Friendly et al, 2010). Years later, with the emergence of computers, statisticians were able to store and collect data in larger volumes, and with new tools developing, dataviz became easier and more efficient.

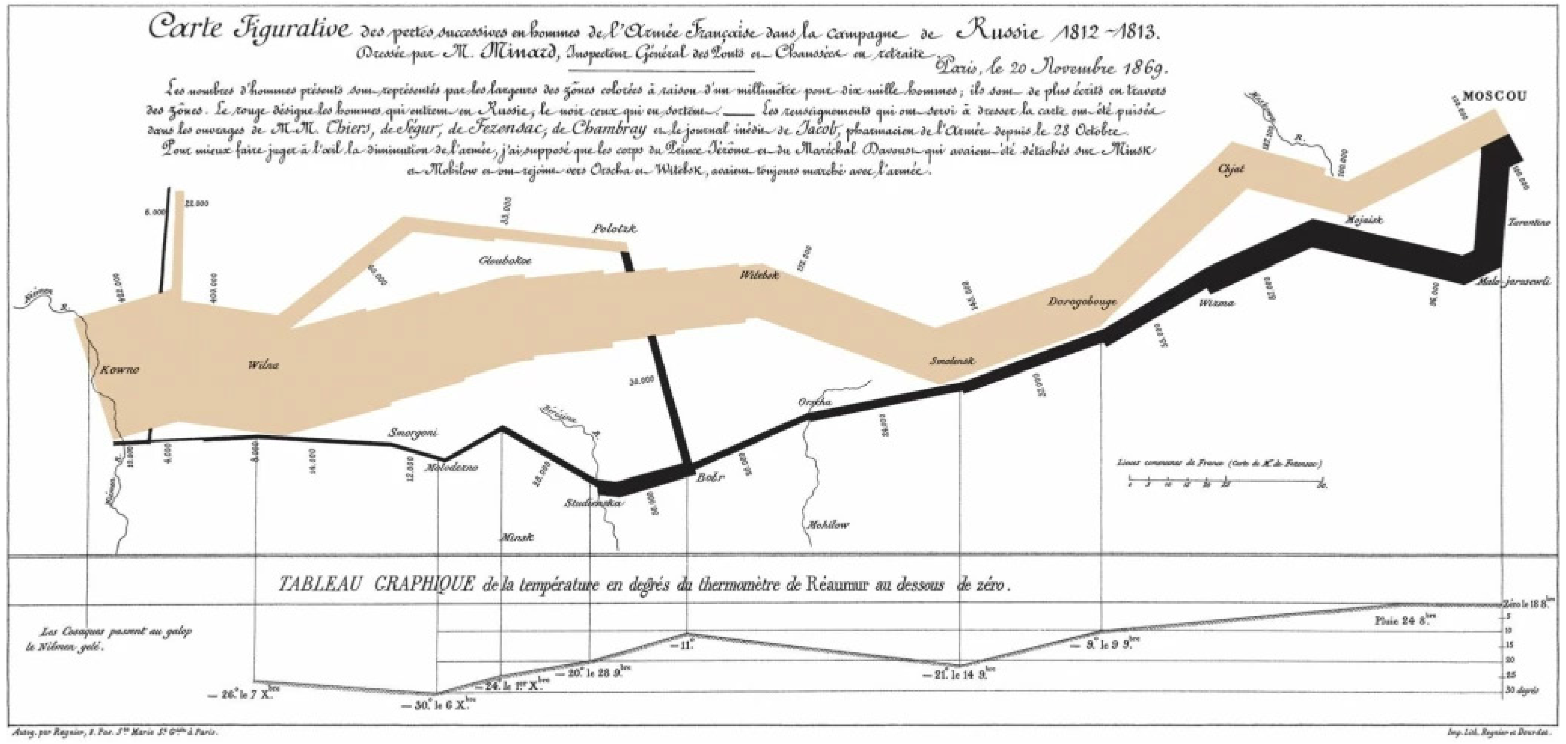


Fig 2.1. *Carte figurative des pertes successives en hommes de l'Armée Francais dans la campagne de Russe 1812-1813* by Charles Minard, 1869. Public Domain. (https://en.wikipedia.org/wiki/File:Minard.png)

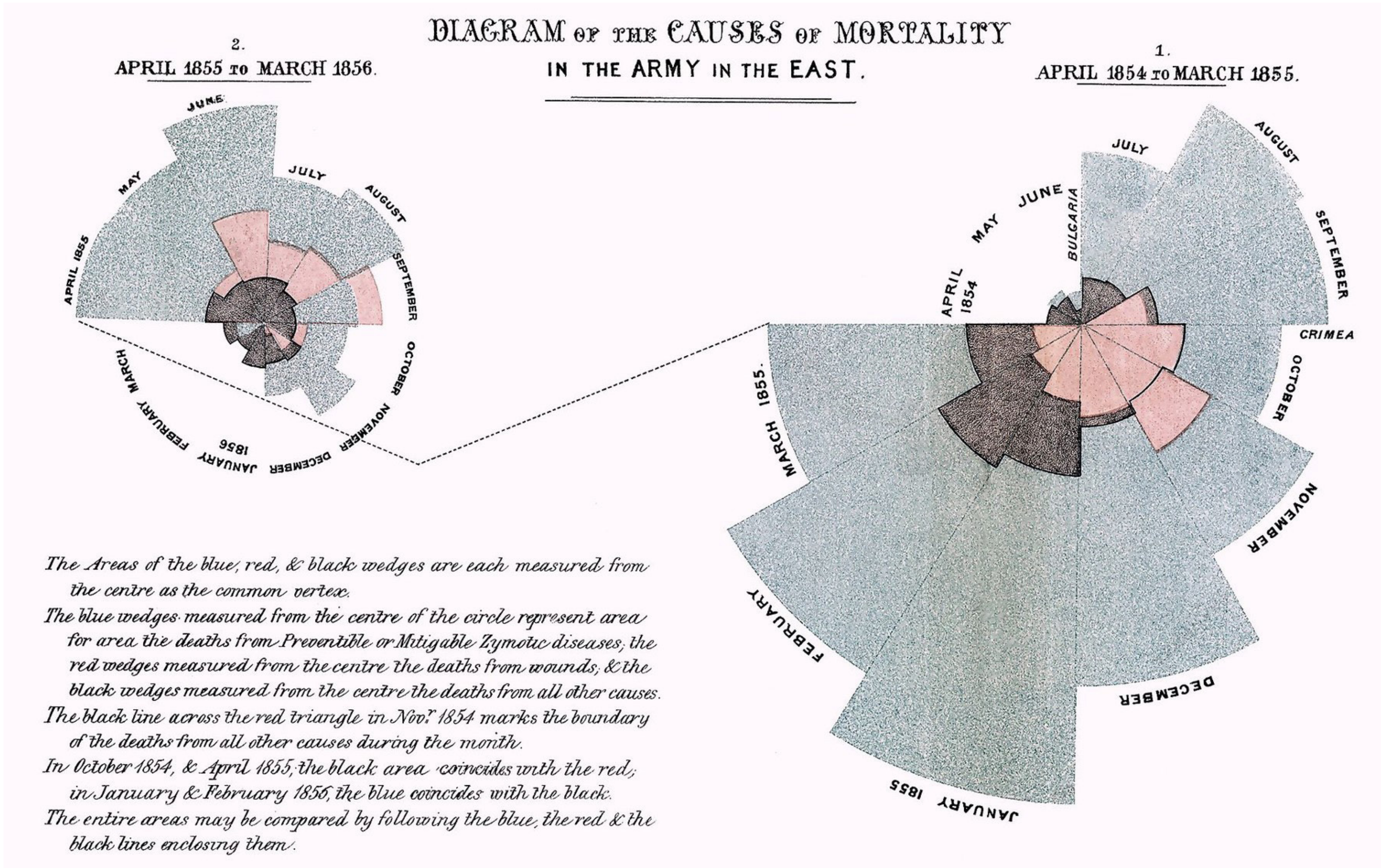


Fig 2.2. *Diagram of the Causes of Mortality in the Army in the East* by Florence Nightingale & Harriet Martineau, 1859. (https://www.davidrumsey.com/luna/servlet/s/h6xid2)

2.2 Visual theory map

Building upon the history, I recognized the need to strengthen my understanding of dataviz holistically. This was important in order to explore the preliminary research question, *Which opportunities and challenges are found within the field of data visualization today?* In order to grasp this vast topic, with both simple and complex theories, I began visualizing as a technique, with inspiration from system-oriented design to comprehend and acquire knowledge of the existing theory.

This resulted in a visual map for internal use – a method of working visually to enhance the learning experience. The map played a significant role in the first phase of my master's project, providing background information on the topic. The map is also included in the appendix. Snapshots of the map will be shared in this chapter, supplemented with reflections and explanations.

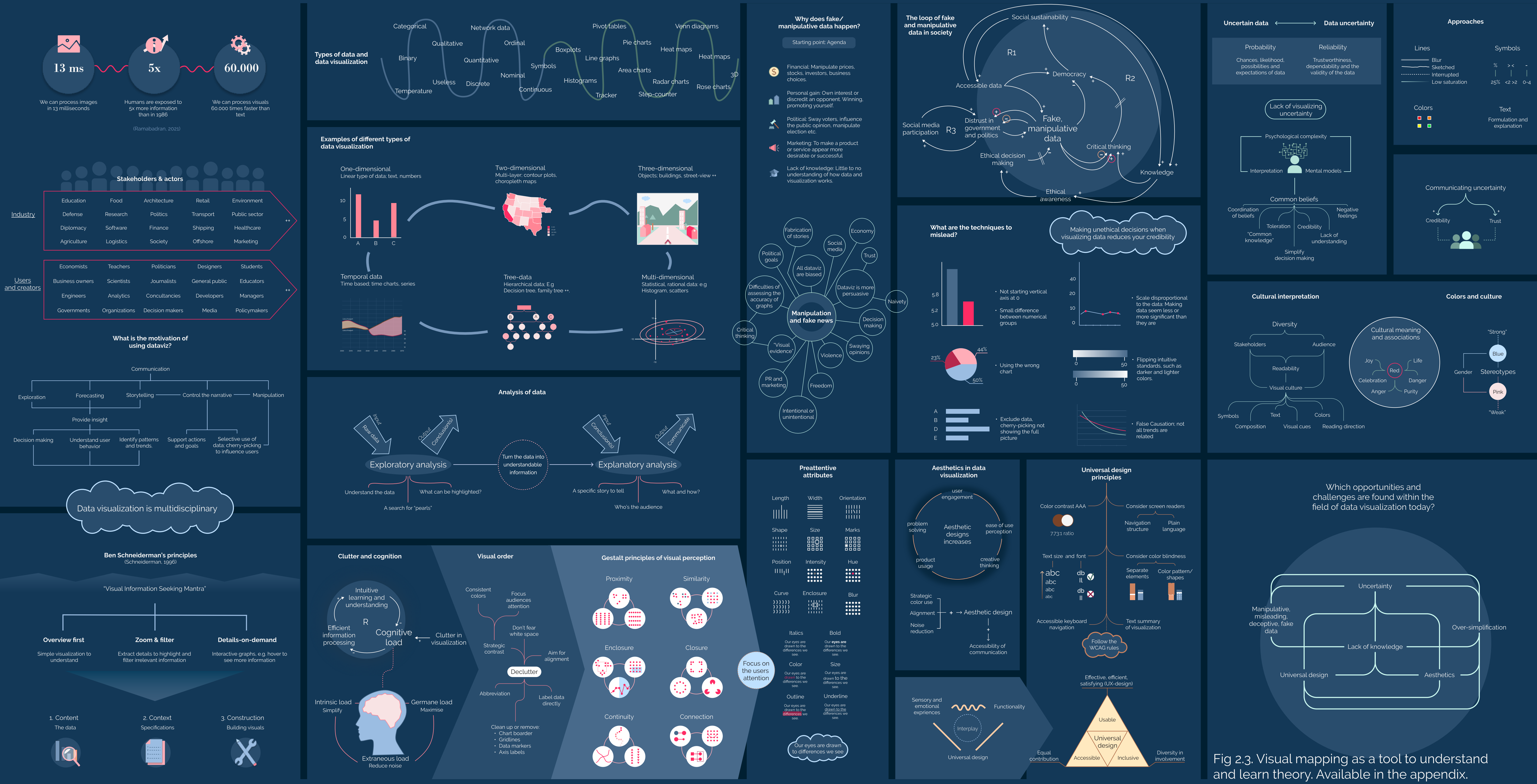


Fig 2.3. Visual mapping as a tool to understand and learn theory. Available in the appendix.

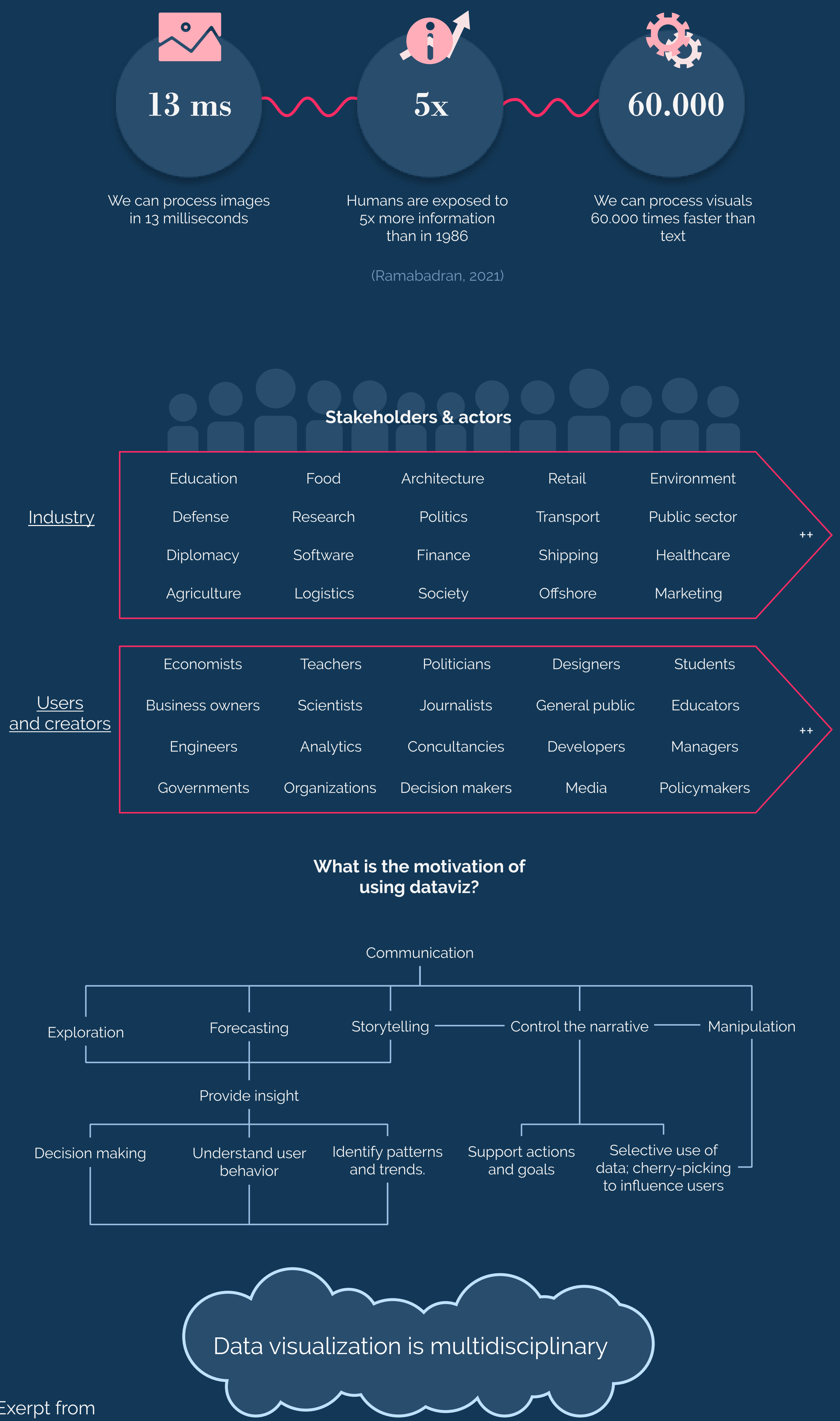


Fig 2.4. Exerpt from the map

VISUAL COMMUNICATION

The visual mapping started by learning about vision related to information processing. Vision is the most frequently used sense to gather insight, input, and perception of our surroundings (Krum, 2014). Visual information can be the most efficient way to communicate information. It is estimated that 50-80% of our brain is dedicated to visual processing, which includes vision, color, movement, shapes, spatial awareness, and more (Krum, 2014, p. 15). Recognizing the potential of efficiency of visual communication provided me with insight into the importance of dataviz and its power as a visual tool.

STAKEHOLDERS AND MOTIVATION

I proceeded to map stakeholders and actors to understand the participants and industries typically involved in dataviz. The mapping provided insights into how multidisciplinary the field is. I reflected on the reasons behind dataviz' multidisciplinary nature. My initial thought was that dataviz is used to communicate information, leading to the exploration of the motivation behind using dataviz. Figure 2.4 shows the variations of motivations. The first potential challenge emerged during this process – stakeholders using dataviz to manipulate and control the narrative. This challenge is further explored on page 21.

> “Data becomes supporting evidence of the story you want to build.
>
> Knaflic, 2015, p. 26

COMMUNICATING DATA

Dataviz is clearly about communicating data, but a key factor of communication is to understand the data you are working with to ensure the audience has the same opportunity. Shneiderman (1996) introduced three guiding principles of dataviz, known as the Visual Information Seeking Mantra: Overview first, Zoom & Filter, and Details-on-demand.

<u>Overview first</u>
This principle focuses on obtaining a holistic view of the data before delving into details. To provide users with an overview, data can typically be visualized as bar charts, heat maps, or other visualizations summarizing the key data.

<u>Zoom & Filter</u>
Once users are provided an overview, the next step suggests to zoom into areas of interest and filter out unimportant and irrelevant information. Interactive visualizations can allow users to adjust the preferred level of detail.

<u>Details-on-demand</u>
Lastly, detailed information about specific areas or individual data points should be accessible. A possible approach is a pop-up window with additional values and information.

In some cases, visualizations might be created without adhering to these three principles, particularly when there is a single main purpose to communicate. This led me to the 3 C's for an internal process: Content, Context, and Construction.

<u>The three C's</u>
First, an overview of the data (content) should be acquired. Second, determining the context – what should be highlighted for users, and what is the story's goal? Finally, construction involves creating the visuals.

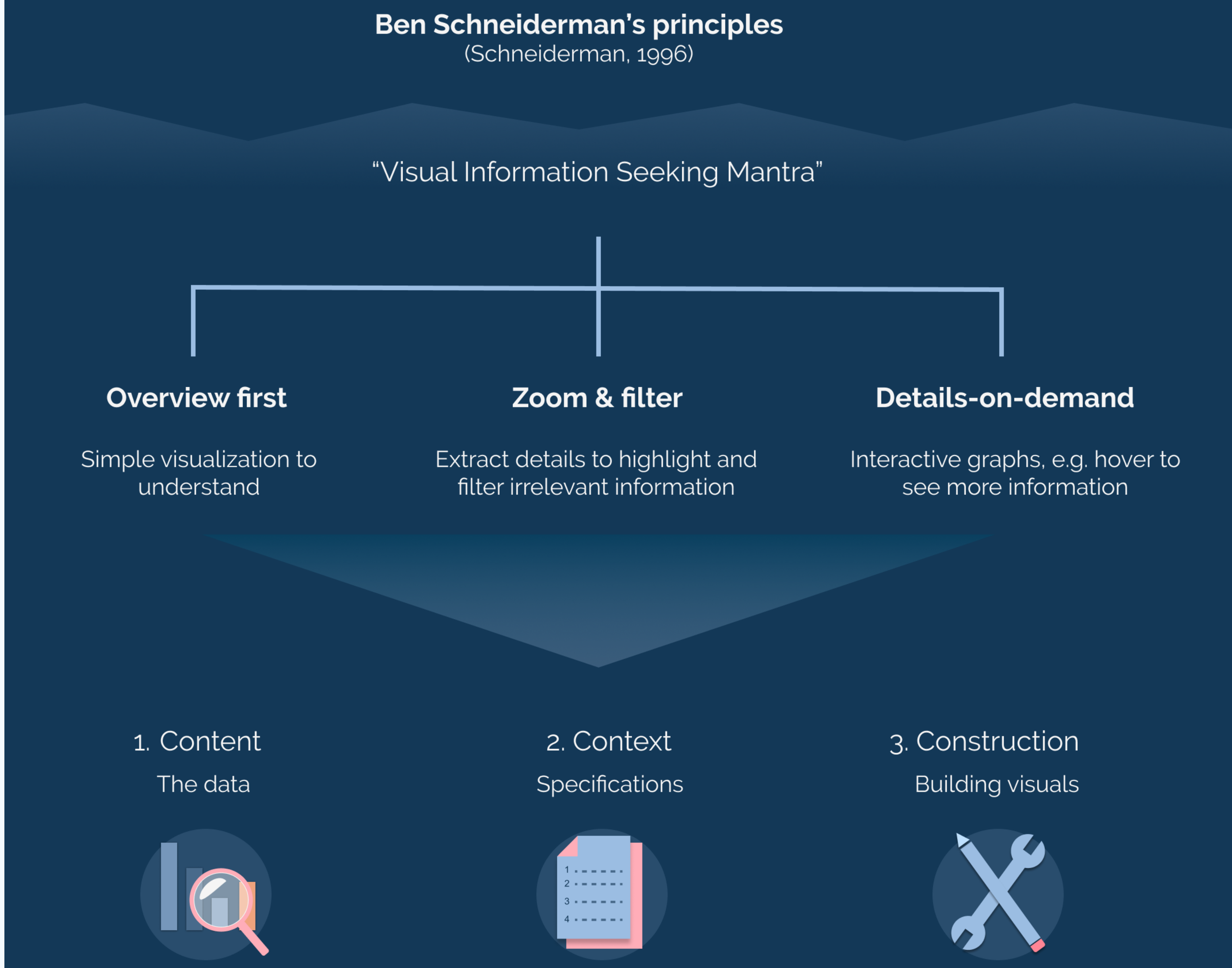


Fig 2.5. Exerpt from the map

DATA ANALYSIS

To effectively understand the content and context of data, data analysis can serve as a valuable tool.

Knaflic (2015) emphasizes the distinction between exploratory and explanatory analysis in her book. As illustrated in Figure 2.7, the first step when working with data is exploratory analysis. This process involves understanding the data by identifying patterns, trends, relationships, and more to determine what can be highlighted. Knaflic refers to this as "hunting for pearls in oysters". By testing 100 different hypotheses or examining data in various ways, you might find a few pearls (Knaflic, 2015). At this state, the data should not be shared with the audience. Knaflic stresses the importance of restraint – not all information should be shared as evidence of your work. Turning the data into consumable information is a significant step to achieve storytelling with data.

Transitioning from exploratory to explanatory analysis involves turning data into comprehensible information. Explanatory analysis aims to provide the audience with a story by addressing three questions: who, what, and how. "Who" refers to the audience; understanding the audience is essential for efficient communication. Consider their data literacy, limitations, strengths, needs, and the appropriate tone to use when communicating.

> “Knowing who you are communicating to and what you want to convey reduces iterations and ensures that the purpose of the communication is fulfilled.
>
> Knaflic, 2015, p. 26

"What" refers to action: what should the audience know and do with the information? To answer this, it is crucial to ask why the audience would be interested in the story. If there is nothing the audience should do or know, the need for visualization should be rethought.

Finally, "how" addresses communication. The method of information delivery impacts how it is processed. For example, live presentations offer a higher control of how the audience takes in information, but require lower detail, allowing for audience interaction and adjustment. In written formats, such as documents, control is lower and detail should be higher to ensure understanding, see Figure 2.6.

The audience ultimately controls how they consume information. Therefore, user testing is a helpful tool when experimenting with new communication methods to ensure shared understanding.

An analysis can, as mentioned, be a helpful tool to understand the context of data. However, conveying the context is just as important. Krum (2014) highlights this in his book. A single text or bar in a chart does not provide context. Context can be shown through comparison, by providing the audience with a second value. At the same time, it is important to be aware of the bias that comes with the chosen value for comparison. I will dive deeper into the responsibility designers have regarding misleading, manipulative or fake data on page 21.

> “If the designer doesn't provide context to help understand the value, the audience will make up their own.
>
> Krum, 2014, p.16

In design education, I have experienced limited education on data analysis. Yet, we frequently use visualization as a tool to convey and understand information. It is important for designers to participate in the entire process, from raw data to visualization, even though our expertise and competence may not cover all aspects. Involving experts can be beneficial as it provides a better understanding of the data and insights, increasing the quality of the explanatory phase.

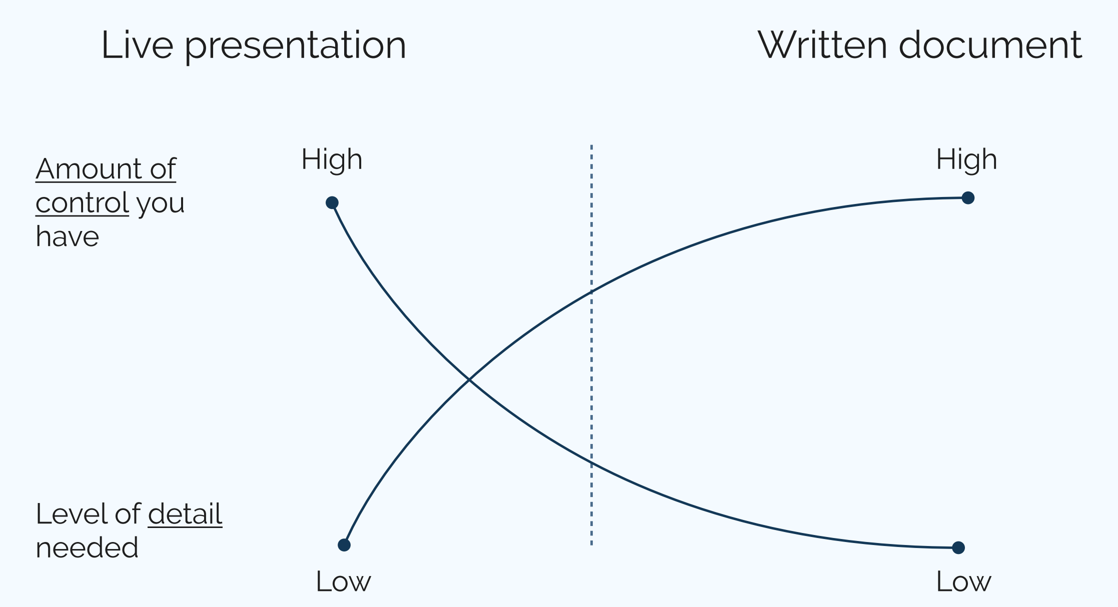


Fig 2.6. Illustration based on Figure 1.1 p. 24 in Storytelling with Data, Cole N. Knaflic, 2015.

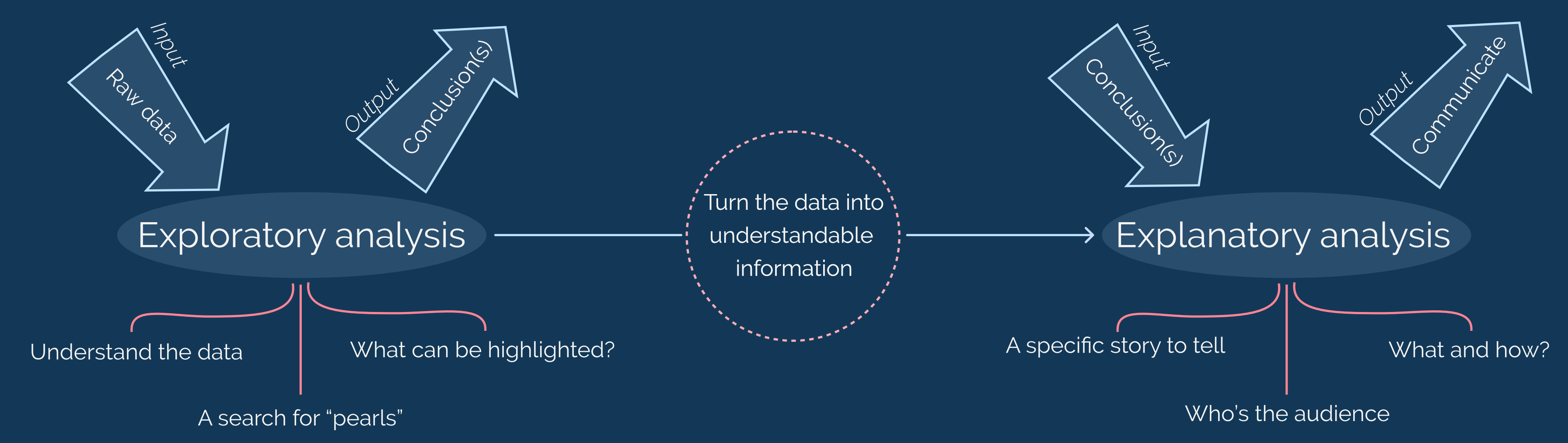


Fig 2.7. Exerpt from the map, visualizing exploratory and explanatory analysis.

CLUTTER AND ORDER

To communicate with an audience, exploring visualization principles in relation to the human brain and cognition was important.

Knaflic (2015, p.71) states “clutter is your enemy” in her book, as the headline of Chapter three. The chapter emphasizes the negative aspects of cognitive load, and how we can reduce it. Every element added to a visualization takes up cognitive load, and being able to reduce unnecessary elements will help users process the information faster. This is visualized in figure 2.8, by using a method from system thinking (Haraldsson, 2004). The causal loop diagram presented shows the relationship between different variables. The plus (+) sign represents a reinforcing effect on the variable the arrow is pointing to, while the minus (-) symbolizes an opposing or balancing effect.

Clutter in visualization increases the cognitive load, leading to less efficient information processing. It is a reinforcing loop, meaning more clutter increases the cognitive load. This could also be related to the work of the psychologist Kahneman (2011), which differentiates between two thinking methods; System 1 and System 2. System 1 is an autonomous process, in which our actions and thinking is driven by intuition and little effort, influenced by our instincts and previous experiences. System 2, on the other hand, is a slower way of thinking, requiring more effort and consciousness, often related to analysis, evaluation, and reasoning.

If information was visualized with unnecessary elements, it could lead to a higher cognitive load activating System 2 thinking. Too many competing elements could increase the difficulty of identifying a visualization’s purpose. This could slow down the decision-making process, as well as reduce the audience’s comprehension. Visualizations free of clutter can potentially facilitate insights with minimal effort, and the viewer can grasp the message more efficiently by using System 1 thinking. However, some visualizations with complex information may require System 2 thinking, but clutter is still not preferred as it hinders users in finding the key insights.

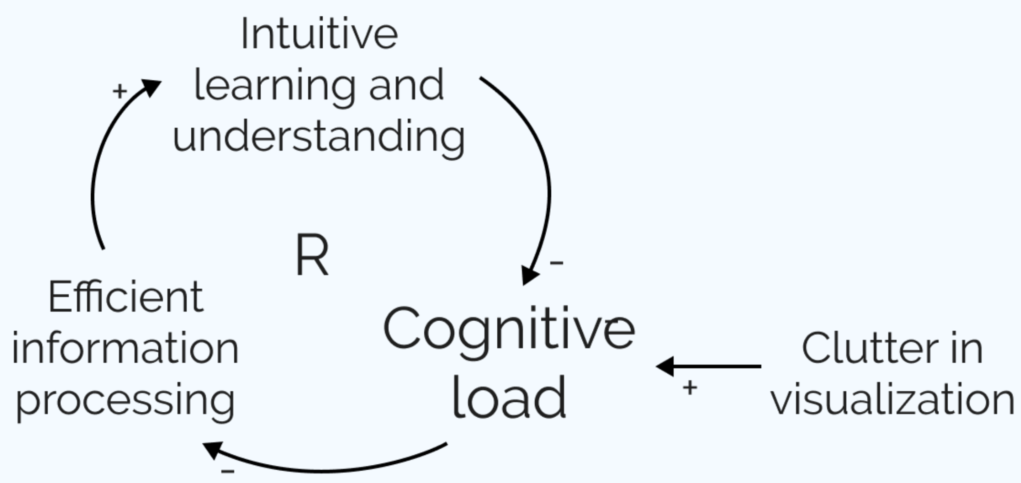


Fig 2.8. Excerpt from the map. A reinforcing causal loop illustrated.

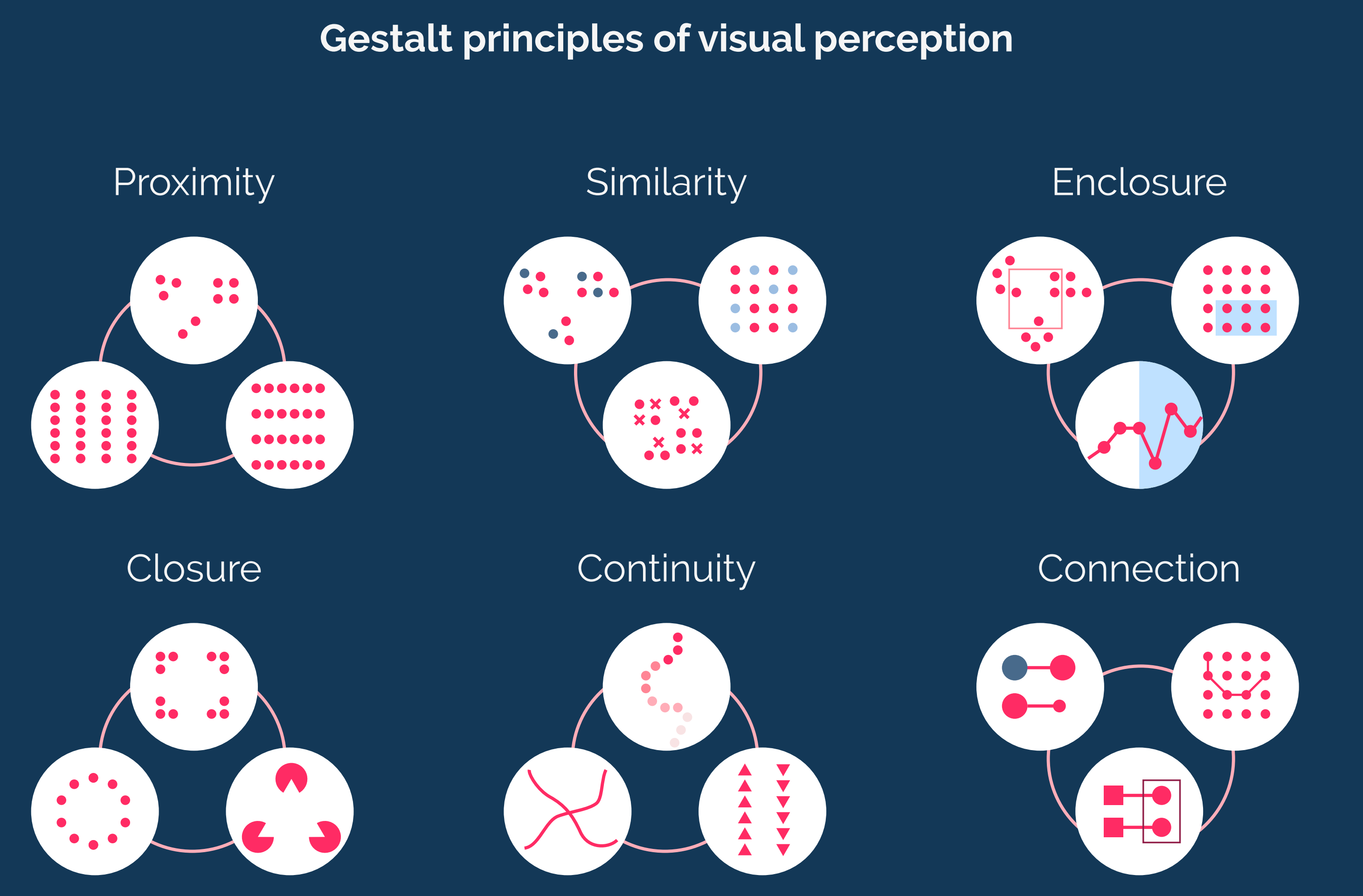


Fig 2.9. Exerpt from the map, Visualizing Gestalt principles

GESTALT PRINCIPLES

Knaflic (2015) proposes several ways to reduce clutter and create visual order. These include aligning elements, not fearing white space (there is a common tendency to fill in open spaces), removing elements such as chart borders, data markers, axis labels, gridlines, and more. Furthermore, she mentions strategic use of contrast, consistency, abbreviation, and more. To understand more of how we perceive visuals in terms of clutter and order, Gestalt principles of visual perception are as relevant today as in the early 1900 (Knaflic, 2015). These principles include proximity, similarity, enclosure, closure, continuity and connection, which showcases how we as humans search for patterns, connect or group elements, and read them. Considering how we interpret these visual elements is important when designing visualizations.

AESTHETICS

Functionality and communication might be considered the most important aspects of visualization. However, aesthetics are closely related to function and should not be neglected. Research shows that people perceive aesthetic designs easier to use than less aesthetic designs (Knaflic, 2015). Other positive outcomes are visualized in Figure 2.10.

What is considered to be aesthetically pleasing in dataviz? Knaflic emphasizes the importance of decluttering; strategic use of colors, alignment, and using white space as a leverage – making the designs appear cleaner and inviting. As these aesthetic actions ultimately help reduce clutter, it might influence the accessibility of a design.

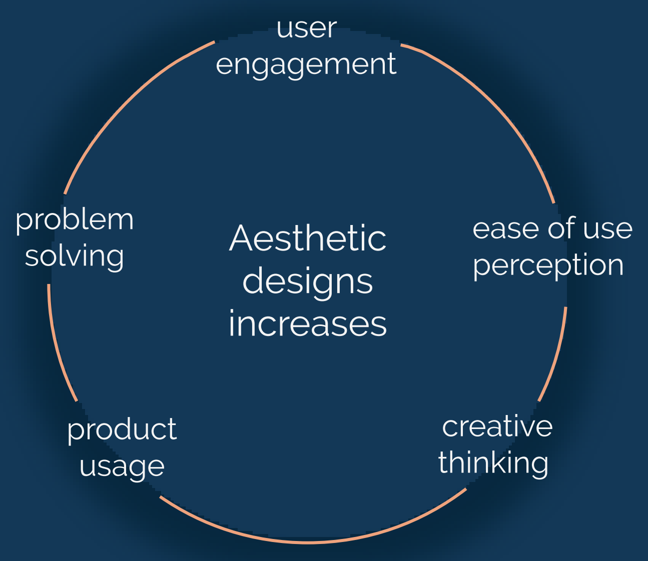


Fig 2.10. Excerpt from the map: "Aesthetic designs increases".

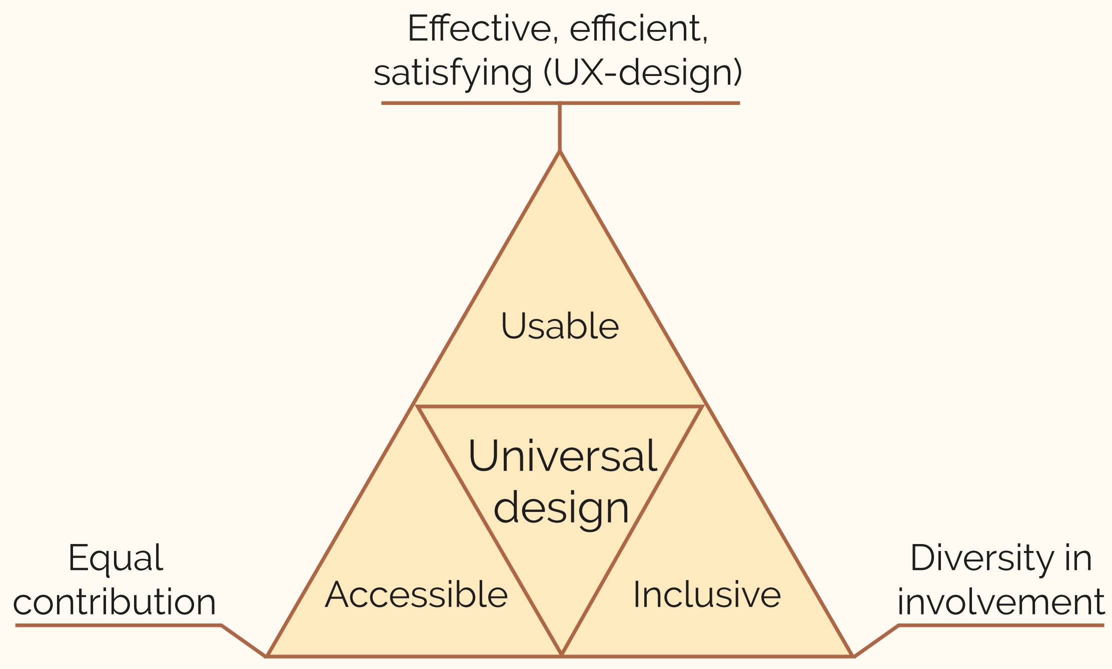


Fig 2.11. Excerpt from the map. The triangle of universal design.

UNIVERSAL DESIGN

The subject of universal design and the term itself has increased in popularity since it first was introduced by Ronald L. Mace in 1985 (Mitrasinovic, 2008). The term has transferred to all parts of society from architecture, transportation, to digital design. Universal design is about making our designs as accessible and comprehensible as possible. I have illustrated it as a triangle, in which the words usable, inclusive, and accessible surround universal design. The design should be usable, meaning functional, and satisfying. Furthermore, inclusive thinking involves ensuring a diverse user involvement. Accessible focuses on equal contribution; making sure as many as possible can take part in the design. How can these principles be achieved?

Web Content Accessibility Guidelines (WCAG) is a helpful tool to make web content accessible for people with disabilities. WCAG provides us with guidelines regarding color contrasts, text, and more. Several of these principles have been visualized in the map, which designers need to consider. Possible principles to think of include font choice, colors, screen reading and keyboard navigating options, and a text summary of visualizations to adhere to a larger audience.

Typical issues considering universal design is the lack of color awareness. Approximately 8% of men are colorblind, and 1% of women (Sandvig, Høvding, 2020). Put in context, 8% of a million people is 80.000 or approximately 1 of 12. The most typical issue is seeing the distinction between red and green – which are very typical colors used in graphs (National Eye Institute, 2019).

Despite the immense research, available tools on the topic and the world evolving into a more inclusive place, there is a lack of good practice on several platforms in our society, making universal design a topic still relevant and important when exploring and working further with dataviz.

MISLEADING, MANIPULATIVE, AND FAKE DATA

Information has never been more accessible than today. The Internet, combined with the availability of digital devices, has made it possible to find answers more efficiently and faster than before – and the information continues to increase. Parallel with the growth, issues regarding misleading, fake, and manipulative information are growing – a threat to democracy and the ability to make informed decisions.

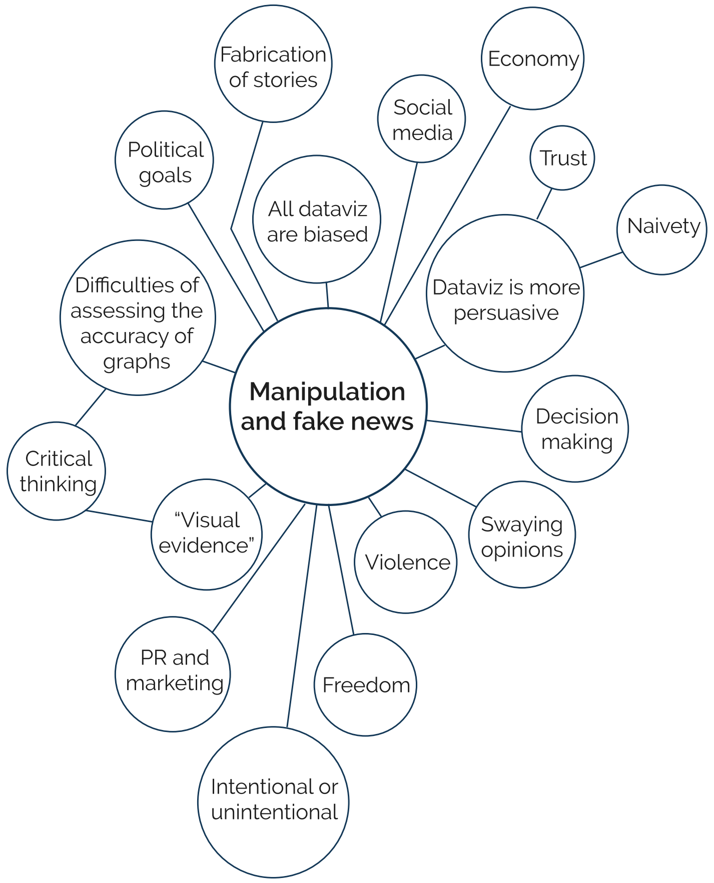


Fig 2.12. Excerpt from the map. A mind map.

These challenges surrounding dataviz came to light early in the process of theory exploration. I started creating a mind map, see Figure 2.12, to capture all the information consumed about the topic.

Fabrication of stories is one aspect, as it can lead to serious impact on the world. For instance, the defense minister of Pakistan used Twitter as a platform to issue a nuclear warning to Israel based on a fake story (Graham-Harrison, 2016). Furthermore, the literature showed how dataviz presents itself as more persuasive. It is often associated with science, which increases people's belief in them (Tal & Wansink, 2016). Decision making and swaying opinions is also mentioned, as people without a strong opinion about a topic can easily be persuaded and influenced through dataviz (Pandley et al, 2014). This research showcases the issues of misleading and fake data. In the visual theory map created, I provided examples of typical ways of manipulating dataviz, such as not starting the vertical axis at 0, cherry-picking data or false causation.

I visualized a causal loop diagram to understand the impact and influence surrounding dataviz; see Figure 2.13. Starting at the top, social sustainability promotes accessible data and is often linked to education – making informed decisions possible, which in turn strengthens democracy. With increased data and social media participation, fake, misleading, and manipulative data increases, threatening democracy.

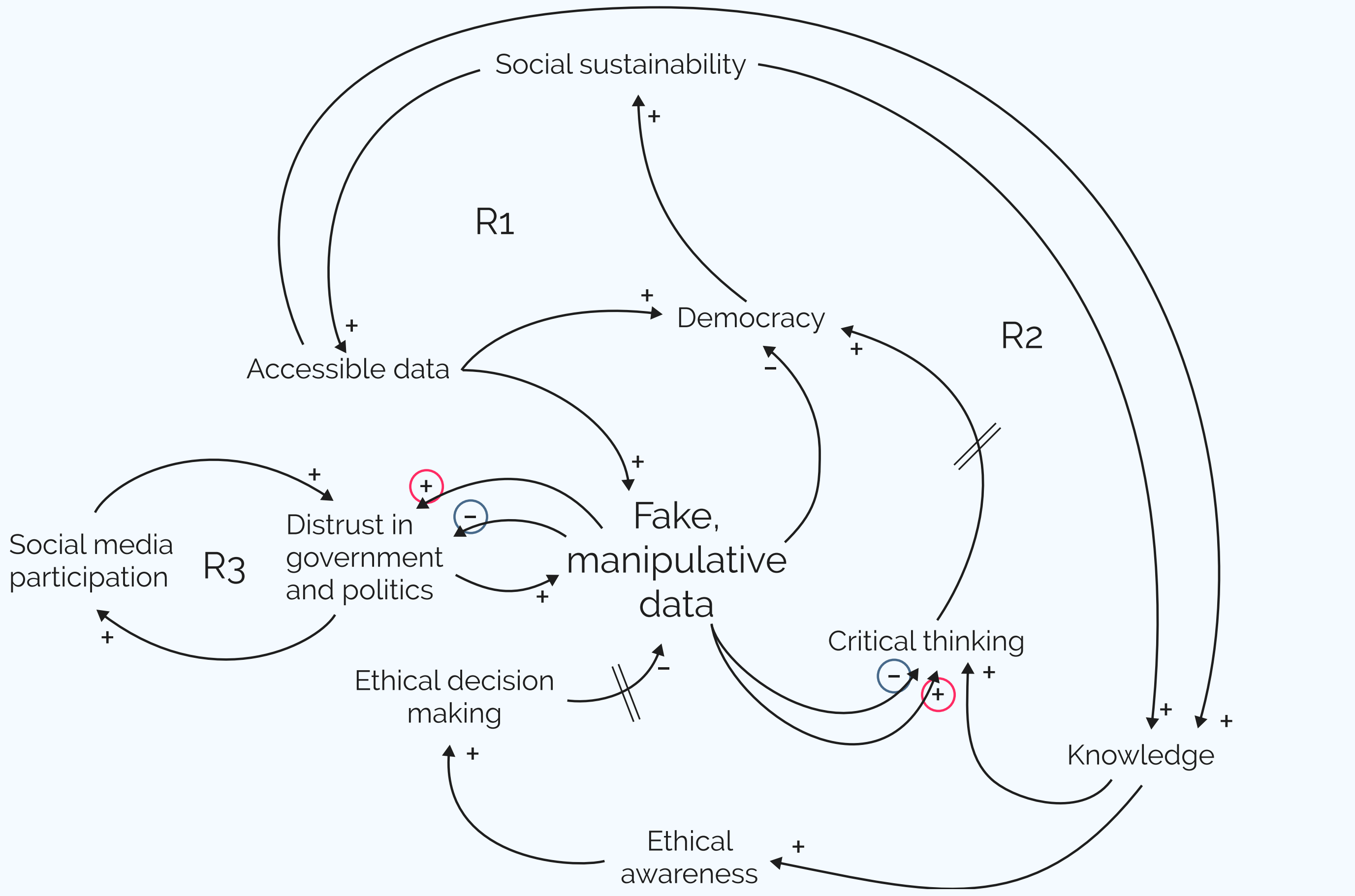


Fig 2.13. Excerpt from the map. A causal loop diagram of fake and manipulative data in society

Simultaneously, as knowledge grows due to social sustainability and its positive impact, critical thinking and ethical awareness increase, leading to a long-term increase in democracy. Fake, manipulative data can either enhance critical thinking if uncovered as fake or decrease it is experienced as being credible. Social media is often driven by algorithms to increase engagement, but this also influences users. Some individuals may have uncertainties about their trust in governments, politicians, or similar. If these individuals encounter news or comments that hold a negative attitude towards trust, they may become more susceptible to further exposure. Such exposure can influence their trust further (Scarlascini, 2021). Thus, social media participation and distrust are visualized as a reinforcing loop.

Furthermore, there's potential for both an increase or decrease in distrust. Research shows that trust and distrust depends on which side is in power (Lazer et al, 2020). Distrust will often grow with misinformation, while some gain more trust as their side is presented, even if the data is false.

In summary, the causal loop is a simplified version to understand impact and influences. It is important to mention that there are always additional aspects, relations, and interconnectedness that make the system more complex than visualized. Regardless, it provides an overview of variables influencing fake, manipulative data and their impact on our society.

CULTURE

Culture has been mentioned several times while exploring subjects of dataviz. As visualized in Figure 2.14, the diversity of stakeholders and audiences is connected to their readability. In communication, as previously mentioned in relation to explanatory analysis and universal design, it is essential to consider the audience. When communicating with an audience from a different culture than your own, it is important to consider the differences, particularly in visual culture, where symbols, colors, and other elements can have varying meanings. In general, dataviz can be a universal language. Most graphs are understood by the majority of people worldwide. However, graphics can speak a foreign language. Colors serve as a good example. An article in National Geographic uses the example of green, in which a business section of an African newspaper, the editors proposed using green while the client preferred blue (Esteban, 2015). This example shows how associations may vary, as not all countries have green money. Red has several associations as well, from illustrating anger to love. In China, some newspapers use green for negative values and red for positive (Esteban, 2015).

Western aesthetics has been the main focus in dataviz, in which harmony, symmetry, color, and proportion are highlighted. In other cultures, visual elements can only be considered beautiful when they possess "the appearance of nature" (Li, 2020).

Cultural awareness is essential when designing to ensure equal interpretation of the communication. Cultural considerations should be made when needed, based on the audience and where the visualization will be presented.

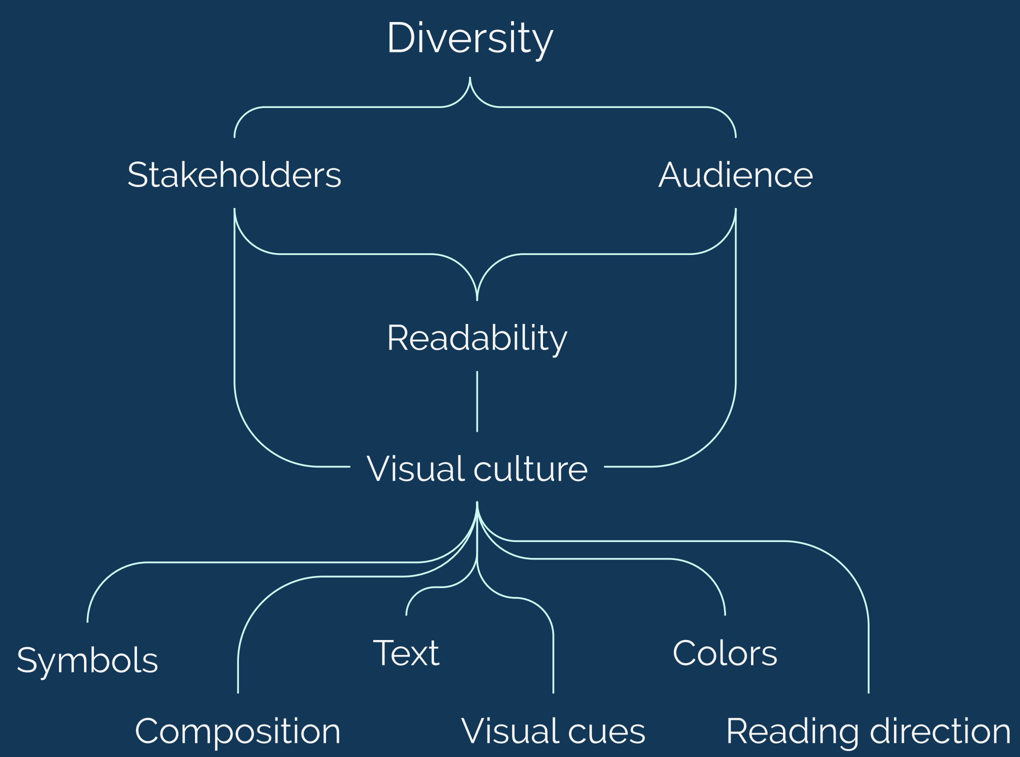


Fig 2.14. Excerpt from the map. Relations to visual culture.

DATA UNCERTAINTY

A subject that seems to be easily forgotten within dataviz is uncertainty. This is often considered a challenge, as it is related to the user's own data literacy, the raw data, forecasts, and more.

Lechner (2020) presents two ways of expressing uncertainty, through probability or reliability. Probability refers to possibilities and expectations, whereas reliability focuses on trust. Both reliability and probability can be used to communicate uncertainty, for example by visualizing various degrees of confidence in the probability.

There are several reasons as to why some choose not to communicate uncertainty, much due to the psychological complexity of it – such as the user's interpretation and mental models. Some believe that uncertainty can create negative feelings or consequences for the credibility of the communicator. Others believe that removing uncertainty might simplify decision making or that the uncertainty is common knowledge, not in need of being addressed (Hullman, 2020). Removing uncertainty might also simplify the visualization process in terms of accessibility and aesthetics.

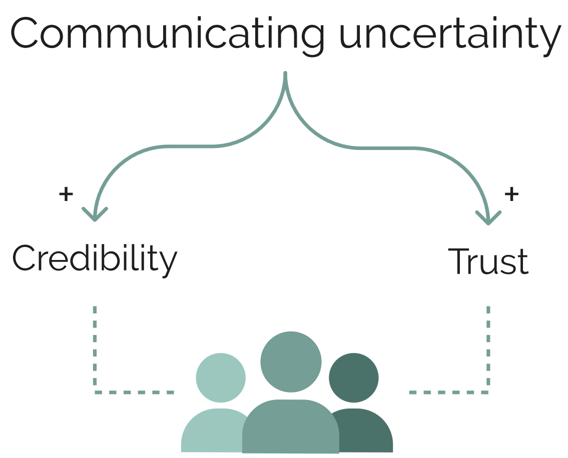


Fig 2.15. Communicating uncertainty

On the other hand, research shows that presenting an uncertain outcome as certain can reduce the credibility of the author. This might result in the public being less likely to follow warnings or consider the information (Leetaru, 2019). Communicating uncertainty remains a challenge within the field, due to its complexity and the difficulty of keeping it simple. Moreover, it can be challenging for users to understand what is being conveyed if information is presented in certain ways, particularly when it requires previous education on the subject.

How can one communicate uncertainty? There are several ways of doing so, in which some have been presented in the visual theory map as shown in the beginning of the chapter. Lines are often used in dataviz, in which research shows that lines being handwritten, blurred, interrupted, or have low saturation are interpreted as less certain (Kinkeldey et al, 2014). Other typical options of presenting uncertainty are through colors, in which green is presented as most certain and red as the opposite. Cultural considerations should as previously mentioned be considered here as well. Other ways are through text or symbols, in which the latter is commonly related to numbers; such as probability expressed as a percentage, intervals or greater/less (>/<) than.

In summary, uncertainty is a complex subject. Producing graphs and charts are not enough in dataviz. Visualizing is about leveraging the data to help and guide the audience to new knowledge and information. Communicating uncertainty needs to be recognized as part of the process, to ensure people make informed decisions based on the full story.

VISUAL THEORY MAP REFLECTIONS

The primary goal for the visual mapping was to facilitate my own, internal learning about the topic. With that, I aimed to discover some challenges and opportunities within the field of dataviz, which was my preliminary research question when starting the master's thesis.

Several challenges were discovered, as illustrated in Figure 2.16.
Many of these challenges impact each other and are connected.
Lack of knowledge is related to all of the surrounding challenges. It affects universal design thinking, aesthetics, misleading dataviz, over-simplification in visualizations, and lack of communicating data uncertainty.

Over-simplification is also connected to several subjects. When working with dataviz, the goal might be to simplify data to enhance the user experience. This is often mentioned in regards to aesthetics, uncertainty, and universal design. Simplifying too much might lead to the author unwittingly misleading or incorrectly presenting the data. Furthermore, uncertainty might be set aside to easier fulfill requirements of universal design and make the visualization aesthetically pleasing.

Lack of aesthetics might also be a challenge. As previously stated, aesthetics have several positive attributes. However, people might think that they have to downgrade the importance of it to meet universal design requirements, instead of making them work and balance together. Focusing only on aesthetics might affect universal design negatively and also lead to over-simplification of the data. Everything is connected to lack of knowledge.

These challenges are interconnected and should be considered when working with all aspects of dataviz.

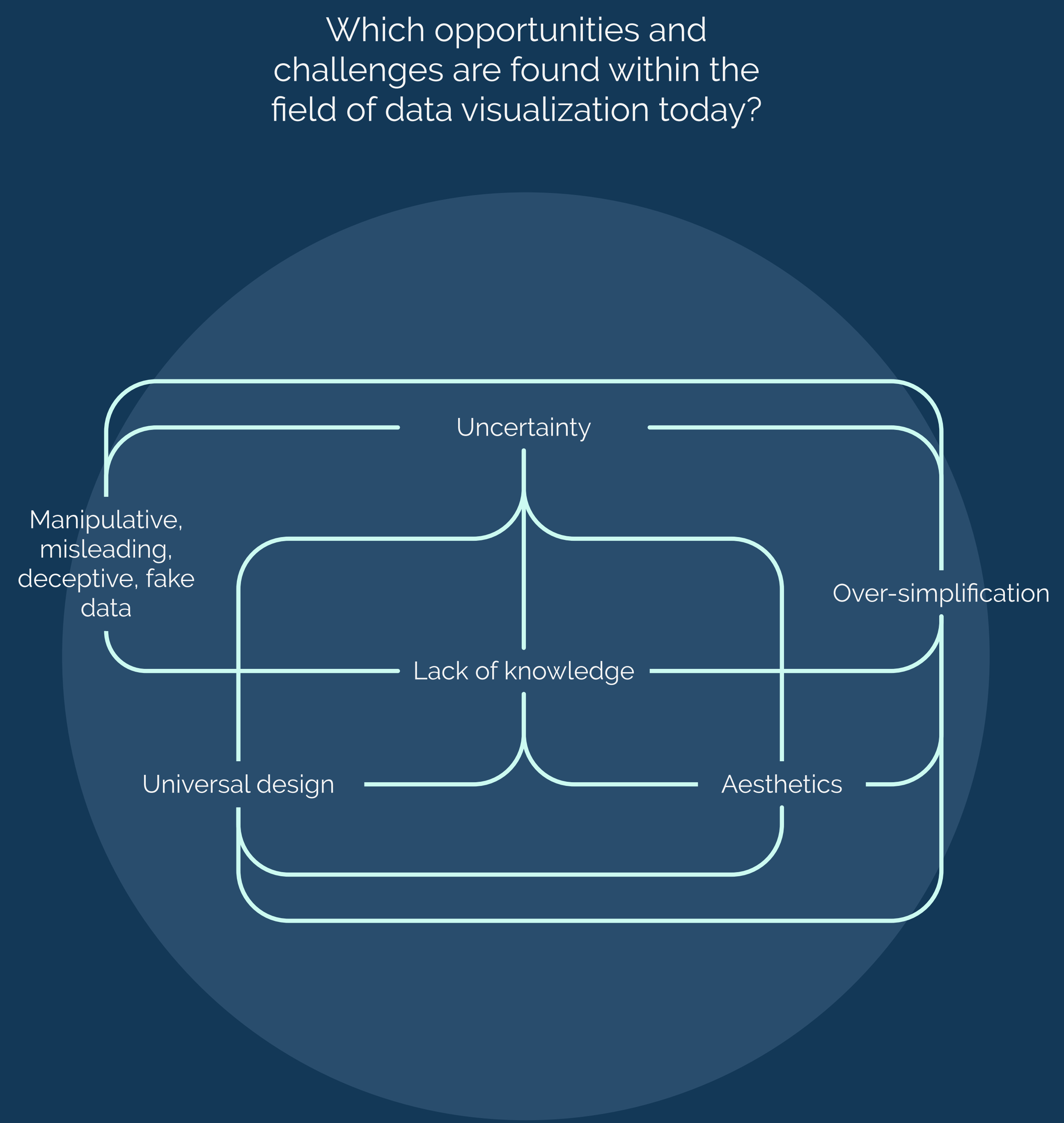


Fig 2.16. Excerpt from the map, concluding the first research question.

Research

Own research, project task & specific theory

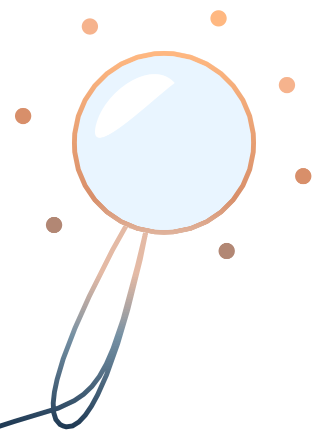
3.

3 Research

The visual theory map in Chapter 2 aimed to provide a holistic overview of the dataviz field, uncovering current challenges and opportunities. This phase of the research was based on existing literature and previous research studies conducted by other scholars.

This chapter aims to narrow the research scope and build on the insights gained in the previous chapter. The first part of the chapter focuses on independent research, consisting of one workshop and two interviews with field experts. The purpose of this research was to gain knowledge from professionals, thus providing insights based on experiences. By doing so, I could obtain a deeper understanding of the field, by reinforcing knowledge or gain new perspectives beyond the literature.

The second part of this chapter presents the primary research task and the reasoning for selecting it. The formulation of the research task required exploration of specific research theory together with three expert interviews.



3.1 Introductory workshop

The impact of dataviz in our everyday lives

We surround ourselves with dataviz both purposely and not, and we might not think about how much influence it has on our lives. To enhance the understanding of dataviz and its influence, I conducted a workshop with 7 designers from the design agency, Halogen. The group consisted of 4 women and 4 men including myself. The workshop was created to serve as an introductory kick off to the beginning of my project, strengthening the understanding of dataviz.

The workshop itself was constructed in two parts; first, a presentation introducing the topic of my master's project, followed by the core of the workshop itself; three questions to generate thinking and discussion.

The first question asked participants to think of dataviz we surround ourselves with and use in our everyday lives. Participants were asked to write down their immediate thoughts on post-it notes, which were later shared. The participants wrote down among others; battery level, calendar, weather forecast, traveling apps, stocks, watches, activity tracking, political choices, and more.

The second question delved into the influence and impact these visualizations have on our lives. The participants were asked to discuss openly from this point. The aim was to create a dialog, rather than thinking individually. Digital tests for measuring consensus related to political parties, google maps, and other similar applications for traveling were highlighted as something influential or we depend on. Weather applications were mentioned several times as it influences clothing, packaging choices, and other plans. Calendar was also highlighted by one participant as a helpful tool to remember better. On the other hand, another participant discussed how the calendar allows for booking of meetings, possibly leading to increased stress as it gives access to information on open time slots in the owners calendar.

The third question aimed to gauge the participants' reflections on our responsibility as designers, and our experiences working with dataviz in our profession. The first argument put forward expressed how dataviz requires statistical understanding, which can sometimes be limited for both clients and ourselves. Still, the task of visualizing data happens to be given randomly to someone without sufficient knowledge. Dataviz consists of several layers; the data, analysis, what to highlight, the audience, and visualization. It requires skills to be able to handle all aspects alone. A participant mentioned the responsibility of choosing a visualization that provides insight and understanding, but at the same time shared experiences of how people might take the "easy route", choosing a random generated or pre-set graph from google, without considering the audience or context. The discussion continued to how designers can contribute in this field, in which considering the audience and how to communicate with them was mentioned.

To conclude, all the input generated from the first question became a reminder of how accessible and commonly used dataviz is. The second question showed how dataviz is not just a tool in our everyday lives, but how interactions influences all parts of our lives – such as our time, choices, thinking, learning, planning, and more. The last question acted as a reminder of how simple it is to take part in dataviz with little to no knowledge, and showed how multidisciplinary teams play an important role when working with data.

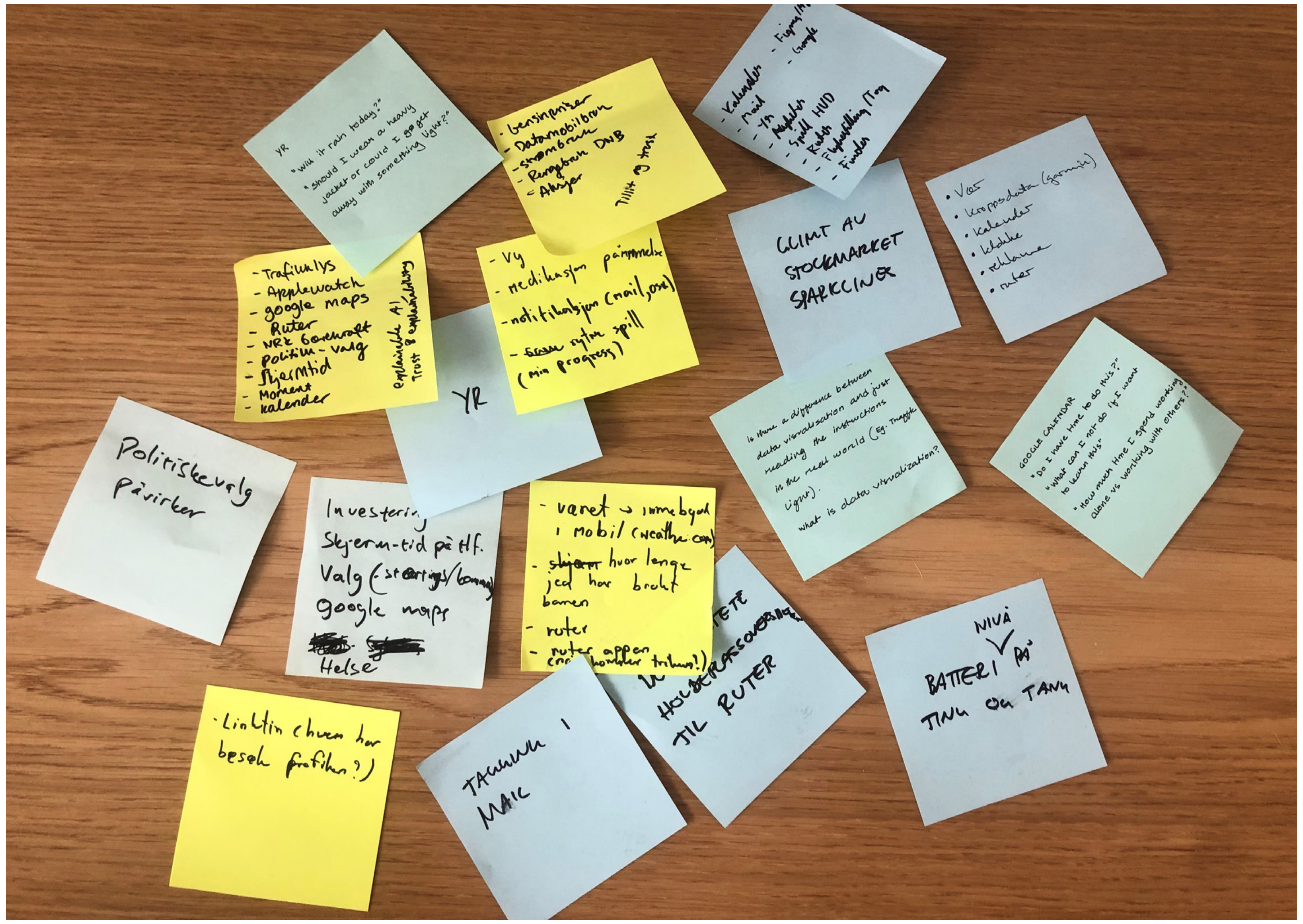


Fig 3.1. Collection of post-it notes from the first question in the workshop.

3.2 Importance of knowledge

Interview discussing the challenge of data literacy

A semi-structured interview was conducted with an Inter-regional advisor on statistical training and capacity building for the United Nations. The interviewee has broad experience with data, such as data collection and analysis. Her background of working in SSB (Statistics Norway) for several years and her current position at UN intrigued me to interview her for the project.

The interviewee has the main responsibility of helping countries build national capacity to produce numbers and statistics to help reach the sustainable development goals (SDG). Her profession and position at the UN give her the opportunity to teach, direct focus, and build data competence within countries, helping them reach out to their citizens.

Fig 3.2. Photo by Mathias Reding on Unsplash.

KEY FINDINGS

1 The interviewee mentioned data knowledge and literacy as a key challenge in the field. She stressed the importance of educating people on data interpretation, to enhance both critical thinking and decision-making. The challenge of data competence is also relevant for those visualizing data. She noted as an example that designers often have competence on aesthetics on the graphical part of visualizing, but may lack the knowledge needed to ensure a good quality representation of the data. Acknowledging her own imperfections, she emphasized the benefits of multidisciplinary expertise in the field of dataviz. The interviewee highlighted three essential attributes: understanding of communication, design, and data.

2 During our conversation on data literacy and competence, the interviewee noted that misleading visualizations and use of fake data is not always intentional. Insufficient domain knowledge emerged as a recurring theme and the cause of several challenges which were discussed during the interview. This aligned with my findings from the theoretical research mapping on page 21. The interviewee cited journalists as an example of individuals who might not have a hidden agenda, but may aim to sensationalize stories. Such actions without considering negative consequences, could spread misinformation. If the audience lacks data competence, they might not realize that crucial information has been left out.

3 Discussing the value of dataviz, the interviewee explained that visualizations can communicate more effectively than plain text. They can be particularly helpful for those who struggle with interpreting data or prefer visual communication, reaching a wider audience, including those with a less academic background. She mentioned SSB's success in creating engagement through visualizing data in an accessible manner on their Facebook page. The conversation ended with her asking a relevant question: How can you achieve similar interest in understanding complex societal challenges?

3.3 Aestethics

Expert perspective: aesthetics in dataviz

The Head of Design, Heidi Bakken, at Scandinavian Design Group (SDG) was contacted because of her experience with data visualization projects and her expertise in visual design. Holding a master's degree in visual communication and having worked in the design field for over two decades, she provides an expert perspective on the topic. The interview aimed to gain further insight from an experienced designer on the topic of aesthetics and dataviz in the industry, supplementing and comparing the theory conducted previously. Her experience with dataviz projects spans a range of application design, financial communication, sustainability reports, public sector projects, decisional support, and more.

KEY FINDINGS

1 The interviewee stressed the significance of simplifying dataviz to prevent cognitive load and ensure comprehension, adding that clear visuals have a subconscious impact on people's understanding. She emphasized the importance of balancing simplicity with precision and specificity to avoid over-simplification which often leads to valuable insight being left out. Translating data into understandable information is time consuming and complex, but very important for users. In some projects, presenting information in layers to reach a broader audience while maintaining the depth of insights would be beneficial. The suggestion of layering information was enlightening, as it shows that a dataviz does not need to consist of one layer. In some areas such as use of symbols, simplifying should be approached with caution as it provides users with a larger interpretation space.

2 The interviewee was asked about foundational principles of aesthetics, in which she mentioned composition, alignment, size ratio, colors, and space. She found it challenging to articulate what works and not, as she finds our vocabulary inadequate in this area. Instead, she suggested the typical design methodology of trying, testing, and iterating designs. She added that she believes aesthetics should be tested to a greater degree than what is typically done today. She also highlighted the value of being critical of how much information to fill in, to avoid clutter – just one pixel might increase the difficulty in reading. Alignment is easier on the eyes. Comparison was another principle mentioned, as an alternative to abstract visuals.

3 The interviewee highlighted the value of aesthetics through the example of a children's teaching book, explaining that text needs to be decoded in a different way than a drawing or visualization. Her profession has shown her how aesthetics can improve the overview of systems and digital services. She expressed that visuals and functionality are interconnected, as aesthetics influence people's perception, which can make information more accessible. It can be challenging justifying choice of visual elements as they are associated with current trends, symbols, emotions, and individual preferences. Still, she thinks human psychology makes it fun. She concluded by stating that storytelling supplemented with beauty and emotions can create value.

4 The interviewee shared both positive and negative experiences working with universal design. Today's rules serve as a technical framework which is based on code, not human factors, showing the importance of using the rules as guidelines and testing continuously to ensure one is on the right track. Additionally, past projects made the interviewee experience some parts of the framework open to interpretations, leaving the process quite time consuming. Furthermore, she believed the rules have a positive influence in reminding people of aspects that can easily be forgotten or are unknown. She also mentioned that universal design should be a more prominent part of the general work process and a continuous part of how you work.

3.4 Research task

Redefining the research question and specifying the project aim

As the challenges and opportunities within dataviz were explored, I reached out to relevant stakeholders to hear if they had some similar challenges or opportunities to explore in a master's project.

Two stakeholders communicated with me and provided several suggestions of possible challenges or tasks to tackle. Reflecting upon the impact and value of these challenges, I proceeded to collaborate with YR, which shared their challenge of visualizing uncertainty in relation to weather forecasting.

YR was mentioned in the first introductory workshop as a service that is both present and influential in our everyday lives, making them a relevant stakeholder to collaborate with. Adding the challenge of data uncertainty, I saw the opportunity of using this challenge and project as a case study or example which could possibly benefit similar fields using visualization and design to communicate data. The challenge itself was specific, yet broad enough to fit within the timeframe of a master thesis, which played an important role in the decision making. YR as a collaborator was also open, giving me the freedom to manage and shape the project through my own process as insights emerged. By this point, the research question evolved to:

How to visualize data uncertainty in weather forecasts to the general public?

The five question words; what, why, who, where, and how, have been used to provide clarity of the project.

WHAT

Master's project exploring how to visualize data uncertainty in weather forecasting

WHY

Create transparency and provide the public with information, enabling decision-making

WHO

YR as a collaborative partner and the general public as the user group

WHERE

YR, as a service, will be used to provide context for analysis, research, and more.

HOW

Through qualitative exploration and design methodology

WHAT IS YR?

YR is a Norwegian weather forecasting service operated by The Norwegian Public Broadcaster (NRK) and The Norwegian Meteorological Institute (MET). MET provides the service with data and professional content, and NRK is responsible for the presentation, design, and the editorial delivery to the users. The service has a website and an application, in which the users can access over 13 million places globally (YR, n.d.). YR describes their service as a contributor to saving lives, values, and providing users with credible weather forecasts to help prepare users for all types of weather.

Fig 3.3 Photo by Valentin Müller on Unsplash. Logos from NRK, YR, and MET.

3.5 Uncertainty

To understand the research question at hand, it is important to gain knowledge of uncertainty and its meaning. In his book "Trusting judgements", Burgman cites the definition that "Uncertainty is the pervasive unpredictability that obscures and shapes our view of the world." (Burgman, 2015, p. 27). Furthermore, Burgman distinguishes between three types of uncertainty: a natural variation, knowledge-based, and language-based.

Natural variation refers to naturally occurring and unpredictable changes of events. For example, the temperature of the water in a river may vary from instant to instant, and from place to place due to a natural variation of surrounding elements.

Knowledge-based uncertainty arises from limitations in available knowledge, inaccurate measurement devices, and insufficient data. This type of uncertainty is often inherent in scientific or engineering applications where predicting the behavior of a system depends on incomplete or uncertain information. This will often result in subjective estimates to predict unknown circumstances.

Language-based uncertainty comes from the imprecise nature of natural language and linguistics. Words can have more than one meaning, and different contexts can alter people's interpretation. Vague or imprecise wordings might also influence different understanding. As a result, it is essential to provide clear and plain explanations and definitions to minimize this type of uncertainty.

3.6 Weather forecasting

To be able to explore the research task, a foundational knowledge of the weather forecasting process was required.

Evans (2020) describes why the weather forecast can never be perfect. This is mainly due to our atmosphere being complex and chaotic. The atmosphere is the layer of air surrounding the earth. The lower levels of the atmosphere is where the weather develops. A weather prediction starts by gathering measurements of the atmosphere. The meteorologists will measure factors such as wind, temperature, and humidity from as many different places as possible at the same time. Thereafter, an analysis will be conducted, describing the atmosphere's current condition.

The analysis will act as a foundation for data to calculate how the weather will develop in the future. These calculations are highly advanced, with a high degree of detailing and complex, numerical weather models developed over several decades (Evans, 2020).

The complex, chaotic and unpredictable nature of weather forecasting increases the likelihood of failure. Tiny errors in the analysis impacts the accuracy of the models over time, leading to a significant deviation from the atmosphere, making the forecasting wrong. With improved weather models over time, it is still impossible to predict and describe the atmosphere to perfection. Simplification is also a contributor to inaccuracy, which again is increased by the atmosphere.

Analysis and faults in models are the main reason for weather forecasting mistakes, but are not the only reason for the discrepancy in forecasting and our own experiences. Local processes are not always described sufficiently in the models. These will often affect wind and temperature, as they are also influenced by each other, amount of sun, land or the ocean. The models will always develop and be improved by comparing actual happenings with the predictions. Observations will be important, but physical measuring devices impact weather elements themselves, such as the wind surrounding the device – leading to mistakes in the observations as well. A third reason for wrongful forecasting is "representativeness error" – an error occuring due to the forecasting not being representative for the area or region you are staying. Wind can have large variations in smaller distances.

The weather is predicted in individual squares in a grid, not always considering the variations within these squares. The grid is also becoming smaller over time, making it possible to predict within smaller local areas than ever before. Still, these grids will not disappear until the square is small enough to ensure no weather variations within it – which will never happen (Evans, 2020).

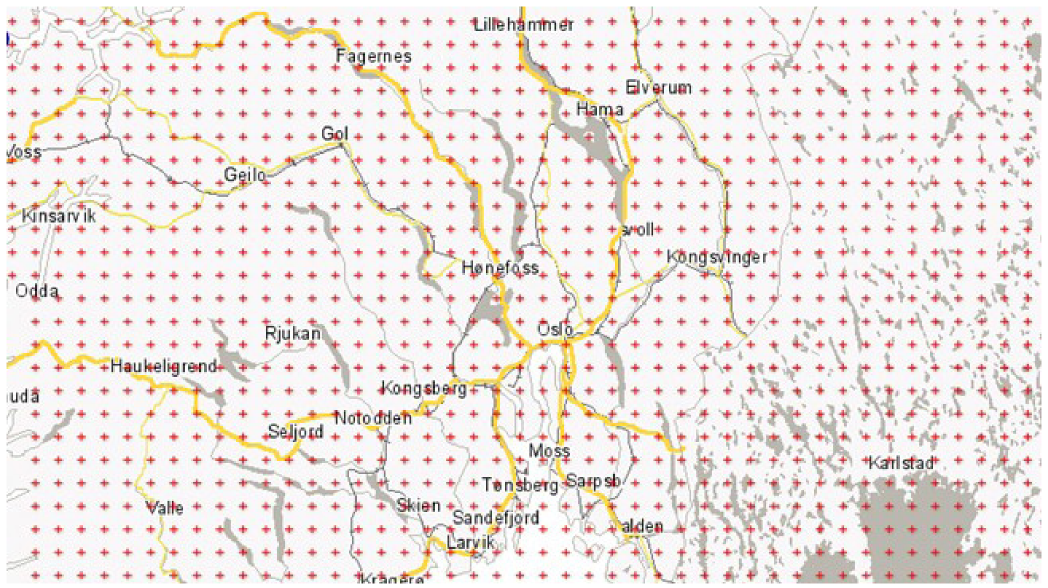


Fig 3.4 Illustration by Erik Bolstad showing the grid used for forecasting. https://hjelp.yr.no/hc/no/articles/360004008874-Slik-lager-vi-v%C3%A6rvarslene-p%C3%A5-Yr

3.7 Why present data uncertainty?

People look for information to help make informed decisions, and studies consistently show users' interest in information regarding uncertainty or confidence in weather forecasts (Seitter, 2008). Visual presentations of uncertainty are seen as helpful to both experts and laypeople (Sivle, 2016). If there is a lack of explicit communication of uncertainty, the audience is left guessing the true uncertainty of a forecast. It is therefore vital to inform on this to support informed decisions (Fleischhut, 2020).

An important aspect of uncertainty is consequences and risk. Sivle (2016) refers to a report from The National Research Council, claiming that failure in communicating forecast uncertainty could contribute to damage and loss of life. A study conducted also found information of uncertainty to increase confidence in the weather forecasts (Hanrahan & Sweeney, 2013). This is an important factor when the aim of communicating uncertainty is to help users with planning and decision-making. Users should be provided information on how to understand and use this information to ensure effective communication. The latter is seen as a challenge, especially as the concept of probability can be difficult to comprehend (Seitter, 2008).

Seitter (2008) proposes several challenges and opportunities regarding communication of uncertainty in weather forecasts. Some of the points mentioned are helping users understand probability forecasts, assisting users in how to use the information, and documenting the value and use of these forecasts in decision-making situations. Conclusively, he emphasizes the economic and social benefits uncertainty information could provide in decision-making.

3.8 Communicating probability

Probability is often used to communicate uncertainty. Burgman (2015, p. 29) refers to the definition "A numerical measure of a state of knowledge, a degree of belief, a state of confidence", showing how uncertainty is related to knowledge, belief, and confidence.

Burgman (2015) also explains how probability is related to a frequently occurring event, such as a chance process. For example, the probability of rain may be known within certain uncertainty limits due to past events, characteristics, data, and other measuring elements. Others suggest that probability should be objectively based on past frequencies of events, while subjective probability may be related to reasonable degrees of belief. Some beliefs are not based on probabilistic terms and without an underlying fact. This can be based on people's past experiences and impressions. A probabilistic weather forecast contains quantifiable uncertainty.

Burgman (2015) further discusses probability in terms of language-based uncertainty. He uses the example of a weather forecast stating that there is a 70% chance of rain. This is seen as underspecificity as there are several interpretations of this statement, including rain during 70% of the day, rain over 70% of an area, and a 70% chance of at least one droplet of rain. Burgman refers to a survey that asked people in different cities to interpret this statement, which showed the differences in comprehension. The interpretation depended on a person's sensitivity to the outcome. The survey emphasized the importance of providing further information behind these statements.

Another study also emphasizes the different interpretations of probability, in which only 33% percent chose the correct interpretation (Fleischhut et al, 2020). These research studies have given insight into the importance of being careful when visualizing uncertainty by showing the probability in the format of a percentage.

3.9 Data literacy

A cause for concern is the poor understanding of forecast uncertainty by the public, despite forecasts being present in people's lives through finance, weather, and other domains (Fleischhut et al, 2020). Fleischhut and the co-authors argue that an increase in weather literacy may improve users' literacy in other domains with uncertainty – which may help them understand societal challenges better, such as climate change (Fleischhut et al, 2020).

Despite the positive aspects of improved literacy and sharing of uncertain data, people's understanding and interpretation of visualizations remains challenging. This is because people's literacy varies based on their experience and knowledge, leading to discrepancies in interpretation.

Familiar situations make it easier to interpret information. Moreover, previous experiences and local contexts influence users' expectations of how to interpret visualizations (Sivle, 2016). Achieving a similar interpretation is important to reduce the negative effects of wrongful comprehension. Standardized symbols could be helpful to simplify interpretation, but factors such as experience, culture, and more could prevent equal understanding (Sivle, 2016).

Sivle's PhD study (2016) uncovered how visual elements such as colors, number of raindrops, and other nuances influence interpretation, even affecting how users understand uncertainty. For instance, a gray cloud compared to a white was interpreted as an indication of possible rain, whereas white clouds meant no chance of rain. This shows how users draw correlations between visual symbols and real-life experiences. This research study further discussed that details in symbols should be carefully designed, as nuances might be interpreted differently than intended. Verbal descriptions to symbols were proposed as a possible solution.

It is important to note that both the receiver and sender of a message have a responsibility, and design methodology can be helpful in this regard. User involvement through user testing, co-creation, workshops, and more are methods used for problem-solving. Sivle (2016) also suggested this by mentioning co-developing solutions with potential end-users.

> “Nuances such as color and the number of drops were important in the interpretations of the weather symbols and forecast uncertainty, which were sometimes interpreted differently than intended by the forecast provider
>
> (Sivle, 2016, p. 8)

3.10 Interviews NVE

Perspectives from actors within a similar field of work

The Norwegian Water Resource and Energy Directorate (NVE) was contacted due to their relevant field of work. The interviews aimed to provide perspectives of challenges, data handling, communication, and further insight.

NVE works with a broad field of water resources and energy. Within their field of work is also their role in emergency preparedness, in case of avalanche, floodings, landslides, and similar. They maintain the website varsom.no and an application, which communicates warnings, and other important information regarding natural hazards.

By contacting NVE, I was given the opportunity to interview two employees – one from the department of avalanche, and one from floods and landslides.

AVALANCHE ALERTER

A semi-structured interview was conducted with a senior engineer and alerter in the avalanche department of NVE.

Each region has its own warning page, containing several levels of information, from text to illustrations, and symbols.

> “It is safe to say that what we do is important
>
> Avalanche alerter. Translated from Norwegian

Fig 3.5. Photo by Krzysztof Kowalik on Unsplash.

KEY FINDINGS

1 The interviewee informed on the impact data uncertainty has on their work. Uncertainty in their data is due to several factors, such as weather forecast uncertainty, lack of recent observations, and the unpredictable nature of avalanches. Communicating uncertainty is important to create awareness, ensuring that the audience does not read the information as pure facts – but can use the knowledge to simplify decision-making and individual reflection in the field.

2 The importance of credibility was highlighted by the interviewee. They cannot create a warning with a higher degree of danger than what their data is telling them. The policy is to fail as much in both directions. Inaccurate warnings and mistakes will happen and are impossible to avoid, which again makes it important to emphasize the individual's responsibility. The interviewee expressed how this is essential to ensure their professional integrity.

3 The interviewee provided in-depth knowledge about their communication process. Their user group is broad and diverse, similar to YR's. They focus on using simple, clear wording, without compromising the professional language. Text is used as the main tool to highlight uncertainty, by writing “look for”, “possibly”, and similar wording. Symbols, illustrations, and colors to visualize the degree of danger are used additionally. Most symbols follow a European standard, and the danger degree follows an international one, but differs from other warning degrees with one additional color.

4 During the interview, I asked about the value of dataviz and communication in their field of work. The interviewee emphasized having been part of the team from the beginning, which provided the opportunity to observe the values in various ways. These include feedback and indications showing that it helps hinder accidents and improves people's knowledge. The interviewee concluded by stating, “It is safe to say that what we do is important.”

FLOOD AND LANDSLIDE

The second interview with NVE involved the department of flood and landslide warnings. I had the opportunity to talk with a senior engineer and hydrologist. In their work area, the interviewee is both a recipient, processor, and communicator of data.

Fig 3.6. Photo by Lukas Hron on Unsplash.

KEY FINDINGS

1 The interviewee began by explaining how their department processes uncertain data today, emphasizing its relevance in their work. They process several data models, both their own and from MET. "The uncertainty of MET's data dominates our work the most" said the interviewee. The participant shared further, that having such focus on uncertainty in the weather forecast models, they tend to forget the uncertainty in their own models. Still, their models do show uncertainty through several simulations. This leaves the employees to make subjective and individual evaluations on warnings, often based on experience.

2 The warnings of flood and landslide are currently issued on a regional basis, meaning an entire area may receive warnings even if not all parts are affected. In the future, the communication model will become more specific in terms of area and level of consequence. The participant expressed concern as the new communication model will use the same data input for evaluation. This means that despite expectations of precise communication of time and place, the data remains the same. The interviewee pointed out that people believe precise messages more, and therefore, the responsibility of addressing uncertainty will become more important. Moreover, he believes that details in warnings will be of greater benefit to users who rely on them to act.

3 The uncertainty in their predictions is communicated through text and the underlying expectation of uncertainty by warning uniformly in larger regions. Additionally, a four color system is used to visualize levels of warnings. During the interview, the participant shared that they have attempted to communicate probability, but the audience has not been receptive to this type of information. The interviewee went on to explain how they are cautious when sharing probability due to people's difficulty in comprehending the information and their tendency to interpret it differently. He explained how they want to use professional/academic terminology but must consider that not all people can understand it.

4 The interviewee emphasized the importance of communicating uncertainty to ensure that users are not misled. The information provided should allow people to make informed decisions, and the participant believes people want a clear message about what to do. However, the interviewee also acknowledged that it is not always possible to be certain, and uncertainty cannot be avoided. How this should be conveyed and how the audience perceives it, is not easily answered. If they consistently convey wrong warnings, people may lose trust – highlighting the challenges of communicating uncertainty and the importance of doing it correctly.

3.11 Interview MET

Anders D. Sivle was contacted due to his employment at MET and his PhD, as previously referenced. He has a Master's degree in meteorology and a PhD in pedagogy, with science and education as his field of expertise. His employment at MET was relevant because of potential insights into internal procedures for weather forecasting, uncertain data, and METs involvement in YR. Sivle's PhD (2016) studied how information in online weather reports is interpreted and used for decision-making by laypeople. With his educational background and profession, he possesses valuable knowledge relevant to this project, making him a significant domain expert to involve. One interview and several follow-up conversations led to the insights presented.

The accuracy of weather forecasting has improved over the years, leading to less error and incorrect predictions. Traditionally weather forecasts were predicted by running a high resolution deterministic weather model once on a super computer and presenting the results to the target audience. In recent times another approach has become popular, in which a lower resolution model is run several times with slightly varying initial conditions. This produces a range of possible weather conditions that may be used to objectively measure how likely different weather scenarios are. A small range of outcomes, for instance if all simulations predict rain in two days, means that the forecast is quite certain. A larger variation indicates greater uncertainty. A subjective evaluation may be conducted on top to adjust to local variations or model errors the human forecasters are aware of.

The interviewee mentioned that predicting local downfall and rain showers is particularly challenging. Atmospheric pressure does not change significantly across larger areas, and temperatures have known dynamics affected by factors such as proximity to mountains and the ocean, which create variations. Rain showers can be predicted to occur, but it is difficult to predict specifically where and when they will happen within an area. This is most apparent during summer times, as local rain clouds occur more frequently. Some weather elements will be easier to predict and more certain, while others may not, regardless of whether they occur the current day or one week ahead. This information may differ from people's mental models about the accuracy of a forecast in advance versus close to the date.

Fig 3.7. Photo by Miguel A Amutio on Unsplash.

The interviewee discussed his PhD and other research, revealing how people use mental models to comprehend uncertainty. People interpret temperature differently; some view it as a fact, while others see it as a range. Some individuals' mental models might interpret a temperature of 4 degrees as being between 2-6 degrees, while others may add a larger range up to 10 degrees. He suggested that visualizing uncertainty is better than leaving people guessing. Additionally, experiences can influence interpretations, such as associating a gray cloud with the possibility of rain, since white clouds "do not rain." Furthermore, nuanced symbols relating to people's experiences make it easier to interpret uncertainty, such as using one raindrop versus three to indicate the amount of rain. The participant also mentioned studies showing that more raindrops imply greater certainty of rain. Details enable visualization of certainty, but it is important to restrain their use to avoid overloading users with information.

When discussing user needs and different user groups, the interviewee believed that visualizing uncertainty was not as valuable for users seeking quick information, whose actions are not as affected by the uncertainty. However, when there is something at stake, people usually search for more details and would benefit from being provided information about uncertainty. The interviewee mentioned a study that showed people make better decisions when they are presented with uncertainty. These studies concluded that it creates value.

4. Process

User involvement, theory & analysis

4.1 User groups

Potential users were mapped to gain a better understanding of who they are and identify those most affected by weather data. The y-axis represents users who are most influenced by this data. They were sorted into four categories: the enthusiasts, the professionals, the unconcerned, and the “nerds”. The naming is used to differentiate between user groups, but it is important to emphasize that users can move between user groups based on time-related situations, which the background circle is meant to symbolize. Additionally, this is a rough picture of potential users, meaning that more exist and some within their category might not identify with the high influence, due to individual circumstances.

By identifying which users are most influenced by weather data, it becomes easier to determine who would benefit most from the information. This is helpful for further user involvement, helping me to target users beneficial to involve in the project. As Figure 4.1 illustrates, the enthusiasts and professionals are most affected by the weather.

The enthusiasts represent users interested in weather due to its influence on their lifestyle or living conditions. This can include users living in danger zones of floods and avalanches or users participating in activities such as outdoor climbing or mountain hiking. The professionals are users whose profession is influenced by weather conditions, such as pilots, farmers, and professionals within outdoor sports. Essentially, these two user groups will further be referenced as “risk users”.

The next group is the unconcerned. They may be influenced by weather when leaving their home for work or other low-risk activities. These users usually do not need in-depth details and information for their activities. They are interested in quick, efficient information to help with simple every-day plans, such as clothing choices. However, as mentioned previously, they may move between categories based on activities. If planning for an outdoor event, a wedding for instance, the influence will be much higher, as well as the risk.

Lastly there are the “nerds”. These users are highly interested in weather data due to different interests but are not at risk or highly influenced by the weather when accessing YR or other weather data applications.

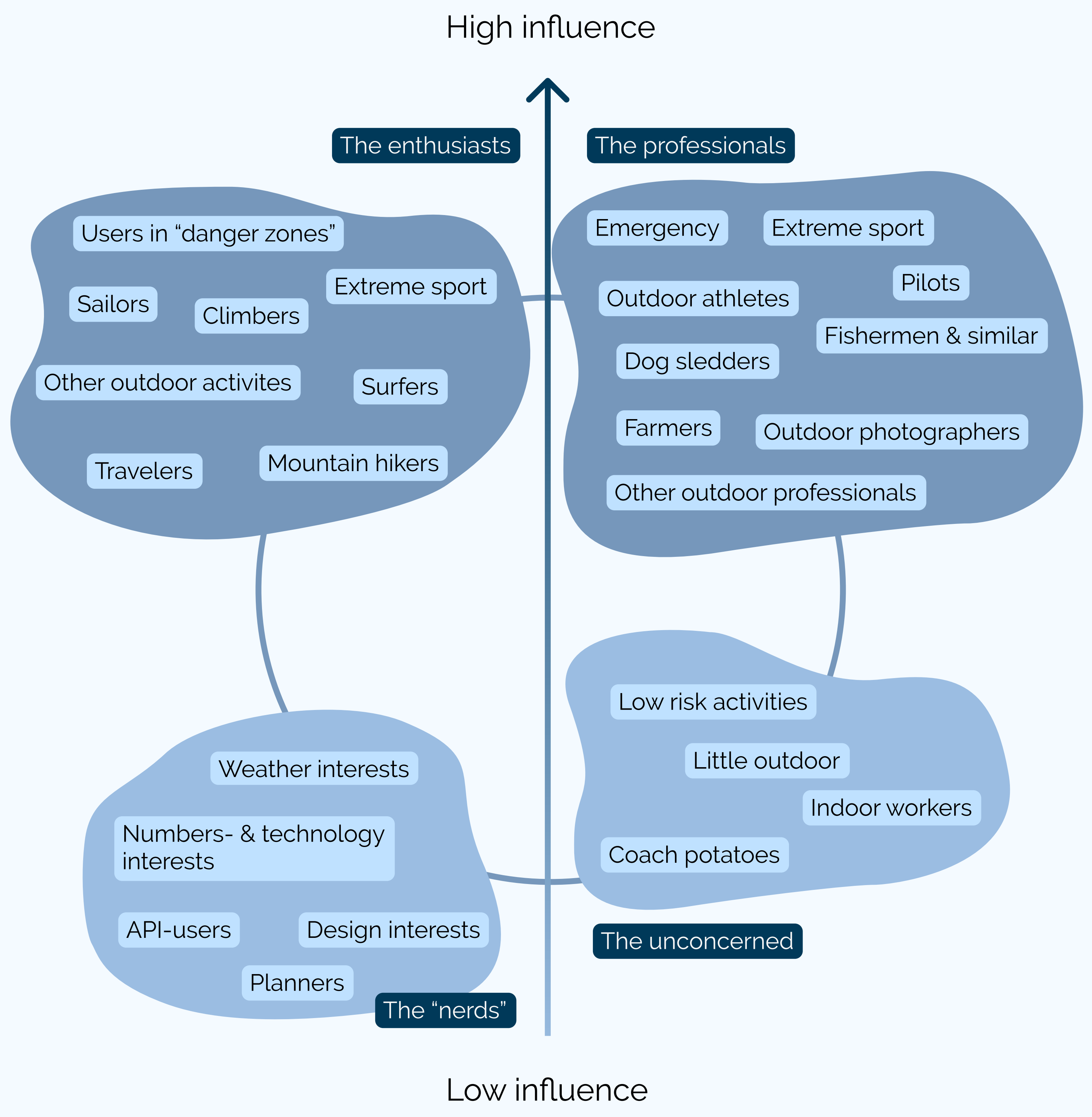


Fig 4.1. User groups categorized in groups from low to high influence.

4.2 Non-risk users

Interviewing non-risk users

Users typically categorized as "The unconcerned" were contacted, resulting in eight semi-structured, qualitative interviews with equal numbers of men and women participating, ranging in age groups from 20-80 years. These users have been named Non-risk users to differentiate from the Risk users later interviewed.

The main findings of these interviews were mapped in a table to gain an overview of the insights. During the interview process I experienced a discrepancy in what users say versus what they actually do. Since all the users used YR, I asked about their trust in the information. Many automatically responded that the forecast is uncertain and not reliable, but when asking if it influences their routines, plans, and other activities, they often realized that even though they know it is an uncertain forecast, they most often read it as or behave as if it is true. Moreover, most users emphasized that long-term forecasts are less certain, and that the current day's forecast was the most accurate. This is not always true, as discussed in Chapter 3.11 with the interviewee from MET.

Furthermore, most of the users fit the category unconcerned, as they mostly checked the weather forecast when planning for cabin trips, choosing clothing for work, or other non-risk activities. The two oldest users did check more often than anticipated, even if they were not planning any risk activities. They highlighted the relevance of checking when driving over mountains in case of closed roads and so forth, but checked YR just as much if they were not traveling. This was due to a general interest in the weather, meaning they also fit within the category "nerds".

While the user group interviewed checked YR on a regular basis, the need for uncertain data was not as present. Most of the users were interested in quick information, meaning they mostly checked the front page of a specific area, and only delved deeper if relevant plans were upcoming. Most of these plans would not have any severe consequences, which made data uncertainty or incorrect weather predictions not something they would search for or need. This is based on their interest and engagement in the subject, as well as how they typically use the application. Specific activities could benefit the users if they knew about the uncertainty, but in their general every-day life, this type of information would not be sought after. Communicating data uncertainty could be relevant when conducting or planning outdoor activities affected by weather. Additionally, it could enhance literacy in weather data interpretation.

Non-risk users

The "nerds" and the unconcerned

	Female, 20-25	Male, 25-35	Male, 25-35	Female, 45-55	Male, 55-65	Female, 55-65	Female, 65-75	Male, 70-80
Weather forecast interests	Interested sometimes, when traveling or similar.	If traveling or other relevant activities	Interested when outdoor events or activities happen	Planning activities; walks, jogging, barbeque, clothing, and so forth	Car related interests, travel and walks	Interested in temperature, and weather related to outdoor sports, activities, and vacation days	Driving through mountains, closed or slippery roads	Preparing for daily tasks. Plan days, trips.
Forecast application used	YR phone application and website	YR phone application and website	YR mostly, Storm periodically	Apple weather application and YR, comparing	YR-appen, smart watch (temperature)	Uses YR mostly	YR, and weather news on TV: NRK and TV2.	TV news, YR, and Storm
How often	Approx. 1 time a week	1 time a week	5 times a week, but depends on weekly activities	From 1-7 times a week, depends on plans	Checks when plans and activities will happen; 4-7 times a week	Checks the forecast every day	About three times a day, dependent on travel	Three times daily.
Functionalities	Table of the day	Checks the table, front page	Tables for specific area, and often details.	Temperature, hour by hour, wind. Uses the table and the front page graph of the YR app	Uses the table, did not understand the functionality of the front page	Uses tables	First looking at table. Uses graph for more specific information. Map through TV. Wind most important.	Uses the first tables.
Trust and reliability	Both yes and no. Believe what is estimated the same day, subconsciously knowing that it is not always correct.	It is not worth checking the forecast if I think it is wrong	"Reliable enough". Packs based on the forecast, but know it cannot be trusted fully. Still no safer source of information. Long-term less certain.	It is OK, but it is not always correct on the cabin being on an island.	High trust in MET.	High trust in YR, but the temperature is not always correct locally	Reliable information. Forecast further ahead of time less certain.	Wind is often not correct. Large variations. Generally most trust in certainty the first day.
Other comments		You cannot put a number on uncertainty without context or comparison. What does "sun with 3% uncertainty mean?"	Wrong information is annoying. "They do not mention the uncertainty in the forecast". You cannot really relate to probability.	YR is less reliable when traveling abroad	Uncertainty most important around 0 degrees, impacts cross-country ski waxing, driving conditions, snow shoveling, and more		"The forecast influences us, as we adjust our activities to the day's prediction".	

Fig 4.2. Table with insights from non-risk interviews mapped in a table. The table is also provided in the appendix.

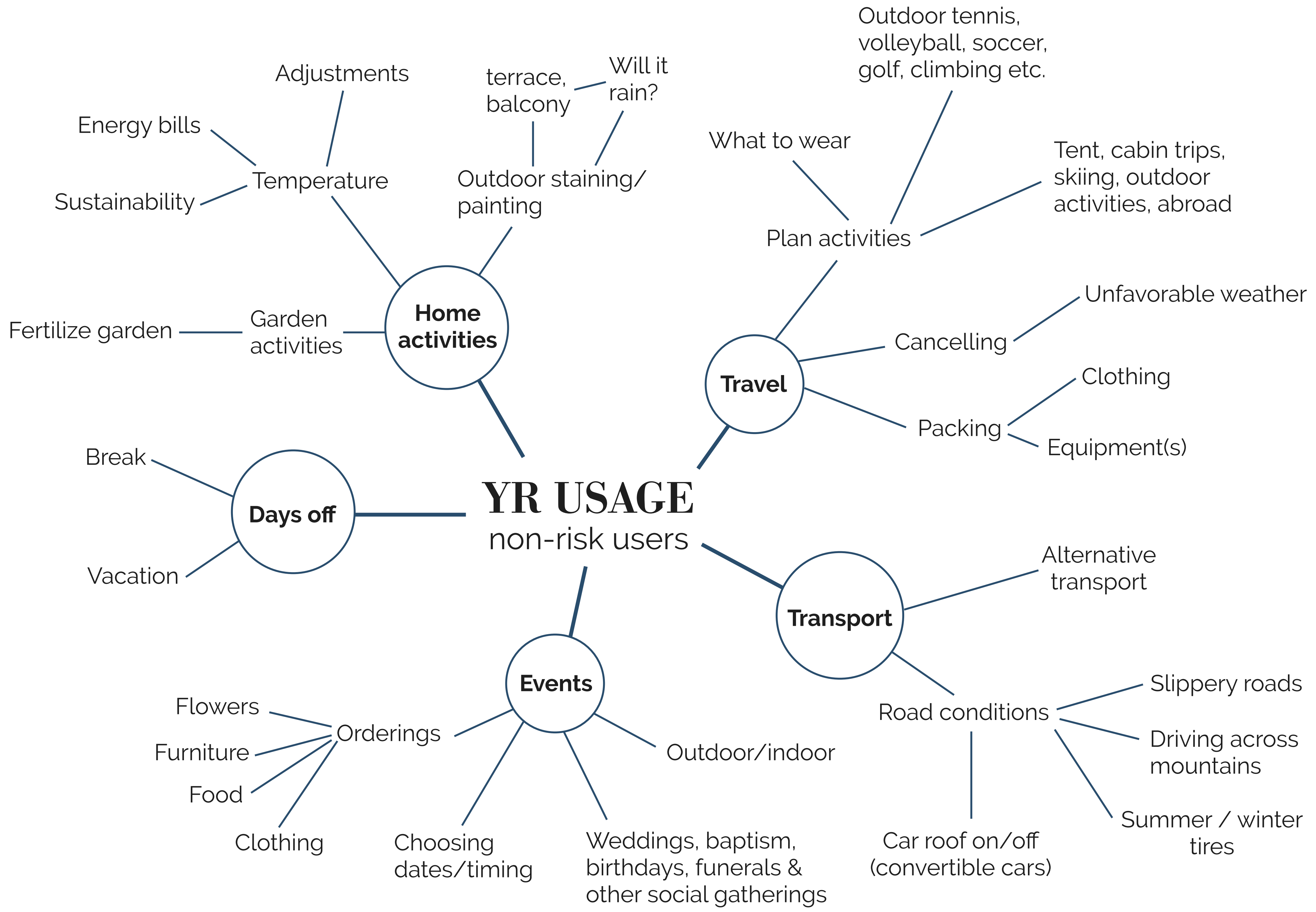


Fig 4.3. Mind map of YR usage by non-risk users.

4.3 YR usage

The non-risk users provided insight on what they use weather forecast services for. Together with their insights, I observed YR's Facebook page to explore if users are sharing insights there as well. Some expressed their annoyance with wrongful predictions, in which some of their plans were ruined due to this. The information gathered from the page was used to map the usage of YR and to explore the main risks and consequences these user groups might face.

The mind map illustrated in Figure 4.3 highlights and emphasizes how YR is primarily used for planning. These plans vary in risk, and the ones with highest risk could involve financial losses, such as outdoor staining ruined due to unpredicted rain, transportation risks such as slippery roads, or larger events like outdoor weddings and birthdays. Users depend on forecasts for planning, and changes to those plans could have negative impacts on the users. Plans that are valuable to the users could lead to an increase in their interest in weather data and uncertainty to ensure that the plans can be adjusted for the best possible outcome.

4.4 Situational awareness

There are several theories on decision making, such as the OODA-loop and Situational Awareness. I have chosen to use the theory of situational awareness (abbreviated to SA) in my project due to its comprehensible nature and how it delves deeper into the cognitive process before acting. In comparison, OODA-loop may be better suited for contexts involving fast and efficient decision-making and situations.

The theory of SA is presented in this chapter due to it being crucial when exploring the risk-users in the following section. SA essentially means having an appropriate understanding of a given situation. In this project, the definition provided by Endsley (1988) will be used:

> "Situational awareness is the perception of the elements in the environment within a volume of time and space, and the comprehension of their meaning and a projection of their status in the near future.
>
> Endsley, 1988

This implies that one must have an understanding of what is happening to make decisions. The first level of SA refers to perception; in the context of weather forecasting, users should be able to perceive the data presented. The next level is comprehension, which entails that users should be able to filter and identify important and relevant information in their situation. Lastly, the highest level of SA is projection, meaning that users can use current events and information to anticipate future changes. This could, for instance, be a surfer observing how the trees are moving to calculate the direction of the wind and its strength, meaning experience can help identify changes and information about current weather. A visual illustration is presented in Figure 4.4.

In worst-case scenarios where users face severe economic implications or even the possibility of loss of life, SA is critical. For example, if an outdoor enthusiast loses their visibility due to a whiteout on top of a mountain, it becomes difficult to determine which direction to go. In winter time, there's a high chance of avalanches in the mountain, and one wrong step could lead to fatal consequences. In this case, their SA is at its lowest level. When uncertainty is presented in a weather forecast, providing additional data could potentially enable users to make their own risk assessments before choosing their next step, or beforehand, decide upon safer situations.

Being aware of SA theory could be helpful when visualizing uncertainty, with the goal of minimizing misunderstanding and interpretations. Such communication should facilitate learning, and allowing users to build upon this theory with knowledge gathered from their own experiences could potentially help with projection. In the interview with NVE from chapter 3.10, the first interviewee mentioned how the information they share should be used to simplify individual reflection in the field. Personal experiences could be helpful to correct and learn about the weather predictions and uncertainty data. A system can only help with suggestions, and in this case, data, meaning that the user needs to make their own choices. Additionally, it is important that the system builds trust so that the user can make their own choices with information they find helpful.

SA is "fresh produce", meaning it decays. Humans always need new information, new data to make informed decisions. In summary, weather data and uncertainty information provide decisional support and have the potential to help build SA for users.

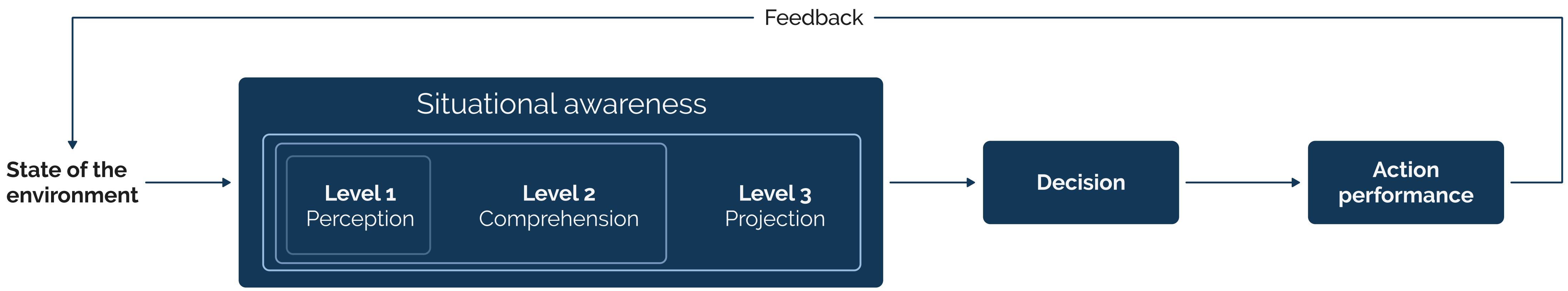


Fig 4.4. The process of situational awareness, based on Endsley's model (Endsley, 2000).

4.5 Risk users

Interviewing risk users

Several risk users participated in interviews, including a professional outdoor photographer, part-time apple farmer, full-time organic vegetable and community-supported farmer, dog-sled professional and outdoor enthusiast, freshwater sport fisher and surfer, and an air ambulance pilot. Ensuring a diverse range of risk users was crucial for obtaining in-depth, qualitative insights into activity-specific needs.

The semi-structured interviews involved participants discussing their use and experiences with weather forecasting systems, how these systems affect their activities, weather risks, and more. Most conversations incorporated observations of the participants' interaction with the platform, mainly YR, aiming to gain a deeper understanding of how each individual utilized the application.

The findings and insights provided are presented on the following page, in Figure 4.5.

DISCUSSION OF FINDINGS

The interest in YR and need for information regarding uncertainty seem to increase as the weather risk associated with the users' activities grow. These risks include mostly financial losses for professionals and both financial losses and life risk for enthusiasts. It is evident that specific professions and activities often depend on weather forecast services for planning. While non-risk users also utilize YR for planning, financial losses and life risks are generally limited to situations such as outdoor staining being ruined due to rain or slippery roads in winter. These are, of course, important for each individual, but these instances are not typically every-day challenges for most people.

Gaining insights into how YR is used for planning provided valuable understanding about why and how data uncertainty could be beneficial. The organic farmer, for instance, could potentially make more strategic choices based on this information, such as when to plant specific crops to optimize their chances of survival and reduce strain and physical load in cases of strong sun or extreme wind. Being aware of the reliability of the presented data could enhance their situational awareness, particularly in relation to prioritization of tasks. Furthermore, as the farm is community-supported, planning for volunteer work involves other people with their own plans and schedules. Inviting as early as possible was mentioned as crucial to ensure higher participation, but it also increases the risk of cancellations in case of unfavorable weather conditions. Having the opportunity to view long-term forecasts and the degree of certainty could lead to better planning and risk evaluation.

The outdoor photographer could schedule filming sessions on days or hours when the weather is more certain, minimizing the risk of wasted time, such as lost filming days. This is only relevant in cases where filming days can be chosen, when not related to a specific time of event. The fishing and surfing enthusiast mentioned the disappointment of planning a surfing trip, only to find that there is not enough wind for surfing, resulting in hours lost. This might not be a life-risk issue or a significant financial loss, but it could be avoided if the wind was forecasted as highly uncertain.

Another example is how unpredictable wind caused material damage and financial losses for the fishing enthusiast due to the chosen boat not being fit for purpose. Unforeseen and uncommunicated fog has also caused the participant to drive on land, as it decreases long-distance vision. The dog sledder also experienced vision loss due to whiteouts in the mountains. Both these weather conditions result in a loss of situational awareness, meaning they might need to act without any perception of surrounding elements in the environment, which could be dangerous or even life-threatening. This would impact their decision-making process, leading to less sufficient and effective actions.

YR does communicate uncertainties today, which is analyzed in the next chapter. One might expect these expert users, who admit to using YR every day and several times a day for planning, to be aware of these uncertainty visualizations, but most were not. They are most often presented in graphs, which, surprisingly, almost all of the expert users did not use. The one user who admitted to using graphs did not understand what maximum precipitation meant when asked. Most users expressed that these graphs might be less accessible, believing they require prior knowledge, effort, or are similar to other visualizations they dislike, such as Excel sheets or ones seen in math. While it cannot be concluded that expert users do not use these graphs, the qualitative research indicates a need to provide alternative visualizations.

Risk users

Enthusiasts & professionals

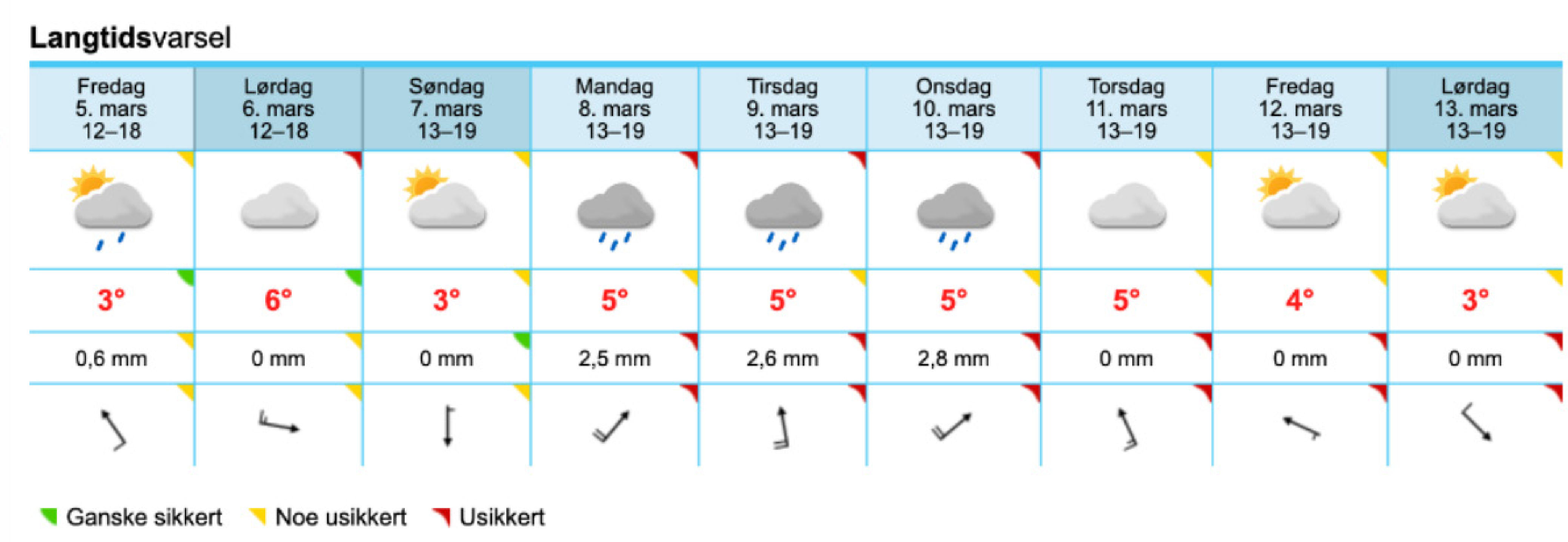
	Outdoor photographer	Apple & bee farmer (Part-time)	Organic farmer (Full-time)	Dogsled guide & outdoor enthusiast		Freshwater sport fishing & surfer enthusiast		Air ambulance pilot
Activities/ doing	Outdoor filming, use of drone, filming from helicopter, assignments from all over Norway	Travel to farm over mountain, apple juice production, maintenance, beekeeping, apple picking, pressing, scything, cleaning, and more. Sogn fjord, Vestland county, Norway	Watering, plant handling, planting, harvesting, temperature regulation in greenhouse, spoil work, weeding, sales, plant care, and more. Eastern Norway, Viken.	*Dog sled* Guiding tourists, feeding, preparing sleds & dogs, dog care, sled allocation, instructor, cleaning, organizing, equipment fix, and more. North of Norway, Tromsø	*Outdoor activities* Mountain hikes, skiing, cross-country skiing, climbing, paddling, and more. North of Norway, Tromsø.	Fishing in all seasons, planning trips, preparing boat(s), equipment, packing, and more. Eastern Norway, Innlandet, and Viken.		Flying helicopter, monitoring weather, logistics with planned patient transport, evaluation of mission and flying options, arranging alternative transport, calling flight meteorologists for second-options, and more.
Ideal conditions/ weather dependency	No large weather variations: stable, bright light. No precipitation.	Min. 19°c for a week (for bees mating) and no rain. Dry weather for scything, not too much snow due to deer activity, dry when climbing waterfall etc.	No extreme weather, a bit cloudy, light rain, partly sun, not too warm, no frost or heavy downpour after sowing etc.	Not too windy. No ice or plus degrees: stable weather. Much snow but no heavy precipitations.	Stable temperature, little wind, not too wet, dry when climbing. No heavy snowing or fog/white-out.	*Fishing* A little bit of clouds and sun. Comfortable temperature. High air pressure over time. Stable weather.	*Surfer* Minimum of 8 wind(gust) m/s, Even and heavy wind from "right" direction	Good sight, little wind, no turbulence or icing. Light, no mountain waves or rain showers. No whiteouts. Stable weather with little insecurities.
Risk & consequences	Cancel shootings, delays, loss of filming days, not being able to work	Water pipe clogged, loss of income, apple trees, and investments. Low pollination, taste/ crystallization in apples ++	Reduced crops, shorter growth season, economic losses, soil erosion, pests, not enough place if new plants arrive at bad timing	Cancellations, having to close; Loss of money. Heavy work with extreme wind or snow, injuries, avalanches.	Loss of grip, avalanches, "white out": loss of sight situational awareness when being on mountains	Heavy downpour, lighting, extreme wind, and fog: driven on land, loss of sight, financial losses, material damage. Unsafe ice.	Time waste, lighting, heavy downpour, loosing equipment, material damage	Postpone scheduled missions, delays, cancelling mission (plan alternative transports). Cooled/freezing rain accumulates on rotor blades, disrupting aerodynamics. Improvising - change in weather may force us to turn or find a safe place to land
System's influence	YR. Planning of filming days (if possible), packing of equipment and clothing.	YR. Planning, prioritizing work, situational awareness, travel days to the farm, and more.	Use of YR all seasons, every day; planning, prioritizing work, off-days, risk evaluation, community involvement	YR. When to open/close, planning, packing, choosing routes, cleaning or secure equipment in dog yard, mental preparation, risk evaluation, timing.	YR. Travel or not, choosing mountains to go to, timing, planning trips ahead, clothing, risk evaluation.	YR. Planning days off, scheduling, planning, choosing between hobbies. Choose right equipment, e.g. boat type		HemsWX system. Improves and support decision making. Efficient access to live data in risk-places. Provides weather overview, fast planning: Time-critical assignments. Situational awareness. Risk and safety evaluation. Uses YR for every-day weather.
System functions & uncertainties	YR. Graphs: too many numbers, not accessible. Too much time to read and understand. Uses tables.	YR. Little trust after 4 days. No alternative outcomes or trends are presented in long-term. Little to no use of graphs: requires effort.	YR. Not aware of today's uncertainty visualizations. Uses tables, not graphs as she believes it requires pre-knowledge	YR. Uses map and mostly table. High trust in YR. Uses graph a few times for overview, but unsure of max precipitation meaning		YR. History function for comparison and understand trend, e.g. ice layer in winter. Snow depth, precipitation, mainly table. Does not use graph - "does not like the feeling of excel sheets"		HemsWX: Checking if risk weather is temporary. Checking live weather images, humidity, cloud coverage, ice, wind, and more.
Highlights	• Activities are weather and time critical • Experiences graphs as not accessible	• Different factors dependent on different weather • Trust varies on long time predictions	• Believes graphs requires pre-knowledge • Long term certainty would be beneficial	• Financial and health/life risks: much responsibility • YR importance to evaluate risk • Uses graph but did not understand/use the uncertainty element		• Yr important for safety and risk • Surfing requires specific weather • Want to filter important information, uses specific functionalities that are not placed together		• Uses weather application designed specifically to pilot's needs: HemsWX. A revolution. • Live cameras all over Norway together with METs weather data. Monitoring weather on duty continuously. • High trust in their tools.

Fig 4.5. Table with insights from risk-users interviews mapped in a table. The table is also provided in the appendix.

4.6 Previous solution

YR previously offered a solution for visualizing uncertainty in their long-term predictions. The uncertainty was visualized as a marker with slightly different shapes and three colors: green, yellow, and red. These markers may clutter the total visualization when displayed for every weather element. The intention behind using different shapes might have been to follow universal design principles. However, it is debatable how effective these small variations are. Additionally, yellow on white does not satisfy the universal design principles of contrast, and several people with color blindness struggle with separating red from green, as mentioned in Chapter 2.2 under "Universal design".

The use of traffic light colors is widely used to present risk levels worldwide, which could lead to a more consistent understanding of the visualization across social groups. YR does no longer offer this visualization, and there is no new, alternative solution to present uncertainty on this level either.



Langtidsvarsel

Fredag 5. mars 12–18	Lørdag 6. mars 12–18	Søndag 7. mars 13–19	Mandag 8. mars 13–19	Tirsdag 9. mars 13–19	Onsdag 10. mars 13–19	Torsdag 11. mars 13–19	Fredag 12. mars 13–19	Lørdag 13. mars 13–19
3°	6°	3°	5°	5°	5°	5°	4°	3°
0,6 mm	0 mm	0 mm	2,5 mm	2,6 mm	2,8 mm	0 mm	0 mm	0 mm

Ganske sikkert Noe usikkert Usikkert

Fig 4.6 Image received from YR showing previous solution of illustrating uncertainty (Personal communication, January 20th 2023).

4.7 YR analysis

Analysis of YR's website to understand current solutions

YR communicates through several platforms, such as their website, phone application, Twitter, and more. YR's website was chosen for analysis to narrow down to a primary area of focus, as their second main platform, the phone application, largely relies on the same visualizations.

The analysis of their communication is conducted from a design perspective, supplemented with additional and previous literature, and informed by insights gathered from conversations with users during interviews. The main focus of the analysis will be on uncertainty elements and how they are presented in their given context. Other elements or interactions irrelevant to the research task will not be discussed.

The NUREG-0700 guidelines, developed by the U.S Nuclear Regulatory Commission (NRC), are used to review human-system interface designs in nuclear power plants. These guidelines will be used as additional theory to which the analysis will refer. While YR differs from the field NRC has researched, their goal of ensuring reliable and efficient interaction between humans and the systems has resulted in recommendations on design, layout, functionality, and other user interfaces relevant to this project. These findings are also useful for other fields, as they are based on human cognition and how to ensure efficient communication (O'Hara & Fleger, 2020).

The analysis will further refer to levels of information. These levels correspond to the layers of interactions users must navigate to access specific information. For instance, the first layer is the front page. Clicking on buttons for additional visualizations and details leads to new depths of information, representing new levels.

Finally, a reflection of the analysis with references to relevant literature and interview insights will be presented to explain the rationale behind specific comments given in the analysis.

1 The snow warning indicates a moderate danger of snowfall. The association to danger and warning implies a sense of uncertainty.

Fig 4.7 Screenshot of yr.no frontpage, retrieved March 10th 2023: https://www.yr.no/en

2 The clouds have different color shades. Drawing from real-life experiences, the darker shades suggest a higher degree of certain precipitation.

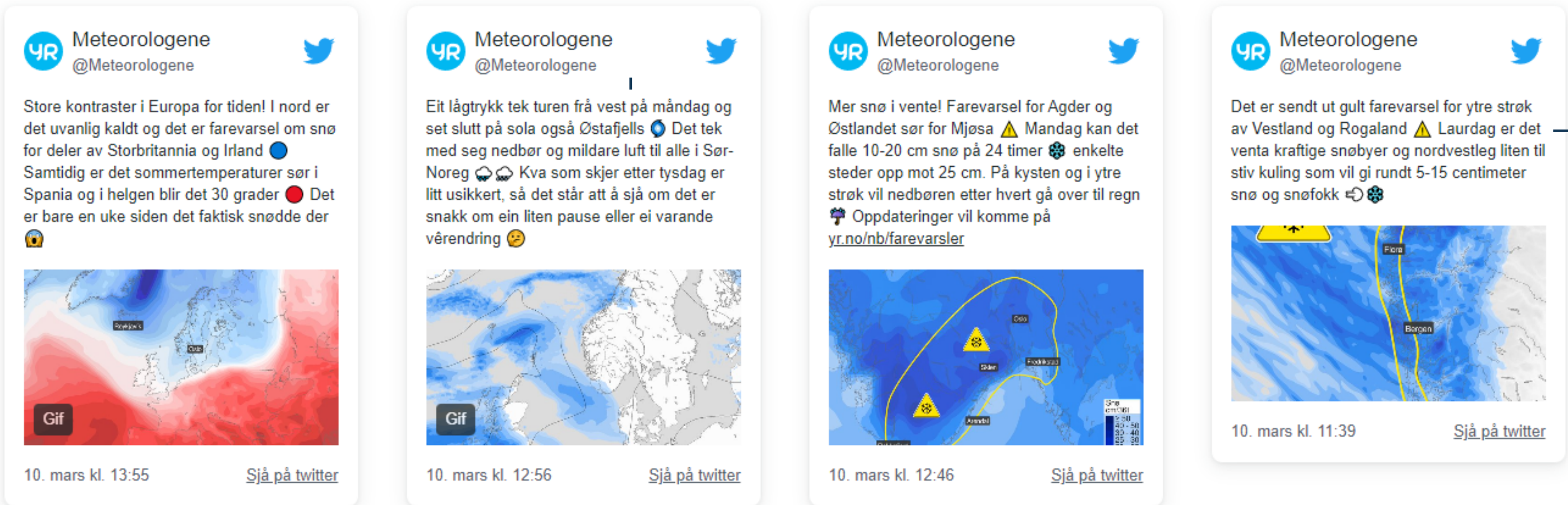


Fig 4.8 Screenshot of yr.no frontpage, retrieved March 10th 2023: https://www.yr.no/

3 When Norwegian language is selected, the latest tweets are showcased, providing textual context to forecasts with the use of language expressing uncertainty in some parts.

However, these snapshots of Twitter messages are located further down on the site and are visualized with a combination of text, graphical maps or images, icons, and links. This could potentially increase visual clutter, making it difficult for the audience to find and utilize the information.

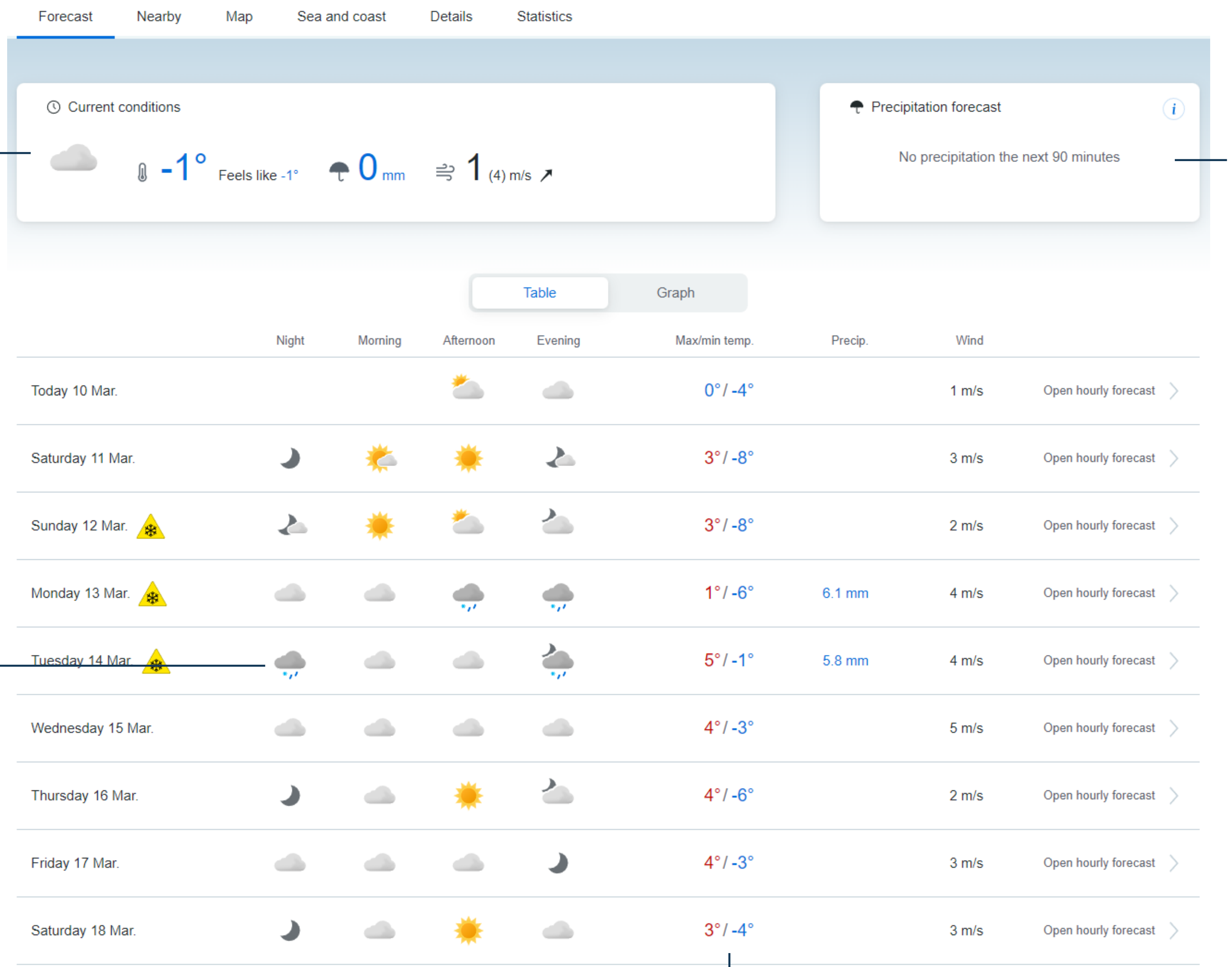
OSLO AREA — 2ND LEVEL

1 This menu bar allows users to delve deeper into the data. The menu is not visible from the front page and becomes accessible at the 2nd level of information.

2 Current conditions combined with users' mental models of certainty and time, gives this section a high sense of reliability.

However, displaying this section alongside the table below may add cognitive load, causing some users to overlook this part. This concern was reinforced during a user interview when the user expressed wanting to see current conditions, not realizing it was displayed right in front of them. Current conditions do not display uncertainties.

3 The language conveys certainty.



4 Snow and rain represent uncertainty, or they can illustrate the weather phenomenon known as "sleet."

Fig 4.9 Screenshot from YR retrieved March 10th 2023: https://www.yr.no/en/forecast/daily-table/1-72837/Norway/Oslo/Oslo/Oslo

5 Minimum and maximum temperatures communicate a degree of uncertainty through the range.

1 Reading from left to right, precipitation starting at -8 on the y-axis, could cause confusion.

2 Uncertainty presented in the shaded area, which is also communicated in the pop-up through hover. The solid colored part of the graph represents certain information.

3 Three graphs are combined into one visualization: wind, temperature, and precipitation. Incorporating these elements alongside icons and other visual elements can be overwhelming for the viewer, resulting in cognitive load. This could cause users to spend more time analyzing the information rather than comprehending it efficiently.

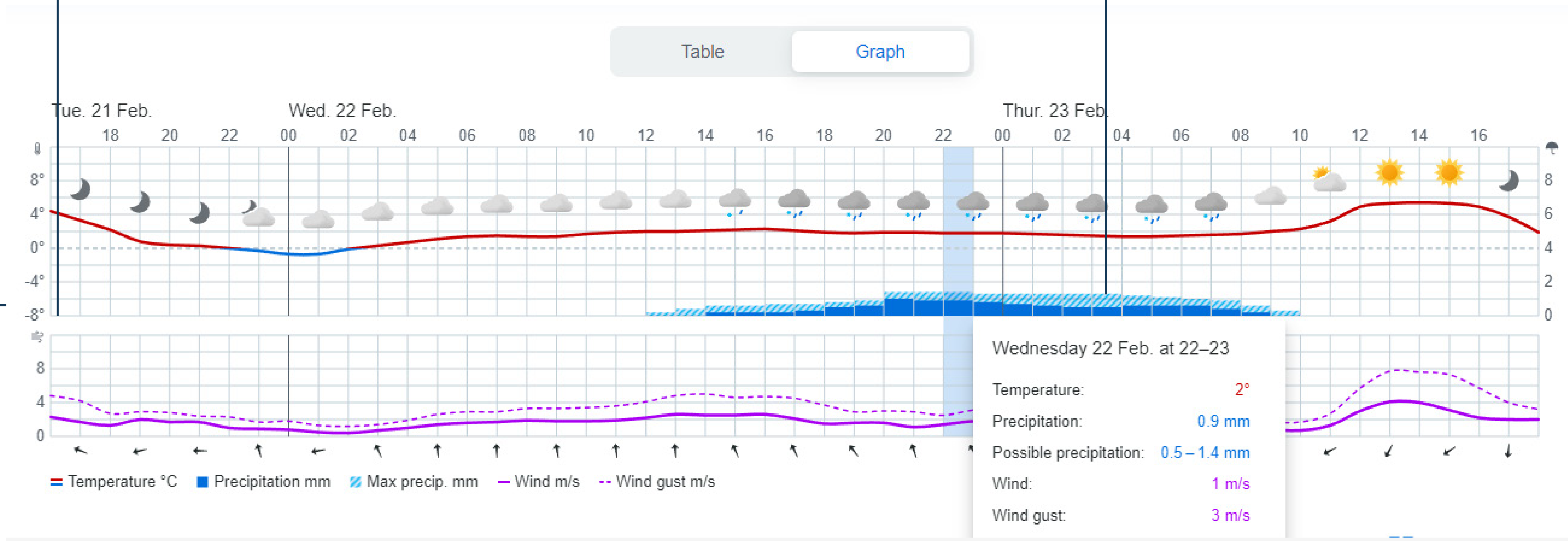


Fig 4.10 Screenshot from YR retrieved February 21th 2023: https://www.yr.no/en/forecast/graph/1-72837/Norway/Oslo/Oslo/Oslo

2 Using mathematical symbols and probability to present uncertainty could make it difficult for users who lack an intuitive understanding of the topic.

3 The "more/less than"-operator is the only specific element displaying uncertainty in the details table section.

1 Presenting a "feels like" temperature alongside the actual might help the audience better understand the variability of weather conditions, increasing both learning and situational awareness.

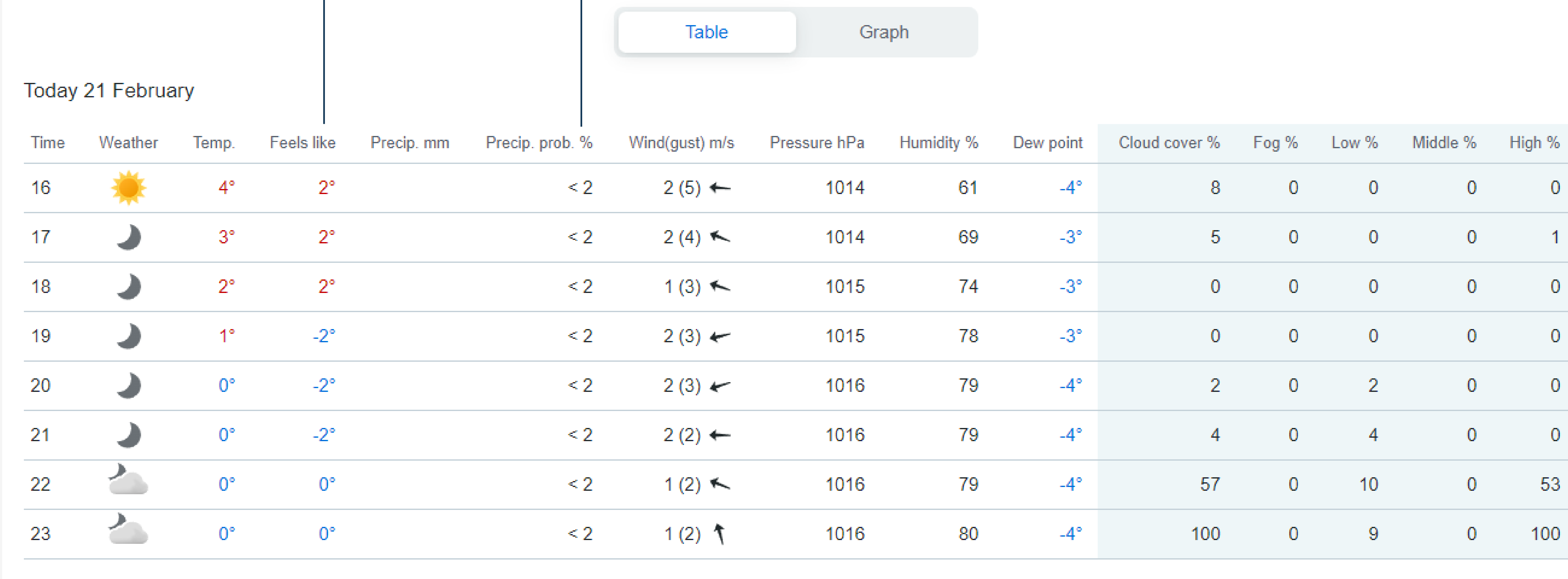


Table | Graph

Today 21 February

Time	Weather	Temp.	Feels like	Precip. mm	Precip. prob. %	Wind(gust) m/s	Pressure hPa	Humidity %	Dew point	Cloud cover %	Fog %	Low %	Middle %	High %
16		4°	2°		< 2	2 (5)	1014	61	-4°	8	0	0	0	0
17		3°	2°		< 2	2 (4)	1014	69	-3°	5	0	0	0	1
18		2°	2°		< 2	1 (3)	1015	74	-3°	0	0	0	0	0
19		1°	-2°		< 2	2 (3)	1015	78	-3°	0	0	0	0	0
20		0°	-2°		< 2	2 (3)	1016	79	-4°	2	0	2	0	0
21		0°	-2°		< 2	2 (2)	1016	79	-4°	4	0	4	0	0
22		0°	0°		< 2	1 (2)	1016	79	-4°	57	0	10	0	53
23		0°	0°		< 2	1 (2)	1016	80	-4°	100	0	9	0	100

Fig 4.11 Screenshot from YR, retrieved February 21th 2023: https://www.yr.no/en/forecast/graph/1-72837/Norway/Oslo/Oslo/Oslo

1 Same shaded pattern as those displaying uncertainty, but it is not representing uncertainty.

2 Visualizations of the possibility of temperature variations. The solid line presents itself as the most certain temperature.

3 Probability is difficult to comprehend and may be interpreted differently, as explained in chapter 3.8. The meaning is not clear without prior competence.

4 The visualization provides a number for the maximum precipitation. It only shows the uncertainty above minimum, not on both sides as temperature and wind do. The visualization differs from the rest, creating inconsistency.

5 Wind uncertainty. The probability explanation below is not clear here either.

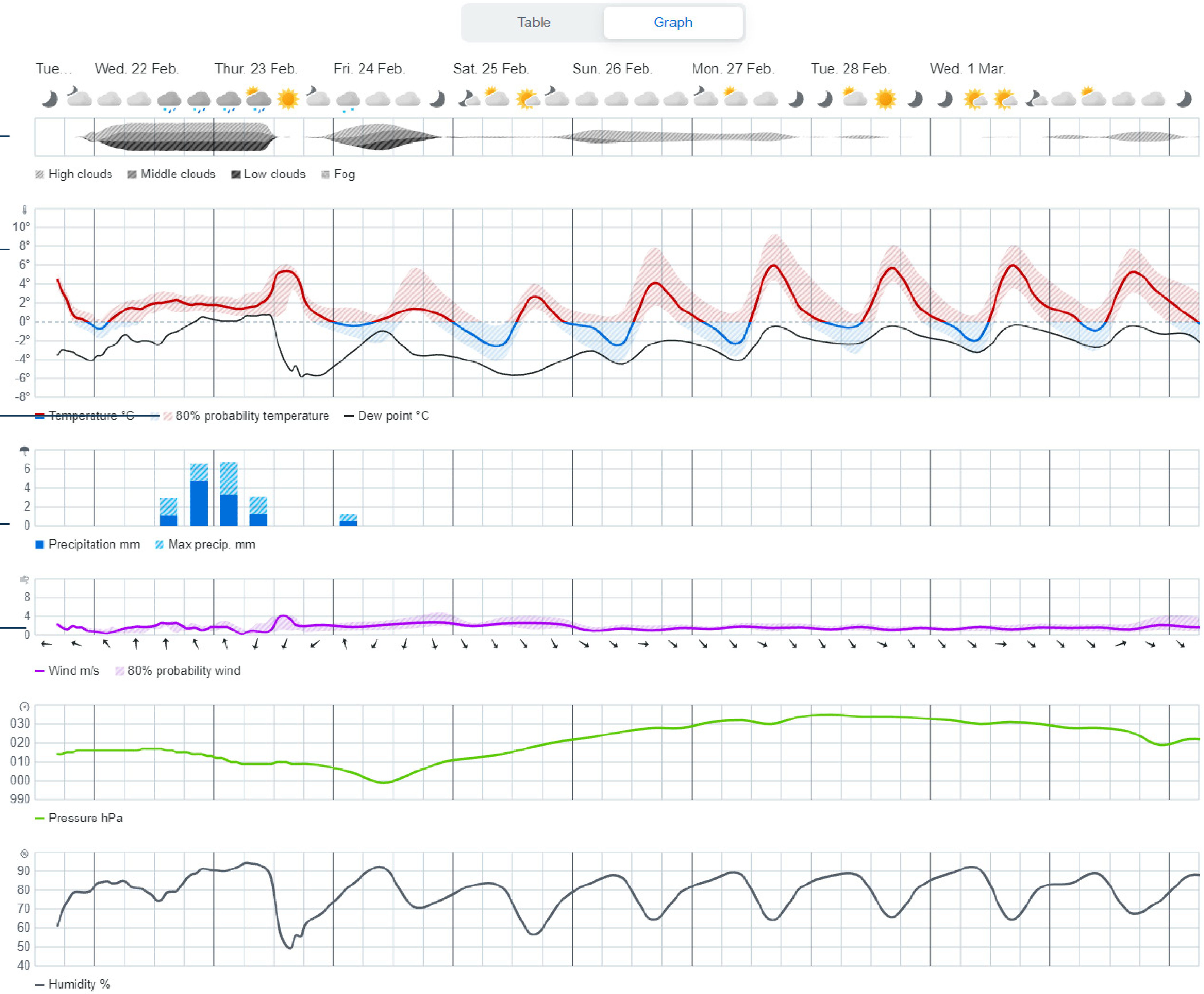


Fig 4.12 Screenshot from YR, retrieved February 21th 2023: https://www.yr.no/en/forecast/graph/1-72837/Norway/Oslo/Oslo/Oslo

4.8 Analysis reflection

In my analysis of YR's visualizations of uncertainty on their website, I focused on critical thinking and leveraged my prior knowledge with additional literature to assess its efficiency.

Several of my comments addressed the challenge of visual clutter, particularly in the third-level graph. Reducing clutter could improve communication and reduce users' cognitive load. Chapter 2 mentioned that focusing the user's attention can reduce clutter, and the first graph analyzed lacked a clear focus point, leading users to spend more time interpreting the visualization. Consequently, the system becomes less intuitive and efficient, activating the users' System 2 processing, as described in Chapter 2.2, under "Clutter and order", or causing them to avoid all visualizations.

This was expressed by several risk-users during the interviews as well. The fourth-level visualization of graphs separated each weather element, offering a step-by-step reading approach, but none of the solutions provide users with a way to filter irrelevant information, a function emphasized in Chapter 2.2, under "Communicating data". Additionally, the head of design at the Scandinavian Design Group discussed the importance of white space and how even one pixel might increase clutter.

The NUREG-0700 guidelines emphasize the value of simplicity, expressing the need to tailor information to users' needs, ensuring the data provided is immediately usable for their tasks (O'Hara & Fleger, 2020). This might be a challenge on YR, as their public website attempts to cater everyone. The air ambulance pilot from the risk-interviews used a tailored weather forecasting system, which has been successful for efficient decision-making, emphasizing the value of customized systems.

YR's weather visualization on the front page does not express uncertainty, which could affect users' actions since the information presents itself as certain. Uncertainty is not explicitly presented in the second level either. It can be easily assumed that expert users may be able to locate and search for this information. However, several risk-users revealed through observations that most of them use only the first few levels of information, and some even miss details like precipitation probability. Multimodal weather reports enable users to use parts that fit their situations, but it is important to avoid information overload (Sivle, 2016). Allowing users to choose what information to focus on can both be an advantage and disadvantage, as they may unintentionally overlook valuable information.

YR's front page offers simple communication but lacks the same simplicity in conveying uncertainty. Users are not provided a clear path to data uncertainty, potentially causing them to overlook or not search for it. The menu with options for history, details, maps, and more does not have an option for uncertainty. Their graphs communicate uncertainty the most, but some aspects such as probability, lack of information, and unclear interpretation weakens its effectiveness.

In conclusion, YR's website has the potential to improve the effectiveness and accessibility of their data uncertainty. The ability for users to customize and filter information should be explored, in addition to making data uncertainty more accessible and simple to use. The uncertain data should be presented at various levels of detailing and difficulty, enabling users to find visualizations that suit their needs for intuitiveness and information. Additionally, the system should give an indication of uncertainty at a higher level of interaction, preferably on the front page, to give users the chance to explore this information.

Ideation

Concept development and testing

5.

5.1 Concept development strategy

The strategy aims to create a step-by-step guide for concept development, influenced by the three C's from Chapter 2.2, under "Communicating data", as well as exploratory and explanatory analysis. Developing a customized strategy was necessary for leveraging knowledge derived from the previous chapters and handling the complexity of the task, hopefully enabling strategic design solutions and an efficient, quality process.

CONTENT

1 Concept scope involves defining limitations that affect the concept process.

2 Goals & strategy aims to establish clear goals and a strategy for achievement through methods and tools.

3 Principles refers to values and essential insights gained from research and theoretical work, to guide decisions and ensure focus on what matters.

CONTEXT

4 Requirements involve identifying key qualities the solution should meet.

5 Main functions determine the functions, data, and information the solution should have.

6 Focus area aims to select specific elements or aspects to focus on.

DESIGN

7 Inspiration means using methods and examining current solutions to draw inspiration for the concept.

8 Brainstorming involves collaborative workshops to generate ideas and concepts.

9 Iterative sketching is a step that turns the ideas and concepts into sketches.

These three design steps are interconnected, not necessarily separated activities.

REFINE

This category focuses on selection and choosing relevant sketches for detailing. A smaller number of concepts should be selected for prototyping, preparing for the next category.

FEEDBACK

Feedback centers on sharing prototypes with participants for testing and receiving reviews and critiques.

Design, Refine, and Feedback are all actions that can be conducted in a loop. Feedback provides new insights to use in Design to explore new ideas, or back to Refine for adjusting prototypes. These three categories can continue as long as time and user feedback permit, forming feedback loops.

From this, the final refined concept can be presented as part of the delivery.

Concept development strategy

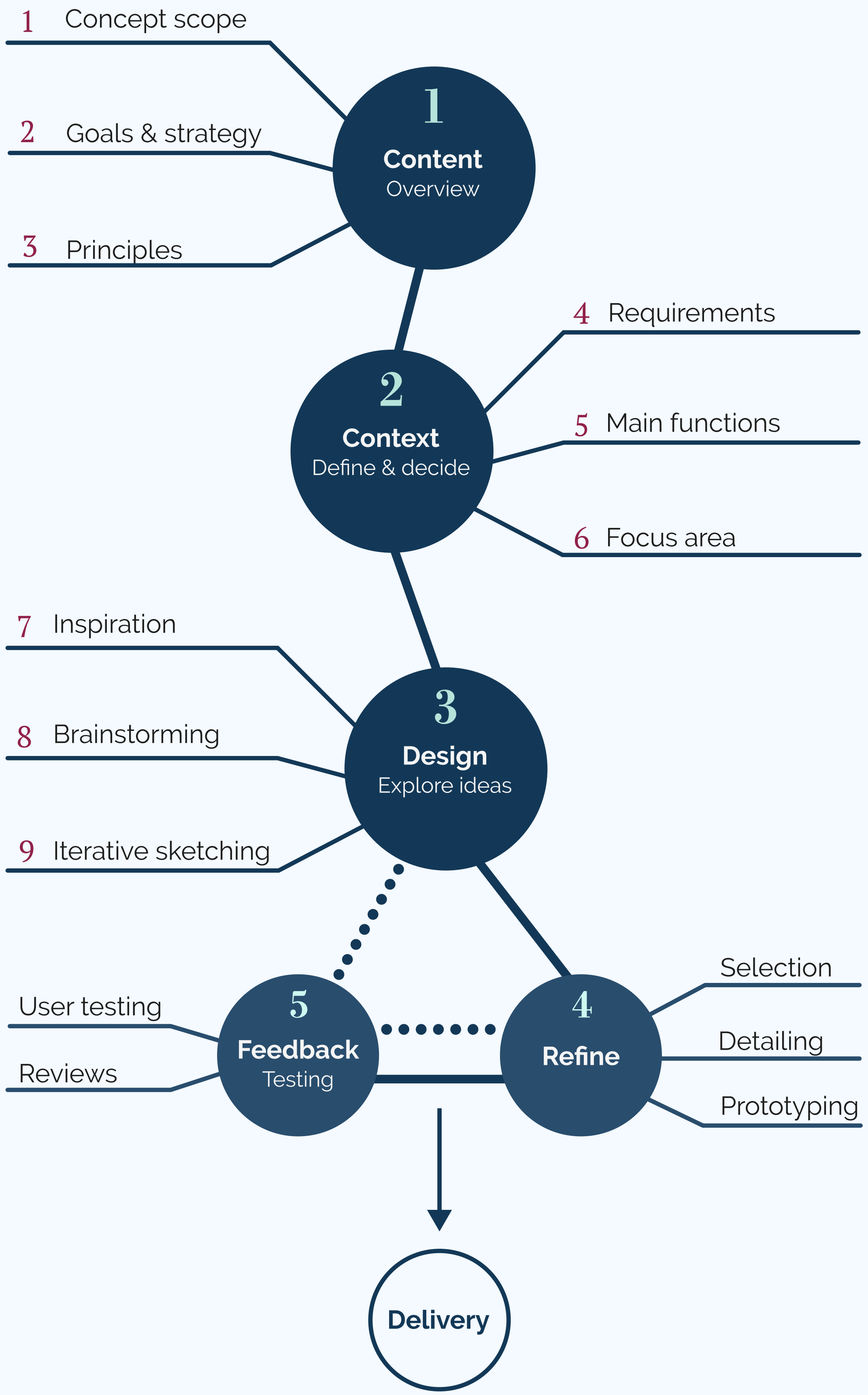


Fig 5.1 Concept development strategy

5.2 Content

A holistic overview of the concept

CONCEPT SCOPE

Careful planning and structure have been important for the process. This includes planning in relation to time allocation, and structure where goals and workflow strategy are defined. Additionally, it is important to elaborate on the research task defined in Chapter 3.4 in relevance to YRs connection to the task.

As defined in Chapter 3.4, YR will be used to provide context. The concept does not need to fit with YR's current solution, but leaves room for increased creativity and freedom to think outside the scope without existing limitations. However, context entails that some concepts will use elements from YR, such as weather symbols, to provide meaning to users when for example user testing. The full reference can be found in Chapter 8.

GOALS & STRATEGY

The process and concept goals have been defined, serving as guidelines for the project to maintain focus and ensure that the concepts align with the overall purpose.

- Involvement of both risk and non-risk users in the feedback process for diverse perspectives
- Use of design methods to stimulate creative thinking, ensuring a collection of ideas for a better foundation to find "the pearls"
- Balance aesthetics and accessibility to enhance user experience
- Effective utilization of research findings and insights to ensure well-argued decisions

To achieve these goals, the strategy involves utilizing various design methods and tools. Several methods have been identified for potential use, shown in Figure 5.2. The first two are intended to boost inspiration, while the next three focus on concept ideation. User testing serves as a helpful method before detailing.

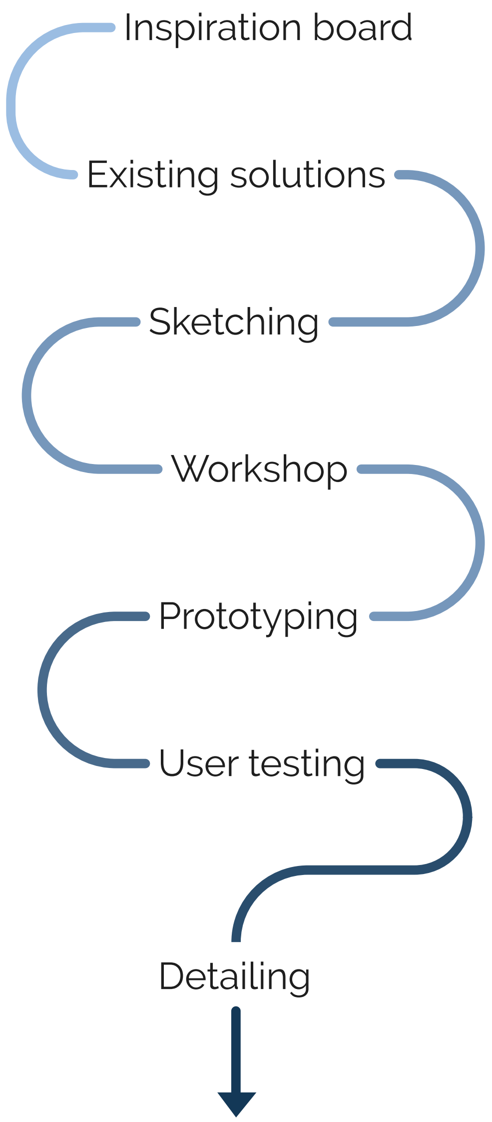


Fig 5.2 Illustration of methods

PRINCIPLES

The principles have been established to guide decision-making, creating consistency, and serve as a reminder of important insights gained, so that they are considered when designing concepts.

Clarity

Elimination of clutter, providing a clean solution with clear information.

Aesthetics

Incorporation of aesthetic principles, considering space, alignment, composition, and more.

Detail levels

Varied information levels to accommodate diverse users and prevent over-simplification.

Intuitiveness

Avoidance of unintuitive visualizations, ensuring solutions that are easy to comprehend.

Comparison

Emphasis on the principle of comparison, helping users to put data into context.

5.3 Context

Defining task decisions

REQUIREMENTS

A set of requirements have been established, which distinguish from guidelines as set rules.

Accessibility

Universal design principles must be considered, ensuring data visualizations are inclusive and accessible to users with varying abilities and needs.

Education

The solution must facilitate self-education and learning, to increase data literacy.

Language

Plain language shall be a key prioritization, to minimize language-based uncertainty.

MAIN FUNCTIONS

The main functions for the concept development are based on insights gathered throughout the project. Mapping these functionalities is to ensure the needs of users are met.

Uncertainty indicator

A simple indicator on the first level of interaction showing uncertainty to facilitate user awareness.

Degree of uncertainty

Communicating the degree of uncertainty in addition to uncertainty.

Filter option

Filter option enabling users to reduce clutter by removing irrelevant information.

FOCUS AREA

To streamline the concept development process and ensure efficient use of time for accomplishing the set goals, requirements, and functions, several focus points have been established.

Three weather elements will be the focus point of my exploration:

Precipitation Wind Temperature

Dew point, wind direction, and gust are not included in the exploration.

The concept will focus on feedback from the risk-users, as they stand to benefit the most from data uncertainty and can refer to real life objectives.

Concepts that help users achieve better situational awareness and planning will be prioritized, with the aim of narrowing the gap between data, information, and decision-making.

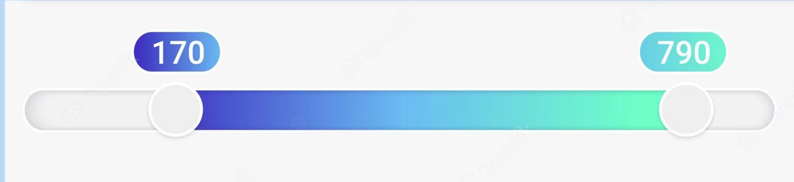
A final research question has evolved to:

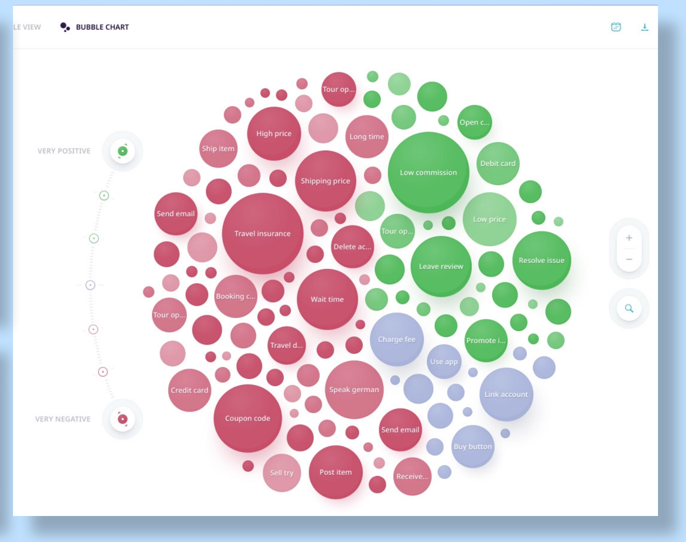
> "How can data uncertainty in temperature, wind, and precipitation within weather forecasts be effectively visualized to enhance user experience and comprehension?

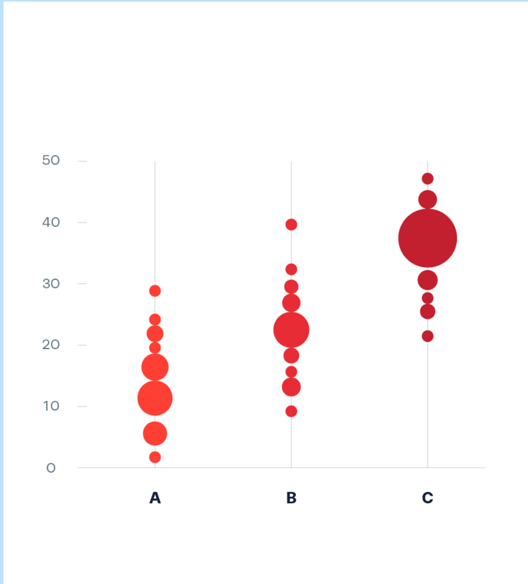
5.4 Inspiration board

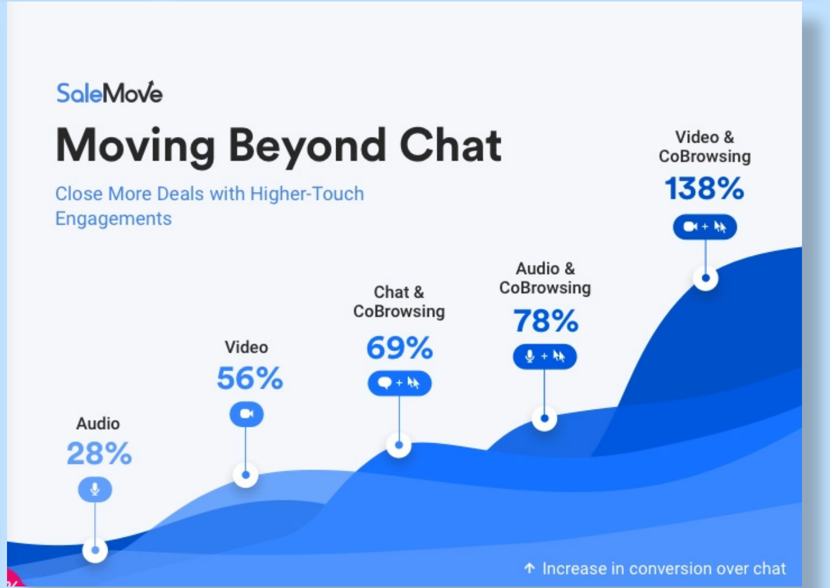
Idea generation

An inspiration board has been employed as a tool to identify examples that generate ideas for concept development. Each image contains elements that have inspired an idea. The board has been named “inspirational board”, as it differs from mood board since the board is not related to a specific mood or emotion. The board has proven helpful in expanding the creative vision for the concepts.









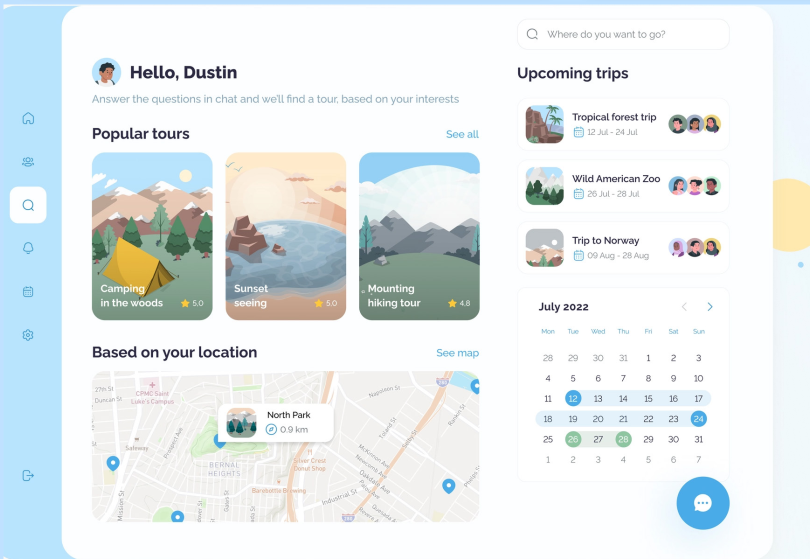


Figure 5.3-5.11: (Foxelle, N.D), (Datavizproject, N.D), (Gregory Muryn-Mukha, N.D), (Brenna Mickey, N.D). (andrey40, N.D), (Wowly Infographics, N.D), (Stanislav Lebedev, N.D), (Sadhin Saleem, N.D), (Glia, N.D).

5.5 Existing solutions

Enhancing inspiration

Examining existing solutions offered by actors within the fields of design and dataviz was crucial for the inspirational aspect of my concept development strategy. This approach not only contributed to inspiration but also revealed tested strategies that may have a well-thought reasoning behind them. However, it is essential to recognize that the visualizations presented were designed for their specific contexts, and these visualizations might not be easily transferable to the context of this master's project. For this process, I will not focus on analyzing the solutions from different fields; instead, I will concentrate on the strengths each solution possesses that could potentially be explored when generating concepts.

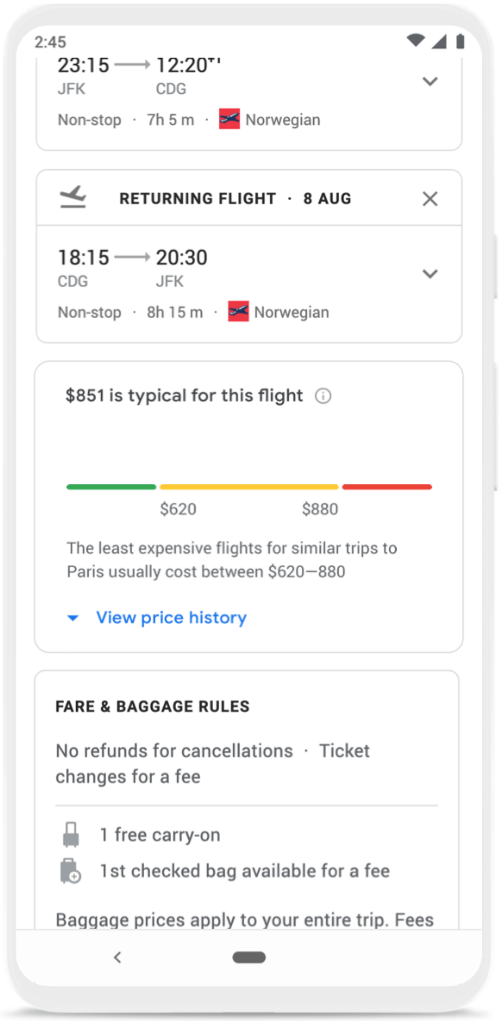


Figure 5.12. *Want the best prices for your trip? Google can help*, 2019, by R. Holden. https://blog.google/products/travel/best-prices-for-your-trips/

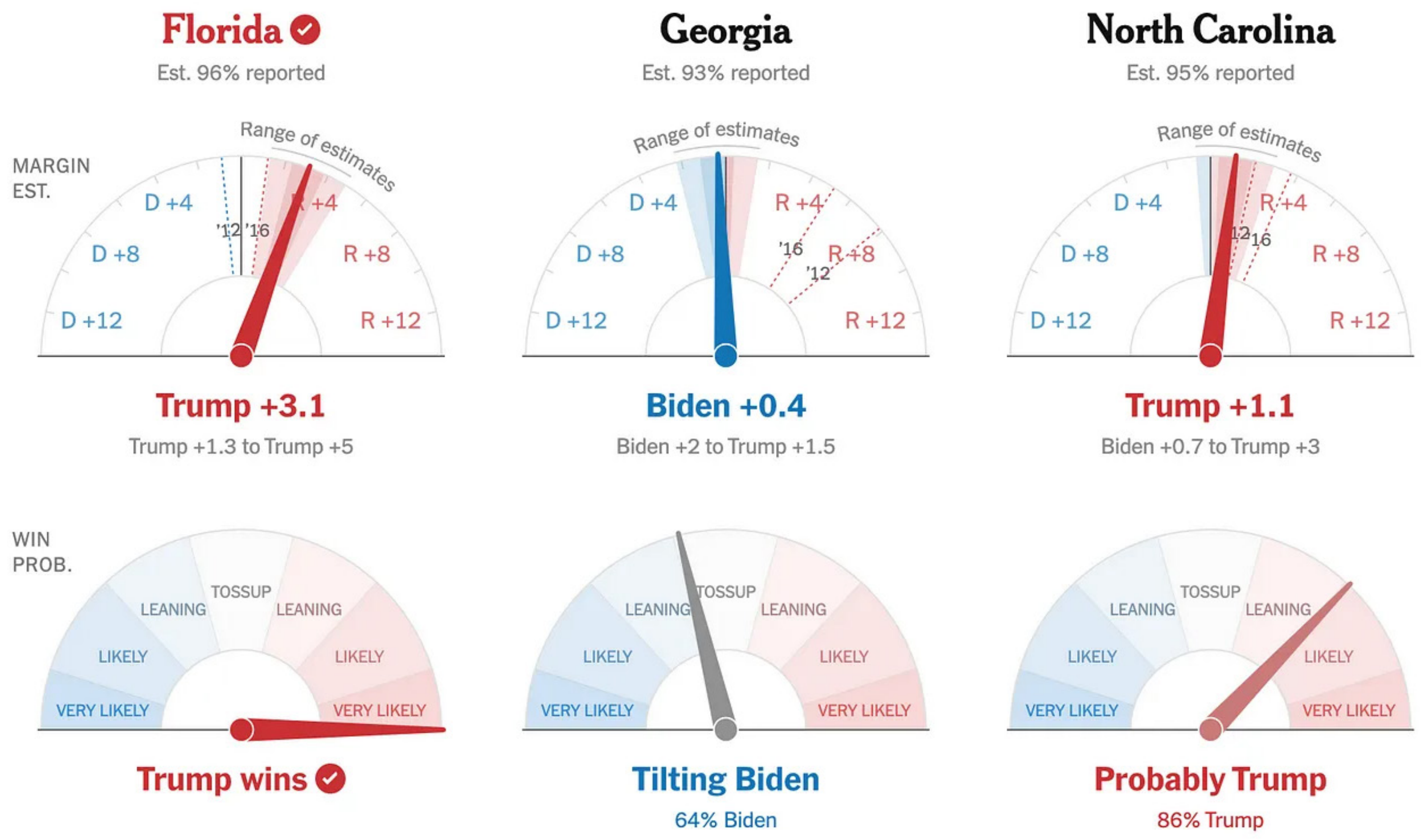


Figure 5.13. *Election Needles: President*, 2020, by The New York Times. https://www.nytimes.com/interactive/2020/11/03/us/elections/forecast-president.html.

GOOGLE TRAVEL

The strength of using a gradient bar for price fluctuations lies in its intuitiveness, where the traffic light colors can be associated with high and low prices. Furthermore, users can choose to view the data on which the prediction is based, such as its history and trend. It also uses language expressing uncertainty, such as "typical". Users can then compare the current price to the usual cheapest and decide whether to wait for better prices or purchase now. In a forecast scenario, a gradient bar could provide users with information on the uncertainty of a prediction, and perhaps give more insight through accompanying text and access to additional data.

NYT ELECTIONS

The barometer needle can be an effective tool for communicating predictions of winning candidates. The barometer needle moves interactively as new data comes in and displays varying levels of certainty through categories, using both text and colors. In a weather forecast context, a barometer with supplementary text could provide users with levels of uncertainty data, perhaps in a temperature scenario where the temperature is at the typical "risk area" of 0 degrees.

NRK

NRK has visualized a forecast of CO2 emissions in relation to climate goals. The graph effectively communicates historical data and future forecasts through the distinct visual differences between the two parts. The shaded area with dotted framing provides a clear and accessible visualization of what is observed and what is uncertain, a similar pattern to YR's existing uncertainty graphs. Continuing to use lighter shades and shading may be helpful for users understanding what is certain and what is not.

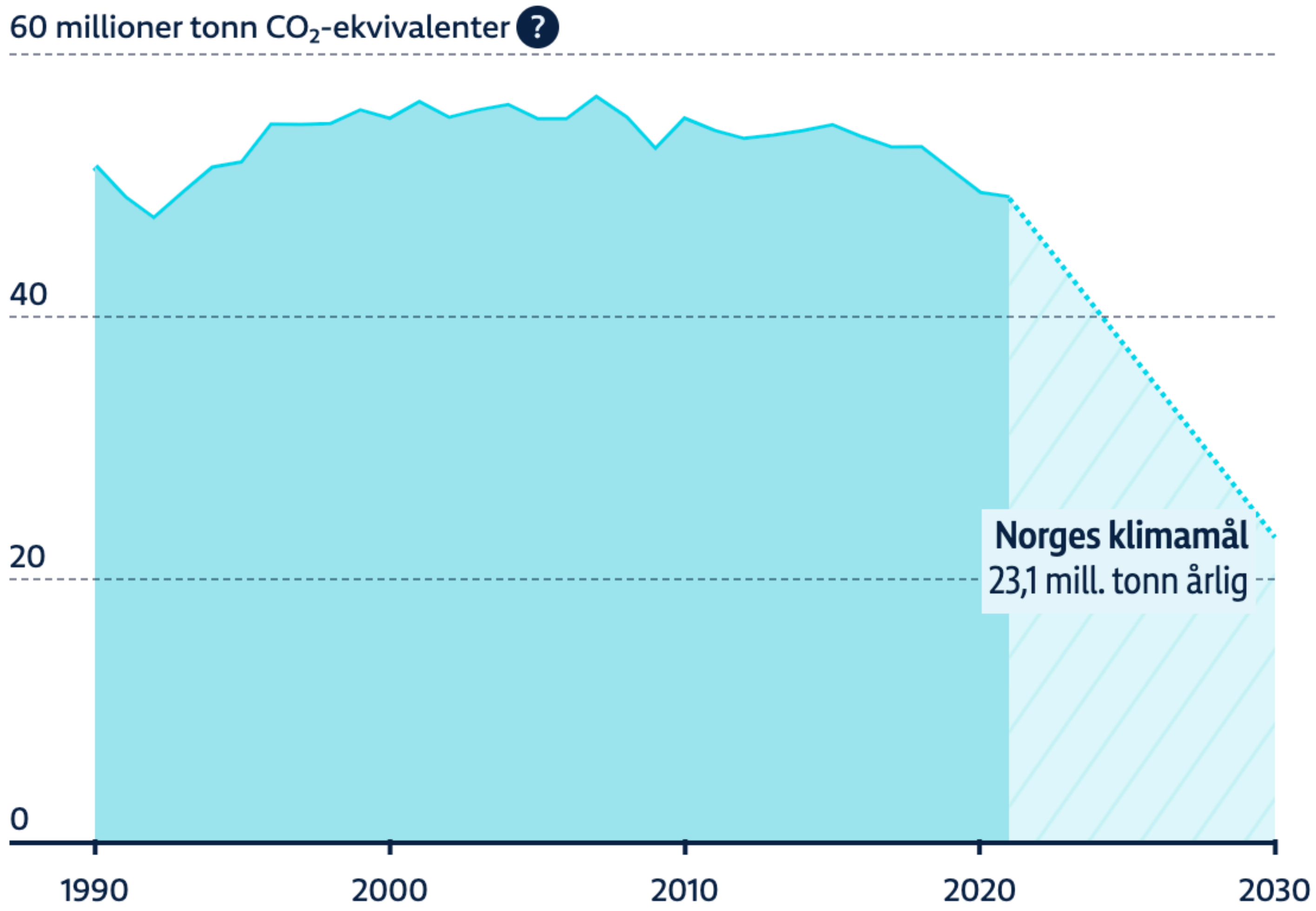


Figure 5.14. Norges klimagassutslipp og klimamål, 2021 by NRK. https://www.nrk.no/klima/status/

VARSOM

The avalanche alert forecast from Varsom provides users with textual information conveying uncertainty, in addition to visual elements illustrating dangers. The text reinforces the importance of making one's own considerations and paying attention to surroundings when assessing risk. Incorporating textual explanations might be a valuable strategy to consider when designing concepts moving forward.

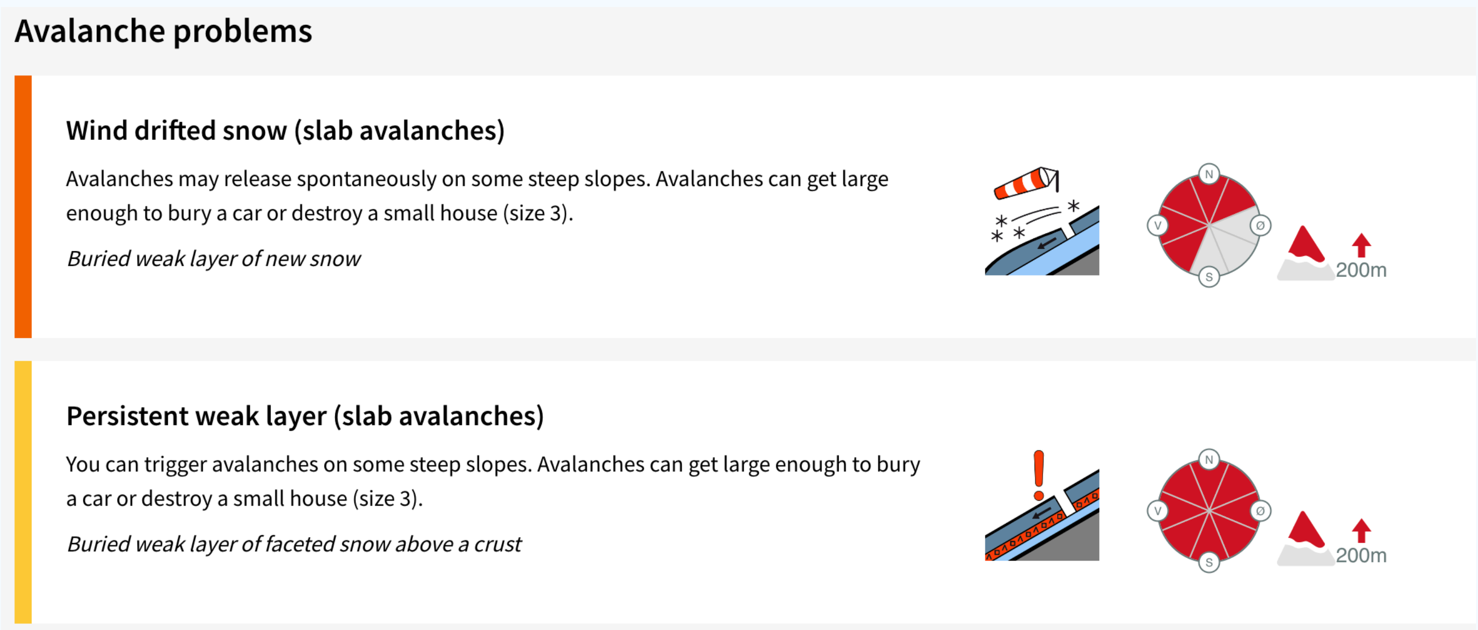


Figure 5.15. Avalanche problems, 2023 by Varsom & EAWS. https://varsom.no/en/snow/forecast/warning/Nordenski%C3%B6ld%20Land/

5.6 Navigation structure

I found it challenging to initiate sketching before having a sense of structure. As mentioned in Chapter 5.2, one of the principles set is to have layers of information. It was important to think about navigation structures to help shape these layers.

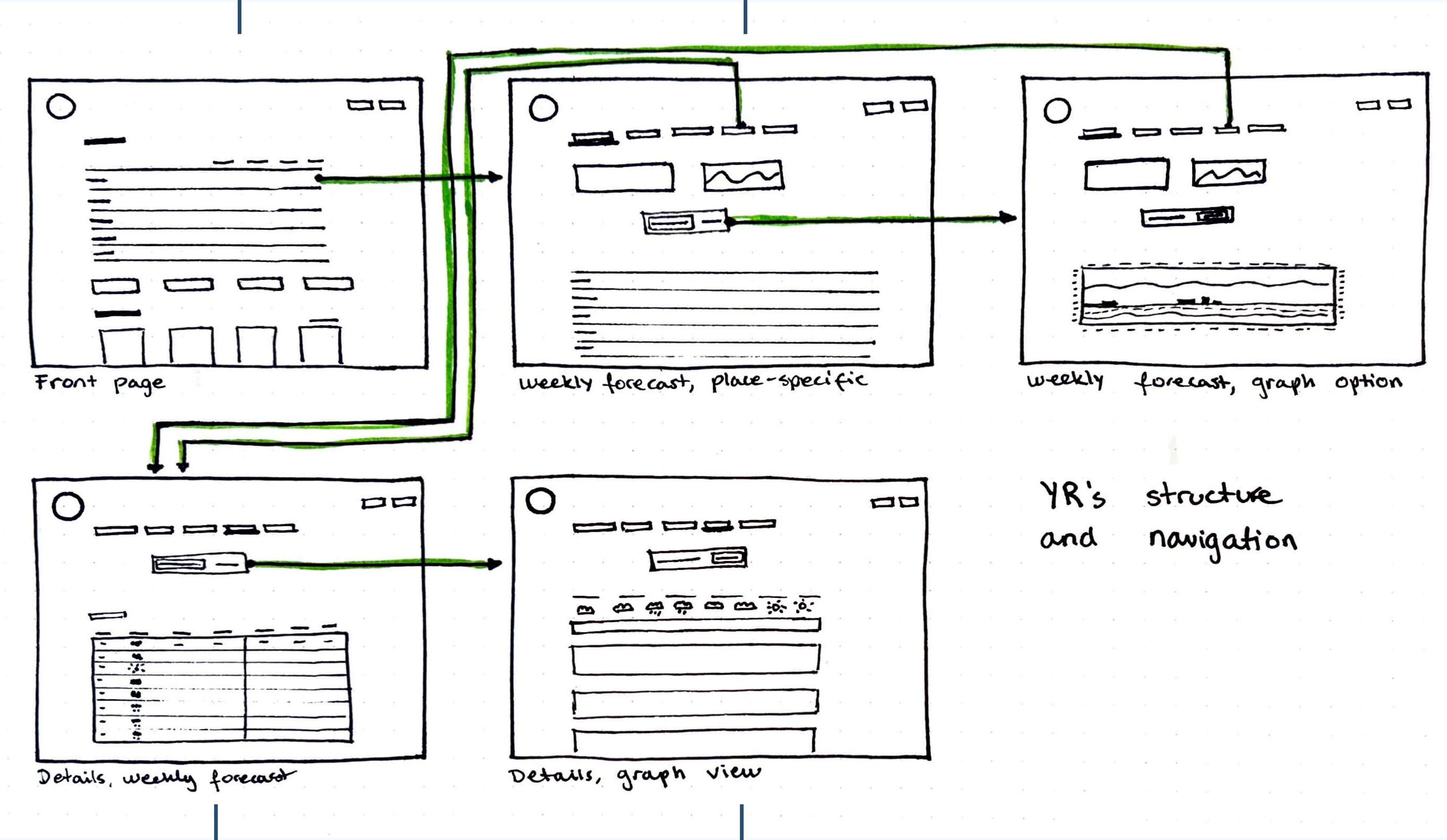
YR'S NAVIGATION STRUCTURE

Before sketching a navigation structure, I mapped out the existing navigation pathways for finding data uncertainty on YR. The current navigation presents data in different layers, necessitating prior knowledge of the website or a willingness to explore it in order to discover available data. The navigation structure is not obvious from the beginning, and the absence of clear pathways to access uncertainty data falls short, as evidenced by user interviews in which some participants were unaware of existing data visualizations.

In summary, the website's design and navigation system may hinder users from accessing data uncertainty. To enhance the user experience, it is essential to think of the visibility and accessibility of uncertainty information through clearer pathways and consistent navigation.

No clear path to data uncertainty, nor does it show the top menu available on the next interaction. Makes it difficult to be aware of what data is available.

Does not display uncertainty data unless choosing to see the information as a graph. Graph only accessible on this specific page. Limits the fluent exploration of data.



Users must choose "details" from the top menu to access more data. This may not be obvious for all. This page presents precipitation uncertainty, in order to find more details one must choose the graph view, only available on this page.

The page displays the most uncertainty and is the most hidden, increasing the issue of inaccessibility.

Figure 5.16. Sketching of YR's navigation structure for data uncertainty.

AN ALTERNATIVE STRUCTURE

Although the project task is not to provide a recommended navigation structure, it is helpful to have an idea of structure when designing concepts.

The structures I explored are inspired from Schneiderman's Visual Information Seeking Mantra, as shown in Chapter 2.2 under "Communicating data". The main point is to have a simple visualization to indicate uncertainty on the first levels of information. Delving deeper into the information, additional data needs to be highlighted to users. The last layers should provide interested users with further details on demand, such as detailed graphs.

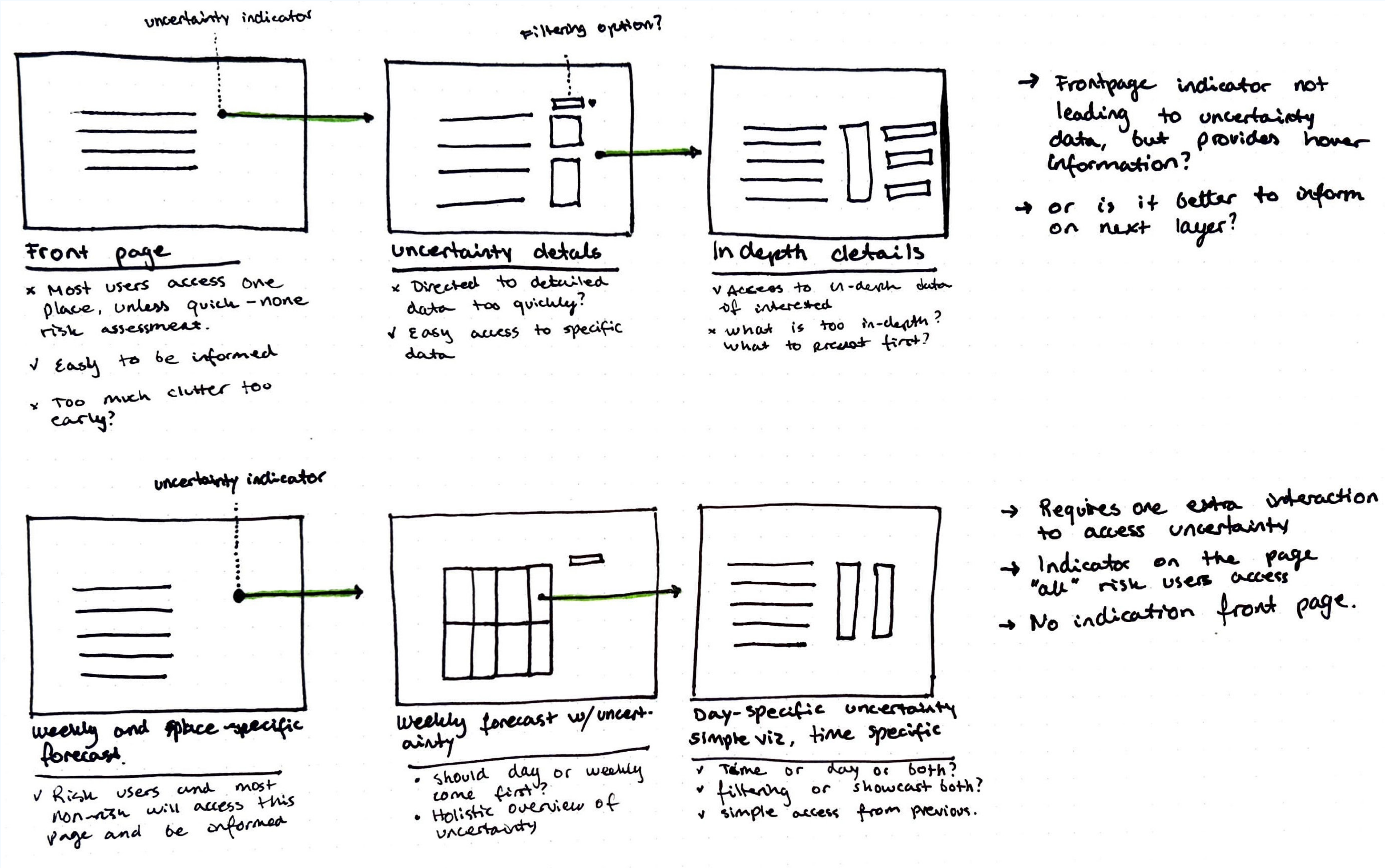


Fig. 5.17. Sketching of two structures for nested navigation.

5.7 Sketching

Iterative sketching and ideation

Paper sketching was the first method used for ideation of concepts.

Sketching served as a tool to transfer thoughts to life in a simple and effective manner. It allowed for written notes with personal reflections and critical thinking. Sketching on paper has limitations related to colors, efficiency of adjustments, and iterations with minor changes. However, it provides new perspectives and its informality relieves some pressure from detail and perfection.

Furthermore, I alternated between different sketches and scenarios, allowing the focus to shift between ideas and concentrating on parts where the inspiration was at its peak.

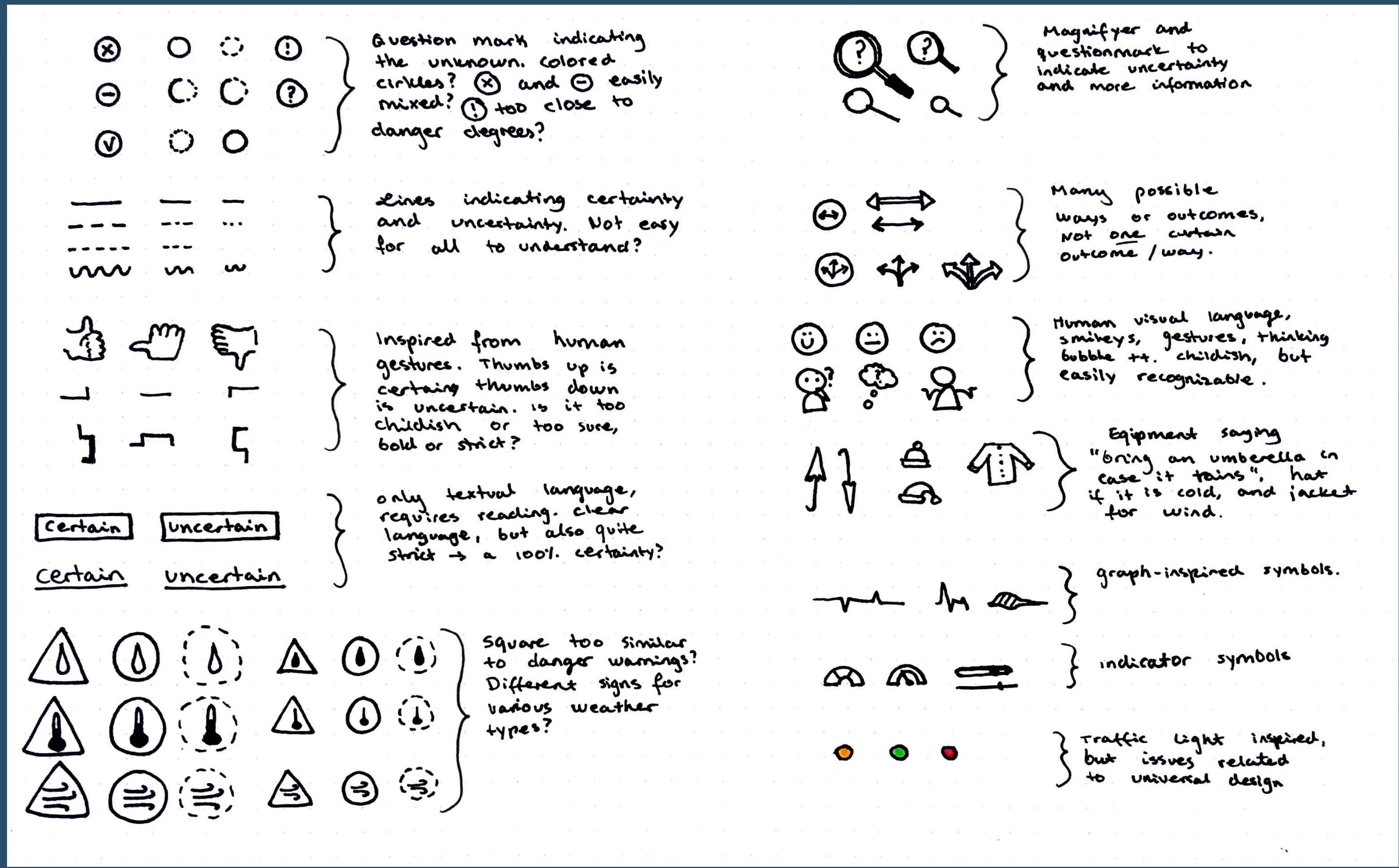


Fig. 5.18. Scan of the first sketch with reflections

UNCERTAINTY INDICATOR

The first sketching activity was initiated by concentrating on a graphical symbol to indicate uncertainty, see Figure 5.18. The indicator should provide users with information that there are uncertainties in the data, before allowing them to explore further details.

Since there exist no universally recognized symbol for uncertainty, I relied on knowledge gained throughout the project, as well as intuition and creativity, to generate various ideas.

The sketching session drew inspiration from various sources, including human-inspired visual language such as smiley faces, clothing/equipment, and thumbs gestures. Other elements were influenced by mathematical and graphical concepts, like wavy lines. Common icons like question marks and check marks were also explored. Despite examining numerous symbols, none of the indicators emerged as the ideal choice. Before proceeding with any of them, I decided to first sketch solutions for other layers. This approach would potentially offer inspiration for how the indicator could be visualized.

INCREASING DETAIL LEVEL

Most sketches used precipitation as an example. Precipitation was the primary focus point due to the two challenges associated with uncertainty. First, the uncertainty of whether it will rain, and second, the uncertainty regarding the amount. Decoding the challenges was the most crucial, as most ideas could be applied to wind and temperature as well, which do not have any uncertainties related to their existence.

Most of these sketches drew inspiration from the inspiration board, with the objective of showing how certain the expected precipitation is.

The “bubble chart”-inspired visualization in Figure 5.20 was intended to display various predictions of a probabilistic weather forecast, in which the biggest bubble represented the most common outcome. The surrounding bubbles were meant to show the alternative outcomes. However, the meteorologists informed that these bubbles were not as realistic as precipitation would typically be in a range.

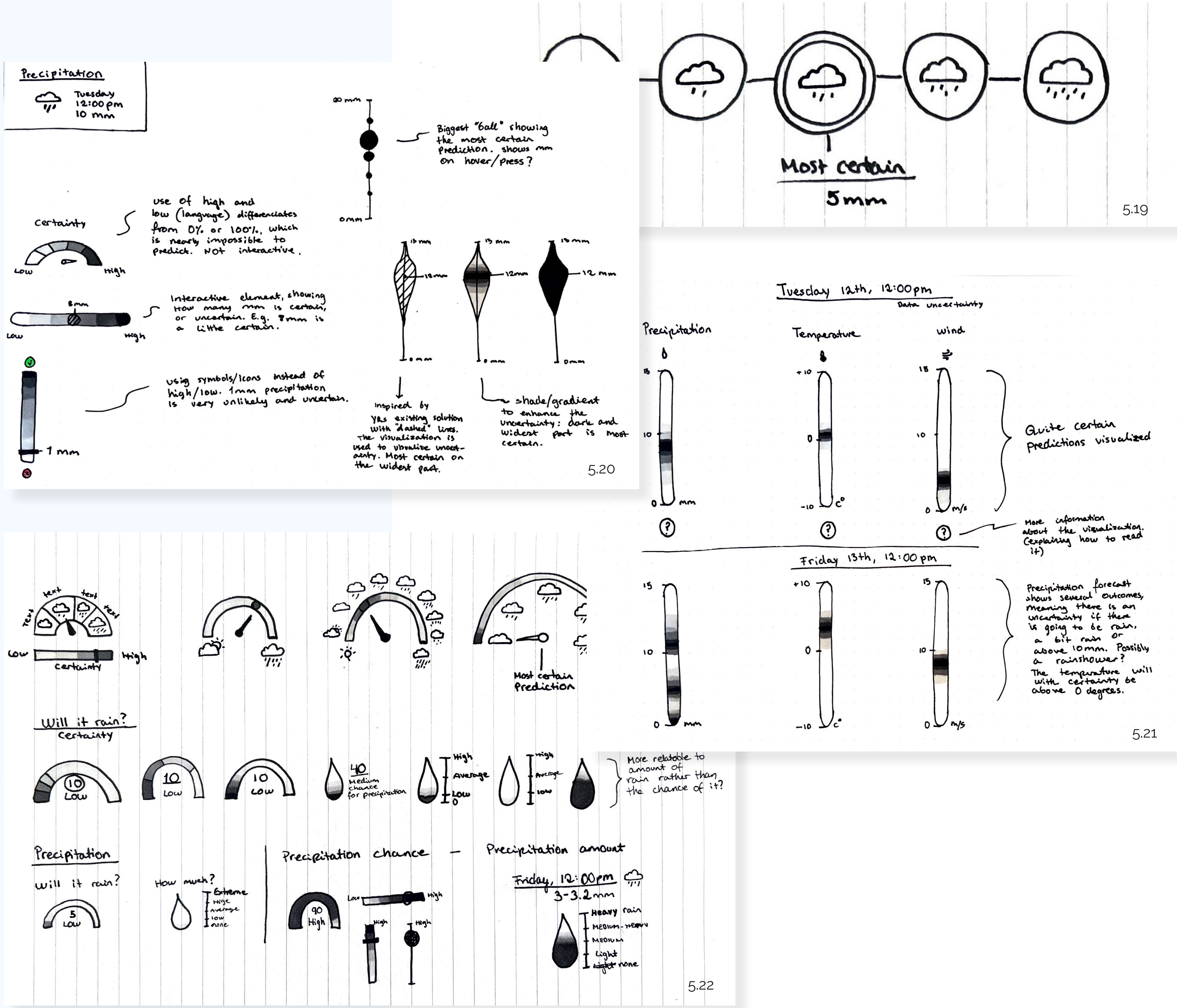


Fig. 5.19-5.22. Scans of sketches and reflections

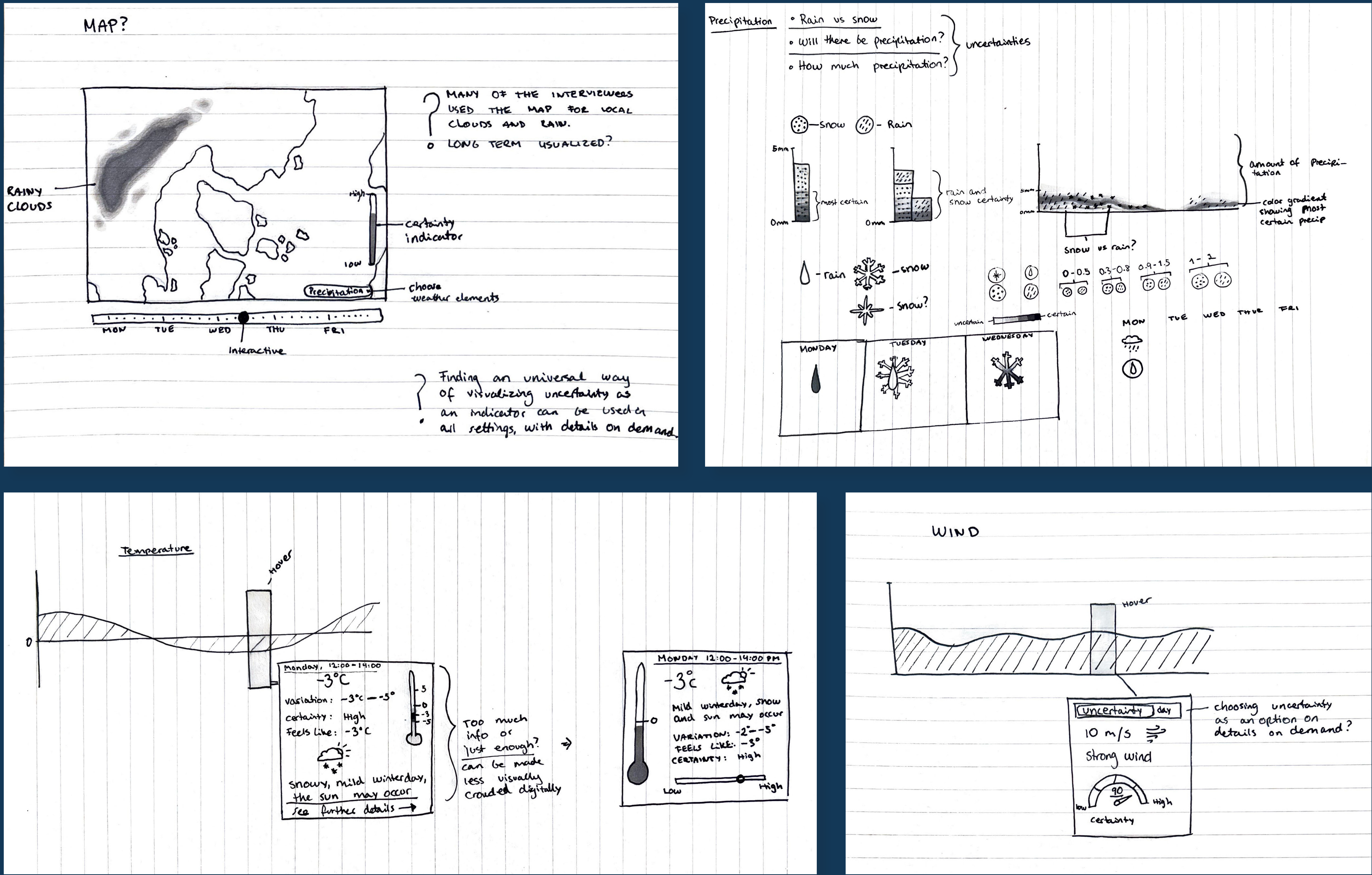


Fig. 5.23-5.26. Scans of futher sketches with more details

HIGHEST DETAIL LEVEL

Users interested in planning are naturally interested in information ahead of time.

As weather forecasts are time-related, it was natural to sketch the concepts in the context of a time-line. Graphs became a natural visual element to sketch for details.

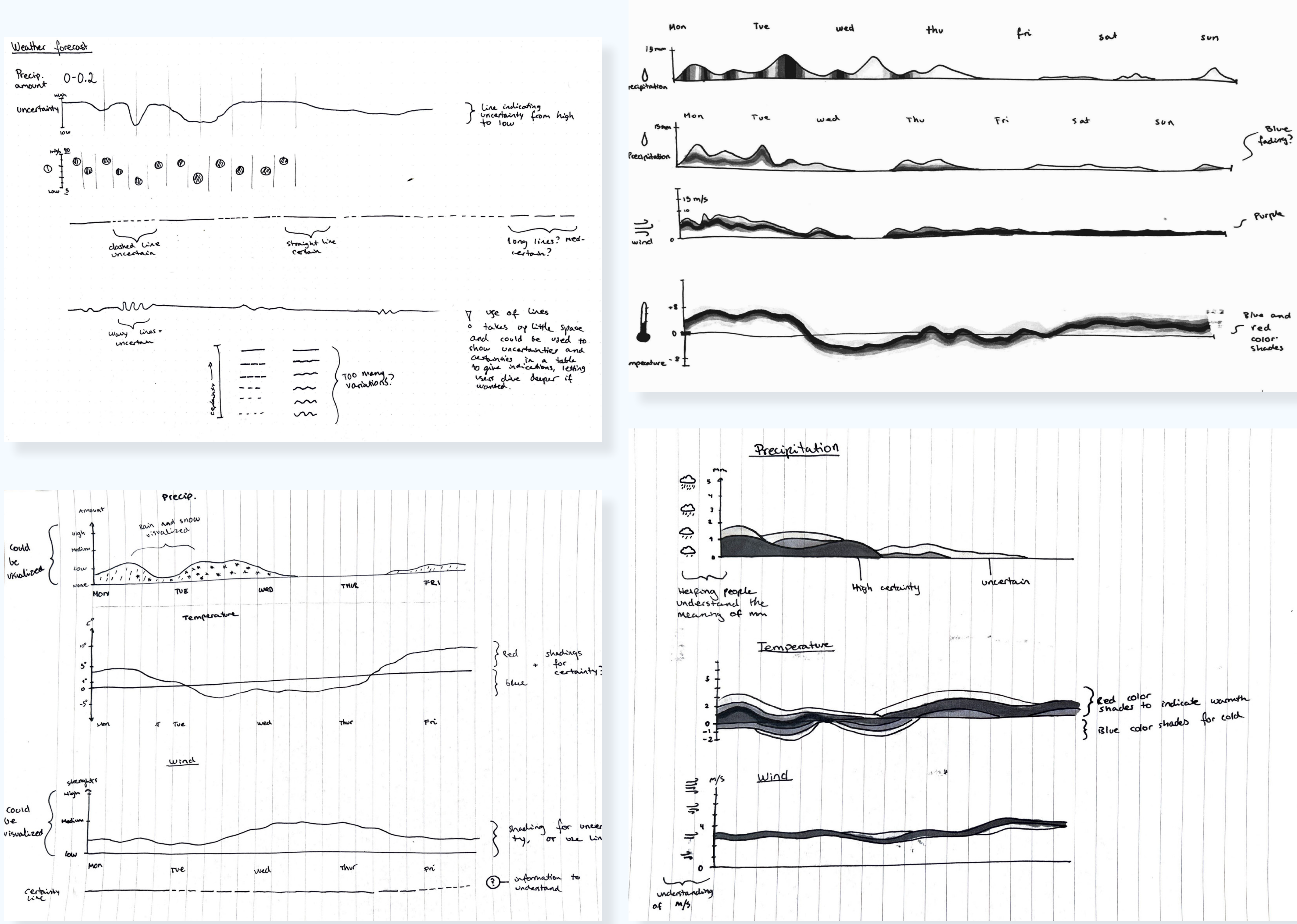


Fig. 5.27-5.30. Scans of sketches exploring long-term predictions.

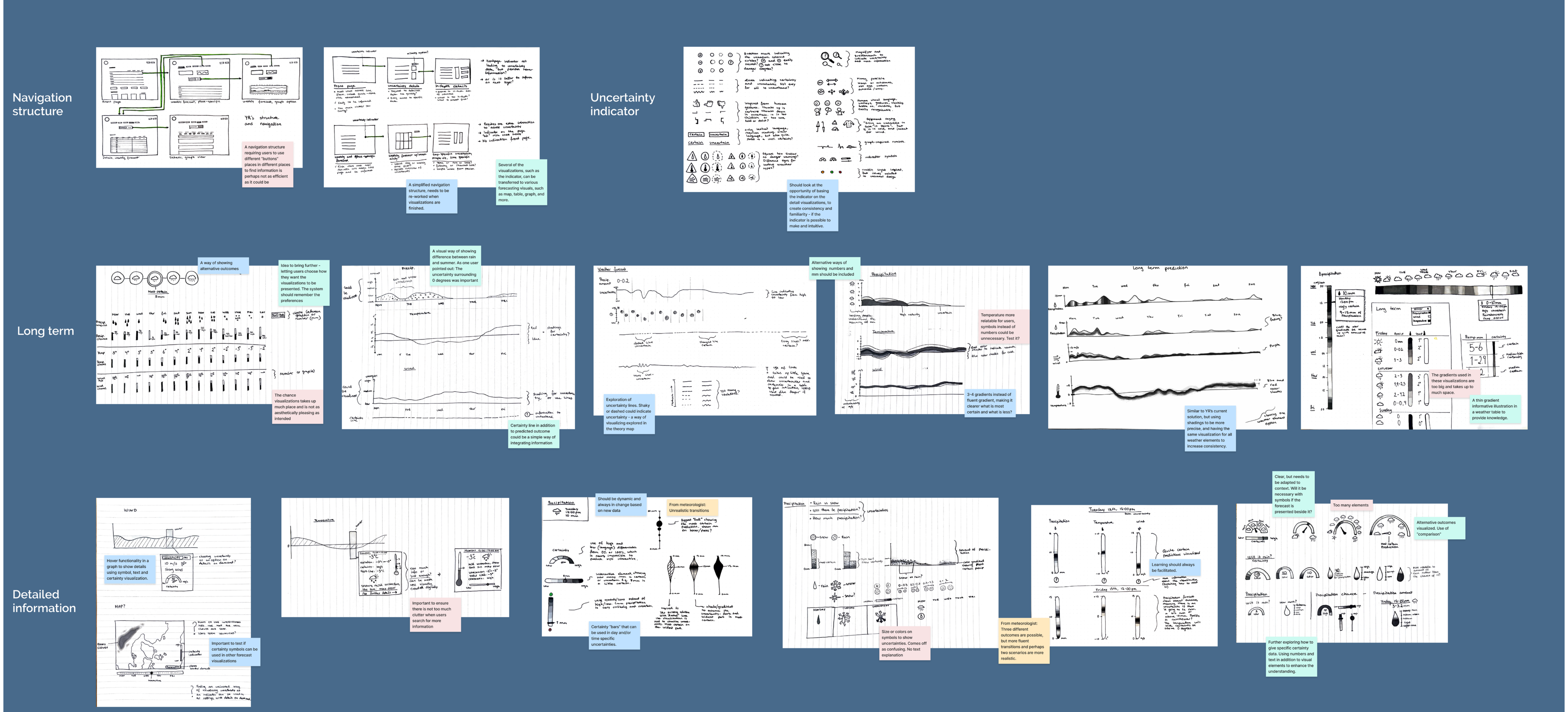


Fig. 5.31. Discussion of concepts through digital post-it notes.

REFLECTIONS AND FEEDBACK

The sketching session was somewhat chaotic, as it typically is at this stage. Sketching is important for understanding possibilities and enhancing one's own learning. This phase revealed necessary adjustments, which were made simultaneously with sketching. One such adjustment was the creation of structures, as described in Chapter 5.6. Additionally, a feedback session with two meteorologists from MET was essential to ensure that the ideas created at that point were possible and realistic in relation to their data.

The sketches were arranged on a digital board, as seen in Figure 5.31.

Personal reflections and feedback from meteorologists were noted. While the meteorologists offered insights into some concepts and their possibility, one also mentioned that being too aware of their current models and data gathering approaches could impact creativity. The meteorologist advised focusing on creativity and user experience, suggesting that their data collection methods could be adapted to suit a visualization if it was uncovered as the best option.

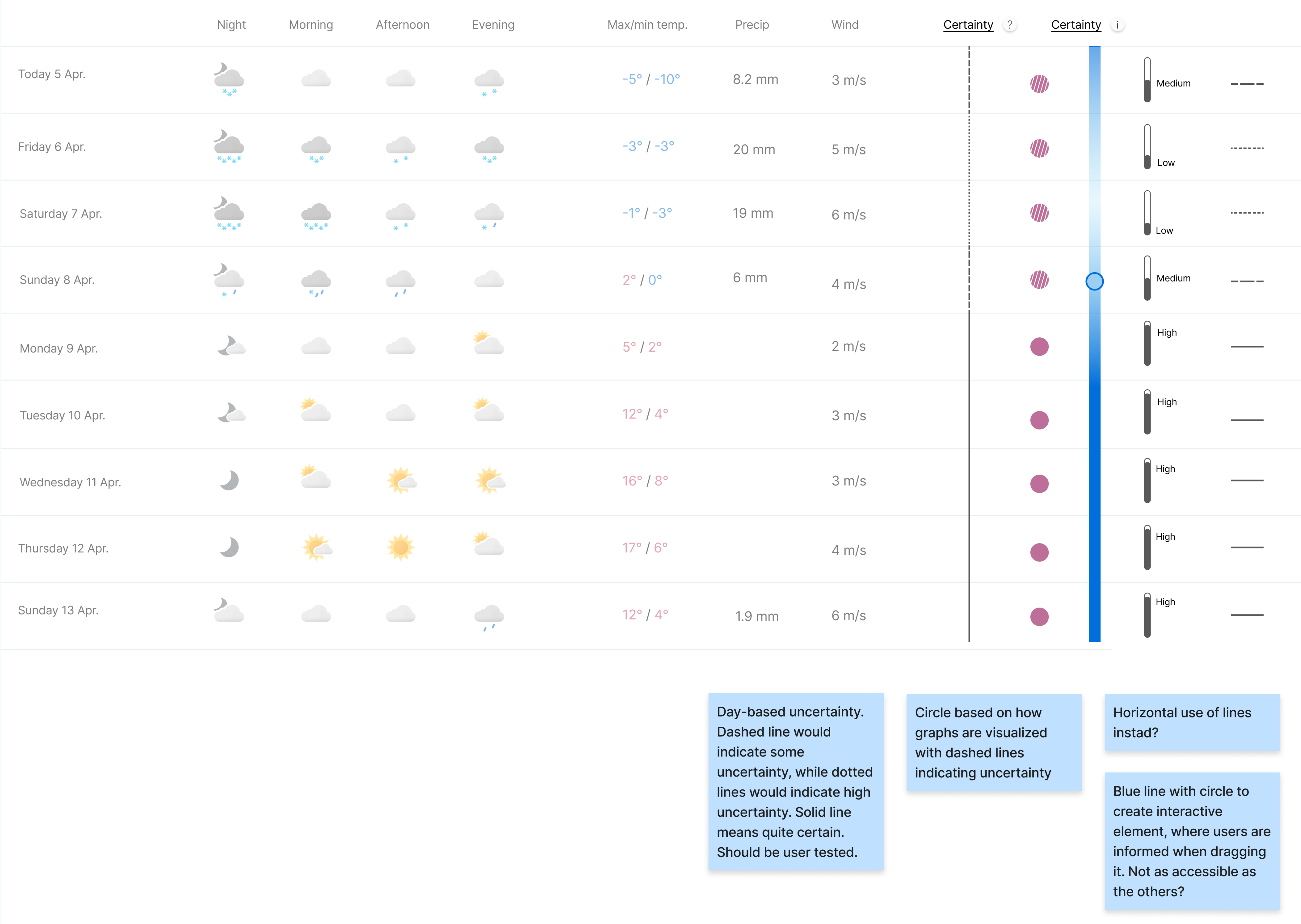
The board can be found in the appendix.

5.8 Digital concept development

The digital concept development started by exploring the indicator. Some ideas emerged from the sketches, while others came when transferring the work area to digital tools.

Four potential indicators were sketched and incorporated in a table from YR. To differentiate my work from theirs, I added transparency to the area that is not created by me.

Post-it notes were added to facilitate reflection in- and on-action. Reflection in-action refers to intuitive thoughts and reflections happening while designing, whereas reflection on-action means thoughts that emerge when taking a step back before assessing the work (La Trobe University, 2022). This approach was essential to ensure a continuous assessment of design choices throughout the process.



	Night	Morning	Afternoon	Evening	Max/min temp.	Precip	Wind	Certainty ?	Certainty i		
Today 5 Apr.					-5° / -10°	8.2 mm	3 m/s			Medium	
Friday 6 Apr.					-3° / -3°	20 mm	5 m/s			Low	
Saturday 7 Apr.					-1° / -3°	19 mm	6 m/s			Low	
Sunday 8 Apr.					2° / 0°	6 mm	4 m/s			Medium	
Monday 9 Apr.					5° / 2°		2 m/s			High	
Tuesday 10 Apr.					12° / 4°		3 m/s			High	
Wednesday 11 Apr.					16° / 8°		3 m/s			High	
Thursday 12 Apr.					17° / 6°		4 m/s			High	
Sunday 13 Apr.					12° / 4°	1.9 mm	6 m/s			High	

Fig. 5.32. Exploring potential indicators in a table designed by YR to provide context.

Numerous visualizations from the sketches were digitized. Apart from weather symbols owned by YR, all visualizations were created by me, including the wind symbols.

The visualizations in Figure 5.33 were designed to represent the second level of information, providing more data than the indicator. At the same time, they are meant to serve as an alternative to graphs.

Additionally, the exploration of language ranges indicating stages of uncertainty was explored. To fulfill the requirement from Chapter 5.3 regarding clear language, it was essential to try and test different words and synonyms.

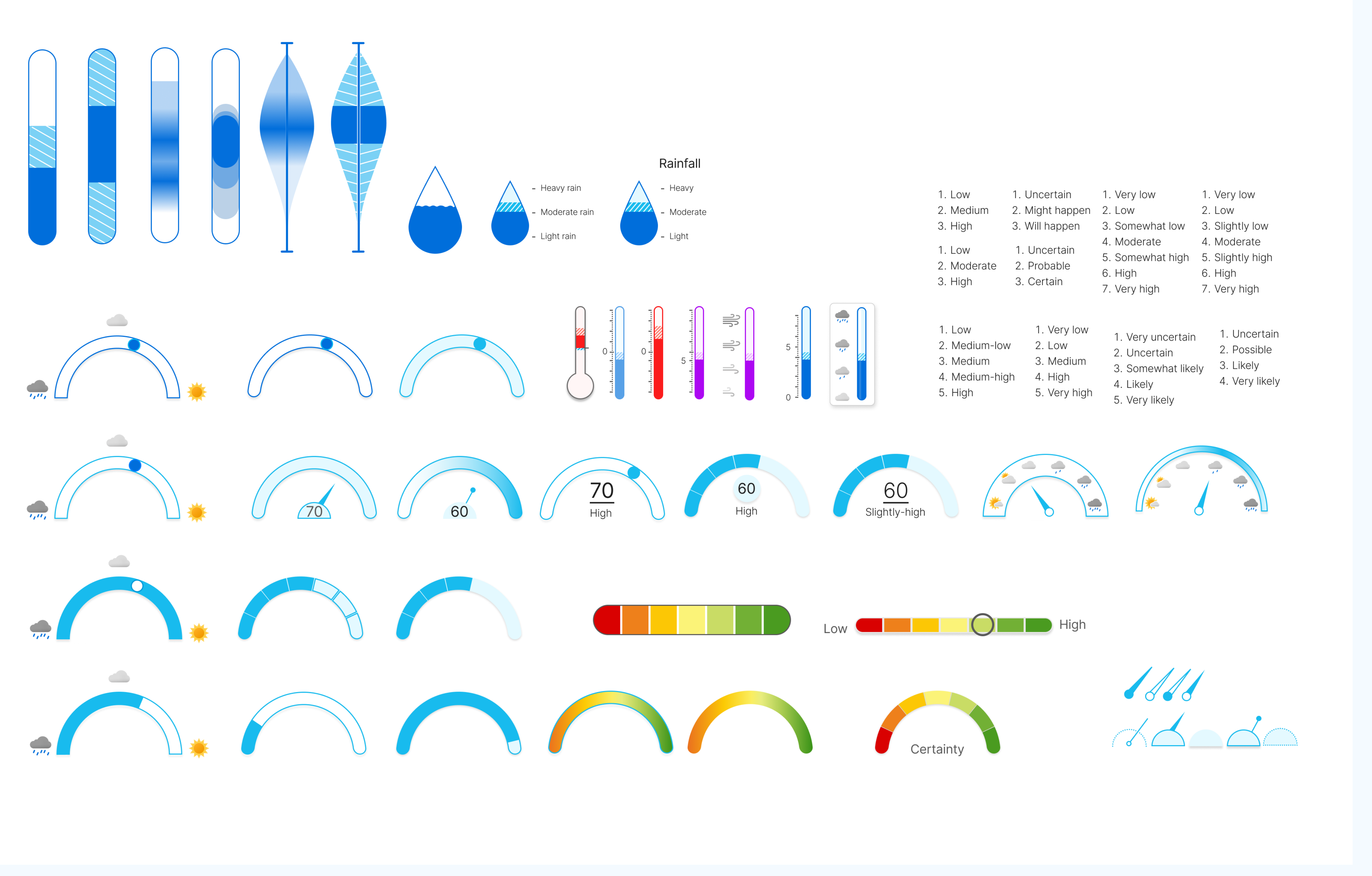


Fig. 5.33. Exploring visualizations from the sketches. Weather symbols are created by YR. *Yr weather symbols,* by NRK. https://nrkno.github.io/yr-weather-symbols/

The concepts presented in Figure 5.34 shows iterations and explorations of graphs, mainly with origin from the phase of sketching. These graphs were created with a main focus on the uncertainty visualization. This means that they were created without context, such as specific days or values. This was to ensure creative iterations of the content and uncertainty in itself, rather than the context.

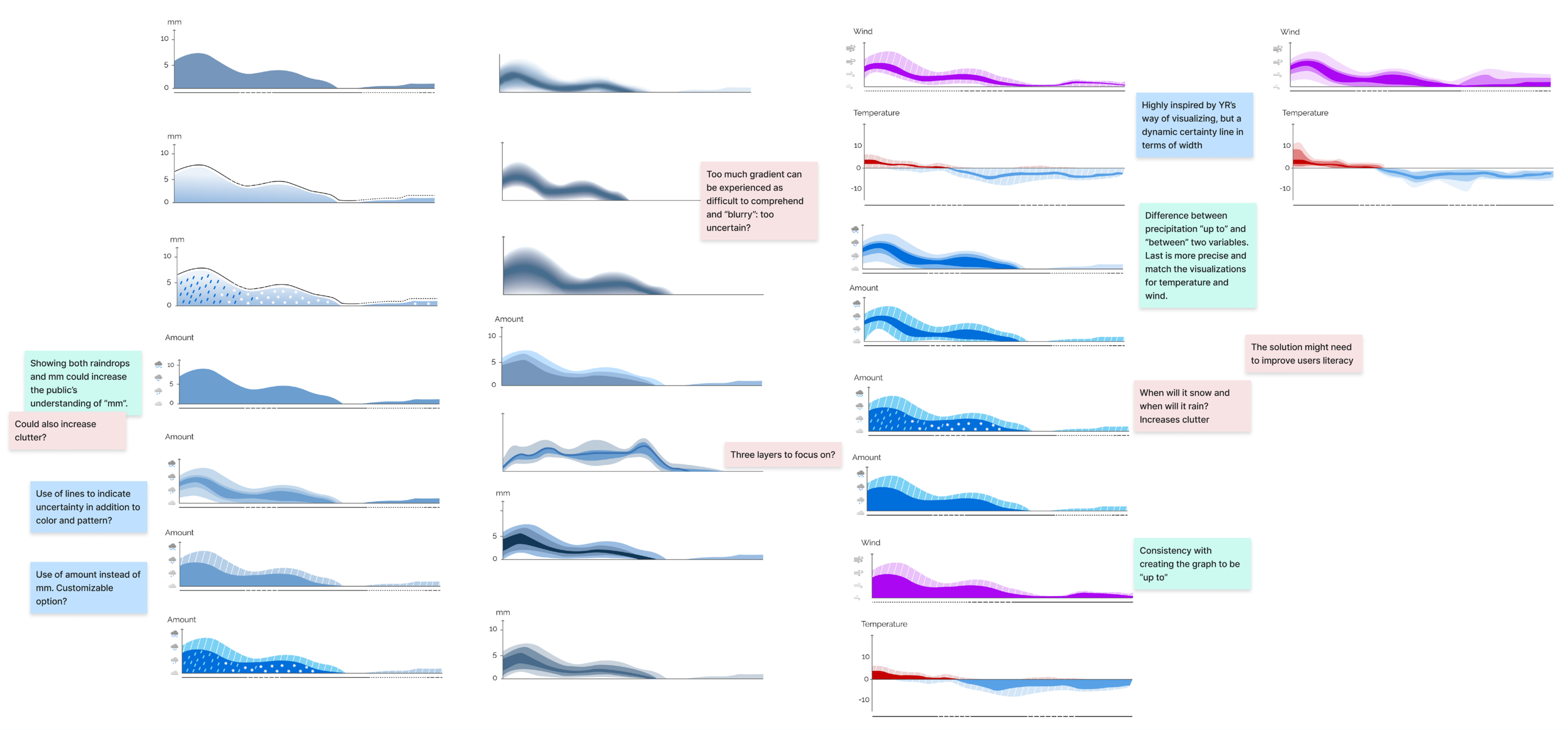


Fig. 5.34. Exploring and iterating on graphs.

5.9 Concept workshop

Facilitating fresh creativity

I conducted a second workshop with Halogen, in which nine designers participated. During concept development, I realized that some of my ideas were influenced by YR's existing solutions and required a broader exploration, aiming for “out of the box” ideas. Having extensive knowledge of current solutions proved to be a challenge when it came to thinking of new and innovative solutions.

The majority of the designers had some familiarity with the project through the previous workshop and sessions where knowledge was shared, but they lacked in-depth knowledge, which was beneficial for the workshop. Organizing a concept workshop in the midst of my own sketching and idea generation was helpful for comparing results with my own drawings. The intuitive ideas of professional designers who were not part of the project were valuable not only for ideation, but also for understanding what they considered intuitive or engaging.

The intended activity was presented with little detail at the beginning of the workshop, allowing participants to use their own tools and decide upon their own approaches. Participants searched for information and details before starting the workshop. Their questions were related to user groups, my expectations and needs, and how they should approach the task. The question, “where to start?” was raised, which made me realize that the beginning of the workshop might have been too broad and open.

The initial approach was to give the participants a blank slate to ensure that they were not influenced by any factors and to have the opportunity to freely explore the challenge as they saw fit. Balancing this freedom with more details and context could have been more beneficial. However, to resolve these uncertainties, we decided as a group to split into three sub-groups of three people each, allowing for more focused and collaborative ideation. This was helpful to spark engagement, leading to all groups discussing, producing low-key sketches, ideas, and seemingly still having fun.

The sketches produced by the participants are displayed on this page and the next, while my own explanations of the ideas are described using post-it notes beside the photos.

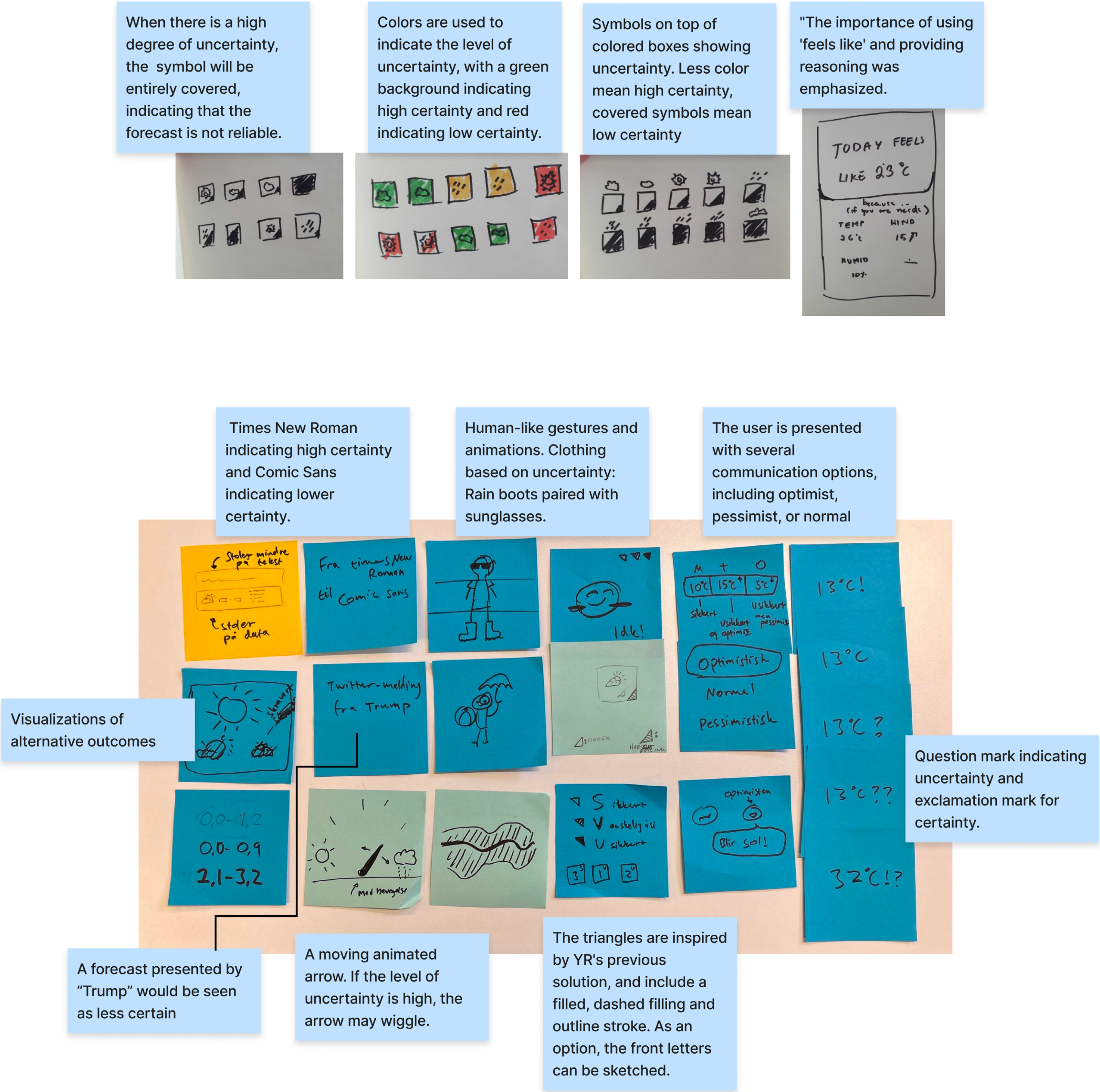
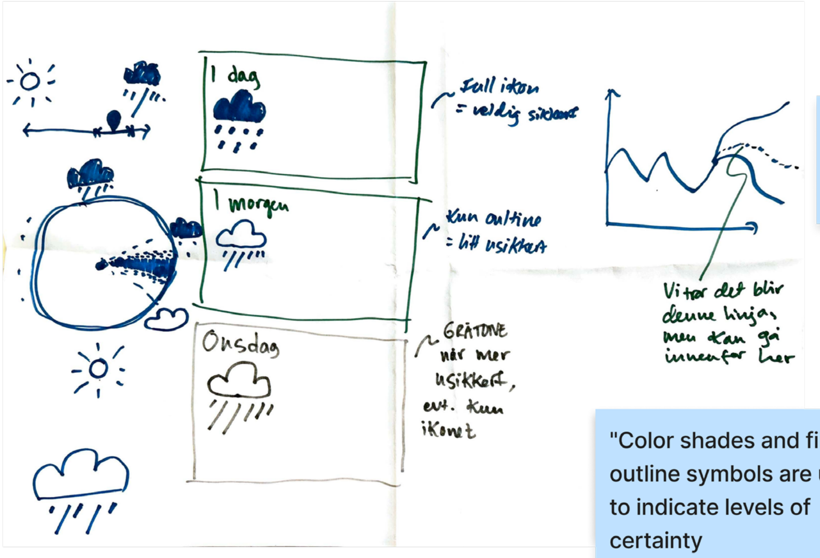


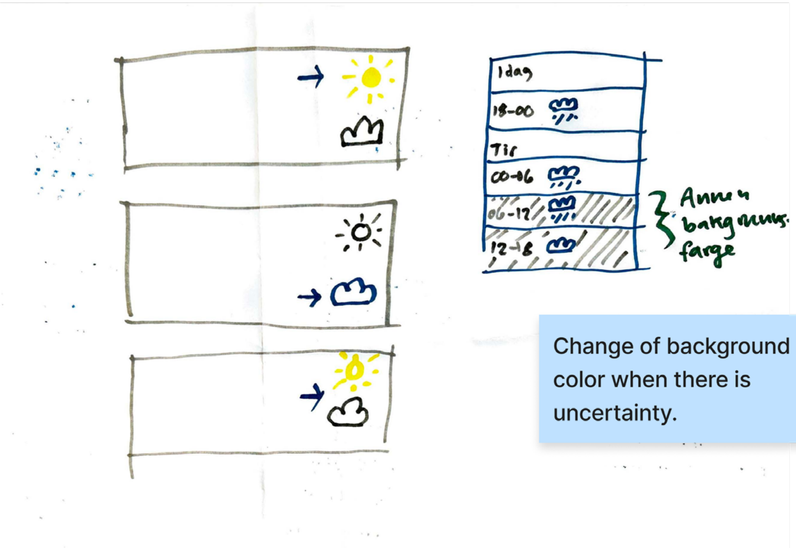
Fig. 5.35. Results from concept workshop

A circle with weather symbols surrounding it. The colored part displays what is most certain. Similar to the half-circle designs that I've explored.

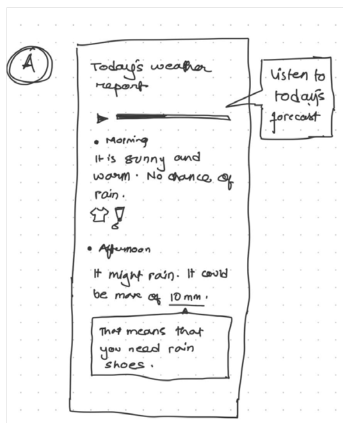


"A graph is used with two pathways to show two possible outcomes."

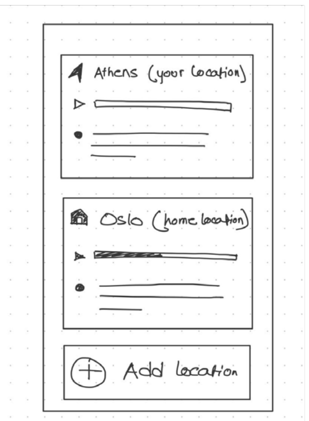
"Color shades and filled/ outline symbols are used to indicate levels of certainty



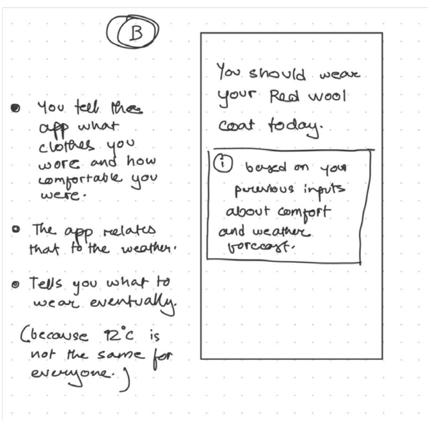
Change of background color when there is uncertainty.



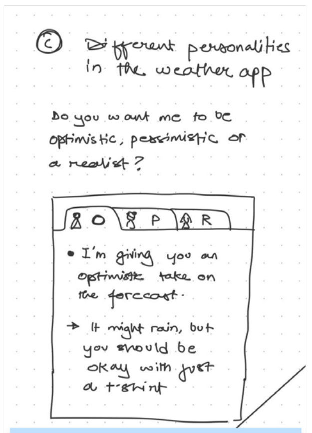
Sound and textual explanations are used to communicate uncertainty, with explanations on hover to increase understanding



Possible to listen to forecast in all "favorite" locations

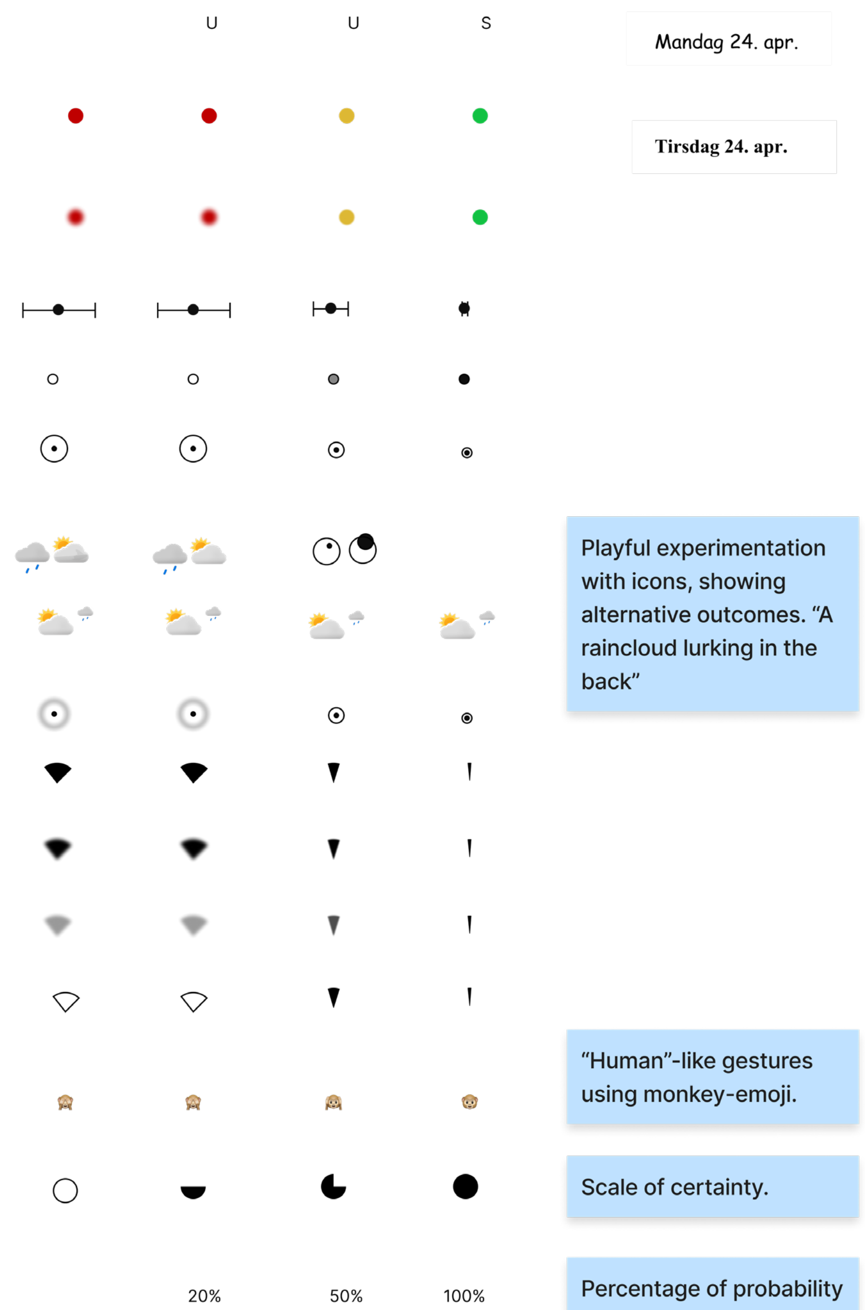


Personalization features. Customized advices for each user.



Different personalities and tone of message from an optimistic, pessimistic, or realistic perspective.

Intervals and ranges were sketched to show the level of uncertainty in wind and temperature, in addition to precipitation (most typical).



Ideation on indicators. Use of letters, colors, blur-effect, outline and filled to indicate certainty levels.

Target symbols where the bullseye gets smaller when it is more certain. The bullseye is relative to the circle. Another version shows that the bullseye is not hit in the center, meaning the forecast might be off.

Playful experimentation with icons, showing alternative outcomes. "A raincloud lurking in the back"

An open fan shows a larger space for alternative outcome, whereas a smaller shows that it is more certain and precise prediction.

"Human"-like gestures using monkey-emoji.

Scale of certainty.

Percentage of probability

Fig. 5.36. Results from concept workshop

5.10 Post workshop concepts

The concept workshop helped spark new ideas to explore further. Some of the participants' ideas were tested and iterated on, as presented in Figure 5.37.

INDICATORS

Exploring alternatives to an indicator was helpful, such as showing alternative outcomes by adding dashed lines on YR's weather symbol, or using the same pattern inside the table to show more specific uncertainties.

Furthermore, the half circle and circle were ideas which had been sketched before. This worked as a confirmation, showing that the idea had potential as it was generated as an intuitive solution by others with little knowledge about the project.

The target discs which resulted from the workshop was a fun approach of communicating the certainty and accuracy of a prediction. This was further iterated upon.

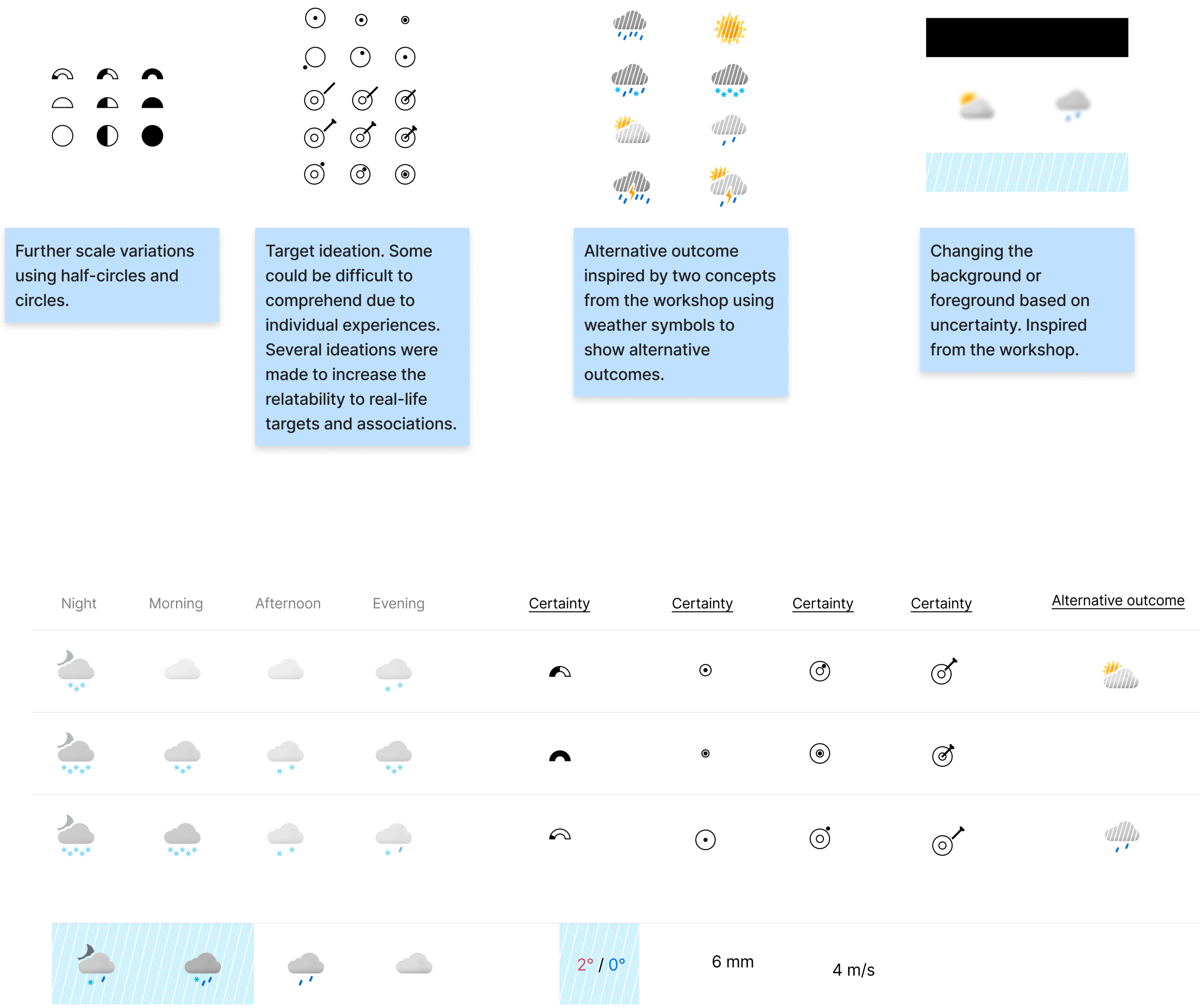


Fig. 5.37. Further concepts developed after the workshop. The half-transparent table and weather symbols belong to YR.

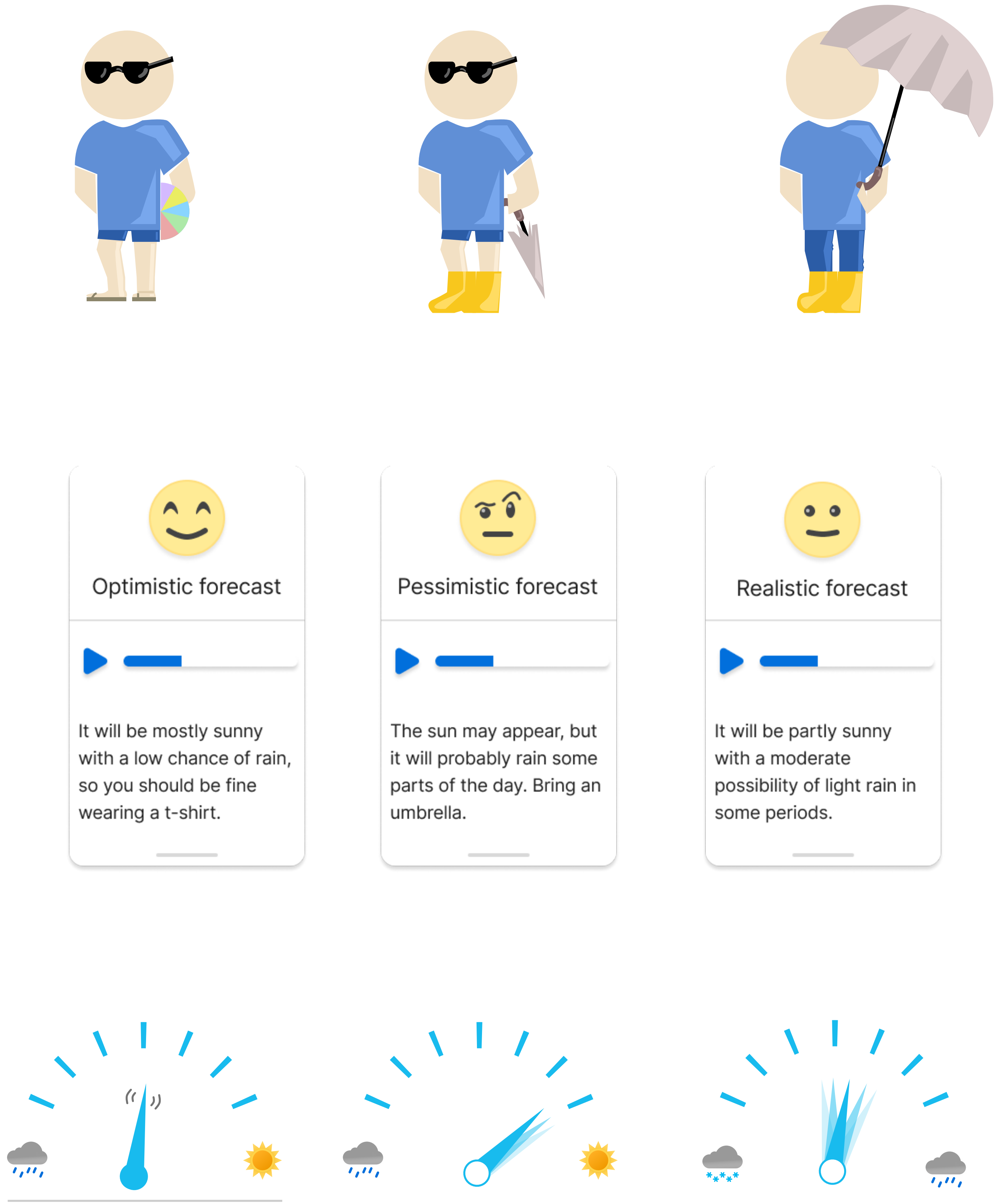


Fig. 5.38. Concepts inspired by the workshop. Weather symbols used in the last concept are created by YR.

INCREASED DETAIL LEVEL

The workshop also generated suggestions and ideas for visualizations representing the second level of information. Iterations of these suggestions are presented in Figure 5.38.

The first concept displays an avatar wearing different clothing to communicate levels of uncertainty. Sunglasses, flip-flops, and light clothing signify high certainty for sunny weather. Wearing sunglasses while carrying a closed umbrella and wearing rain boots indicates the possibility of rain. Lastly, rain boots and an open umbrella conveys the highest level of certainty for precipitation.

The second concept further iterated upon the ideas of having personalities present the forecast. Choosing a personality could offer a fun and engaging way to set the tone, along with a voice message. These choices emphasize uncertainties through various interpretations of the weather data.

The final iteration was similar to previously explored concepts from Chapter 5.8, but the arrow is intended as a moving object, potentially adding a fun and dynamic element highlighting uncertainty through the rhythm of its movements.

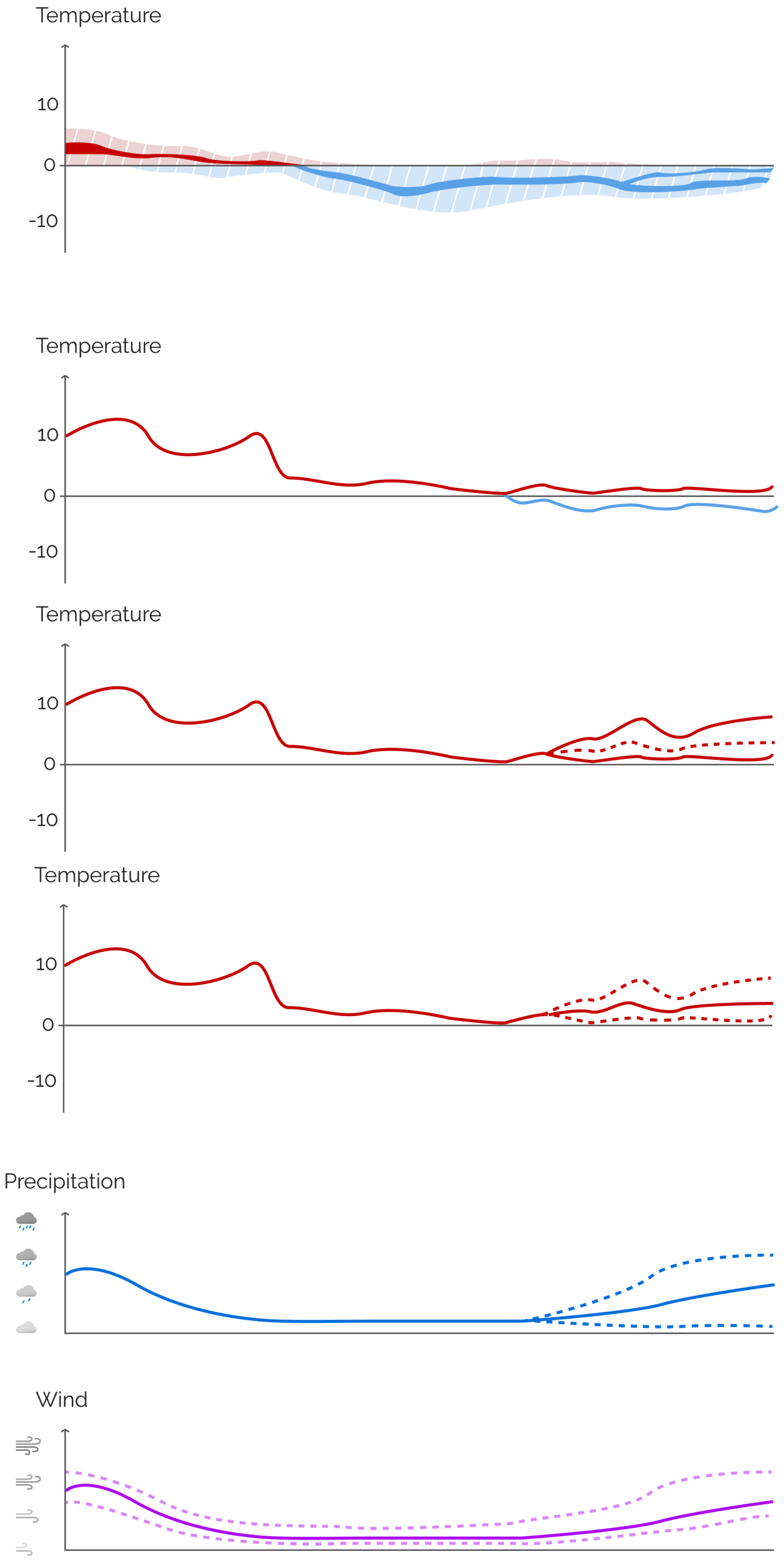


Fig. 5.39. Concepts inspired by the workshop. Weather symbols used in the precipitation graph are created by YR.

GRAPHS

The participants from the workshop had a suggestion for a graph. This idea was based on showing the “alternative outcome”, meaning one path branching into two. Their sketch was used for further iterations, presented in Figure 5.39.

The first visualizations used an existing concept to test the idea of two paths. The second attempted to use only a line, without shaded areas. The third was the original idea from the workshop, using a dashed line to display the estimated outcome within a certain range of solid lines.

In previous concepts, the dashed line symbolized an uncertain outcome. Therefore, further iterations tried using this approach instead. This meant that the solid line symbolized the expected outcome, while the dashed lines were used to show alternative outcomes.

The final visualization explored using a lighter color for the alternative paths, in addition to the whole prediction having uncertainties.

Testing these suggestions was essential for exploring further possibilities within graphs.

5.11 Preparing for user testing

INDICATORS

Four indicators were chosen for user testing, in addition to one visualization for alternative outcome. The last was presented together with an indicator. Additionally, an explanation visible on hover was also tested. The concepts are presented and have been given names in Figure 5.40.

Concept 1.1 was chosen due to its quick scan-through features. It could easily be read horizontally or vertically. It does not take up much space. However, its meaning is not necessarily obvious.

Concept 1.2 was chosen due to its similarity to previously explored thermometers, which together could create a consistent visual profile. The text provides an explanation for users, increasing its accessibility. It does however take up more visual space and it is not as easy to scan through a table forecast with it.

Concept 1.3 was also selected to create a consistent visual profile to the bows presented in Chapter 5.8.

Concept 1.4 was selected due to its fun approach of expressing certainty. It might express a message saying that the forecast is totally wrong or totally correct, not creating those nuances of interpretations the others might have. Additionally, it might be less accessible, due to its small size and details.

Lastly, Concept 1.5 was included in user testing as it expresses not only uncertainty, but provides users with visual information of what could happen.

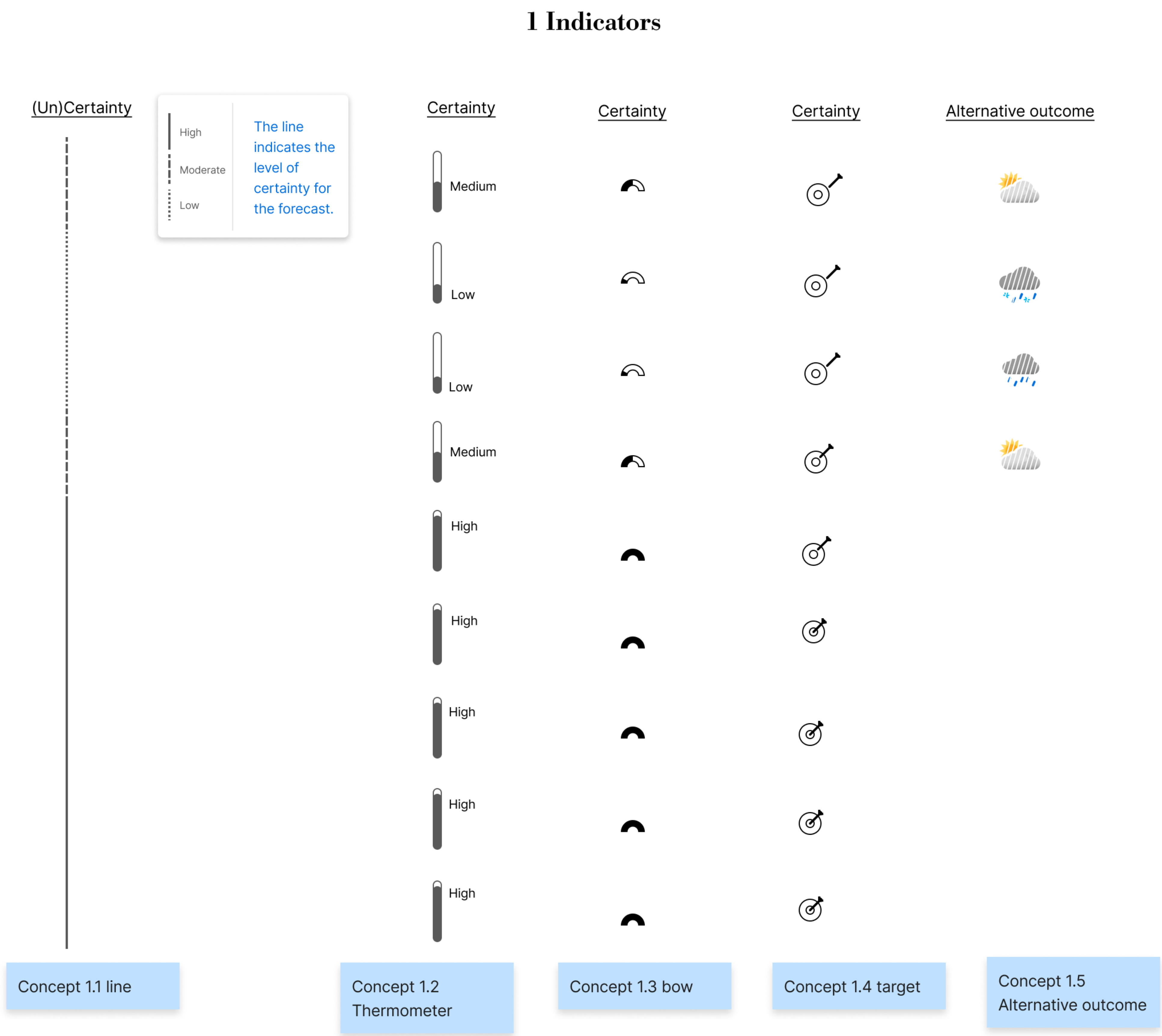


Fig. 5.40. Indicators chosen for testing

GRAPHS

Compared to the indicators, the graphs are intended for the opposite level of details. The indicators are meant to provide an indicator of uncertainty, while the graphs are meant to provide users with the most details.

Concept 2.1 and 2.2 were both chosen as I experienced the shaded area to be the most accessible. Pattern in addition to color is an important principle for improved accessibility. Previous solutions using gradient colors were not taken further, as they would not be universally designed.

The shaded area is an approach YR is already using, and is more common when visualizing uncertainty in graphs. This solution was taken further, as it stood as the best option in relation to accessibility principles. However, as presented in Chapter 4.6, YR presents precipitation as a bar graph, meaning the graph types differ from each weather element. This creates inconsistency. The graphs taken further aimed to be consistent, presenting each weather element using the same structure.

Concept 2.1 was inspired by YR's bar graph by only showing the uncertainty on top, meaning the user has to read "up to x amount of wind/temp/precip".

Concept 2.2 Shows the uncertainty on both sides, which is something YR is showing in temperature and wind today. The graph differs further from YR's by showing a larger span of certainty instead of one expected line. Other than that, the visualizations are created by aiming for less visual clutter by not having a frame for each graph and a grid background.

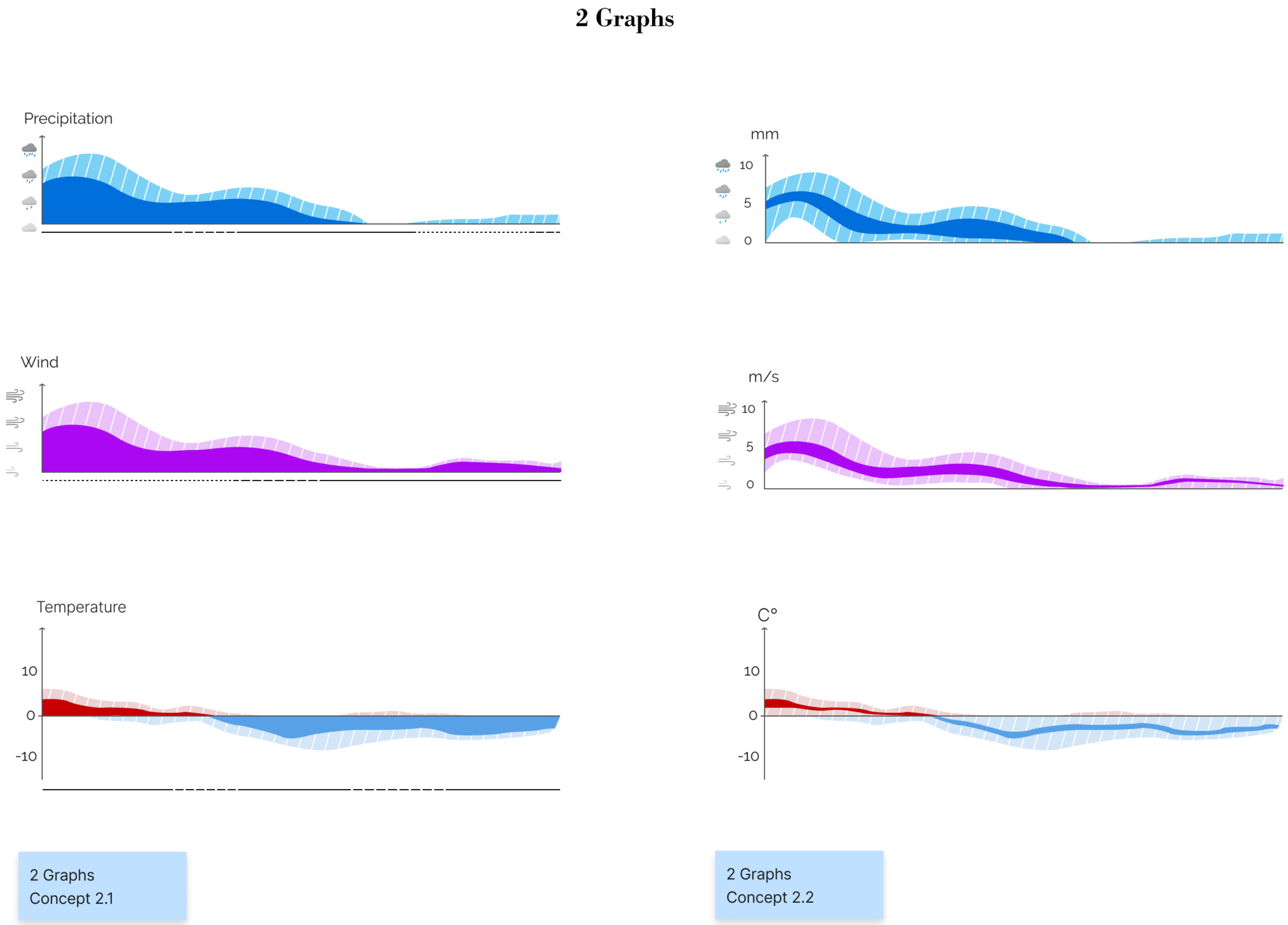


Fig. 5.41. Graphs chosen for user testing

ALTERNATIVE VISUALIZATIONS

The visualizations presented in Figure 5.42 were chosen for user testing. These were designed to be presented in the second level of information – meaning they were supposed to provide more information than the indicator, and serve as a simplified alternative to graphs.

The bows were designed to point at the forecast outcome most likely to happen. By showing surrounding weather symbols, they provide information about alternative outcomes as well. Concepts 3.1, 3.3 and 3.4 were tested on the first three users, but concepts 3.2 and 3.5 were added later due to feedback received.

Each bow has some elements that differ beyond the visual aesthetics. The first, 3.1, was intended to move between two opposite weather symbols and the second, 3.2, has three weather scenarios. This means that users must fill in the nuances in between.

Concept 3.3 does not have any weather elements related to it, but is intended to show the degree of certainty. The next two bows, 3.4 and 3.5, display a larger span of weather symbols, meaning users do not have to fill in the last symbols. Bow 3.4 has a bow with gradient of color intended to show certainty.

The thermometer concepts are very similar to each other. They are intended to be one excerpt of a graph. 4.2 and 4.5 are showing the certainty on both sides, while the others do not. These thermometers were selected due to their similarity with real thermometers, which users may recognize and understand more easily.

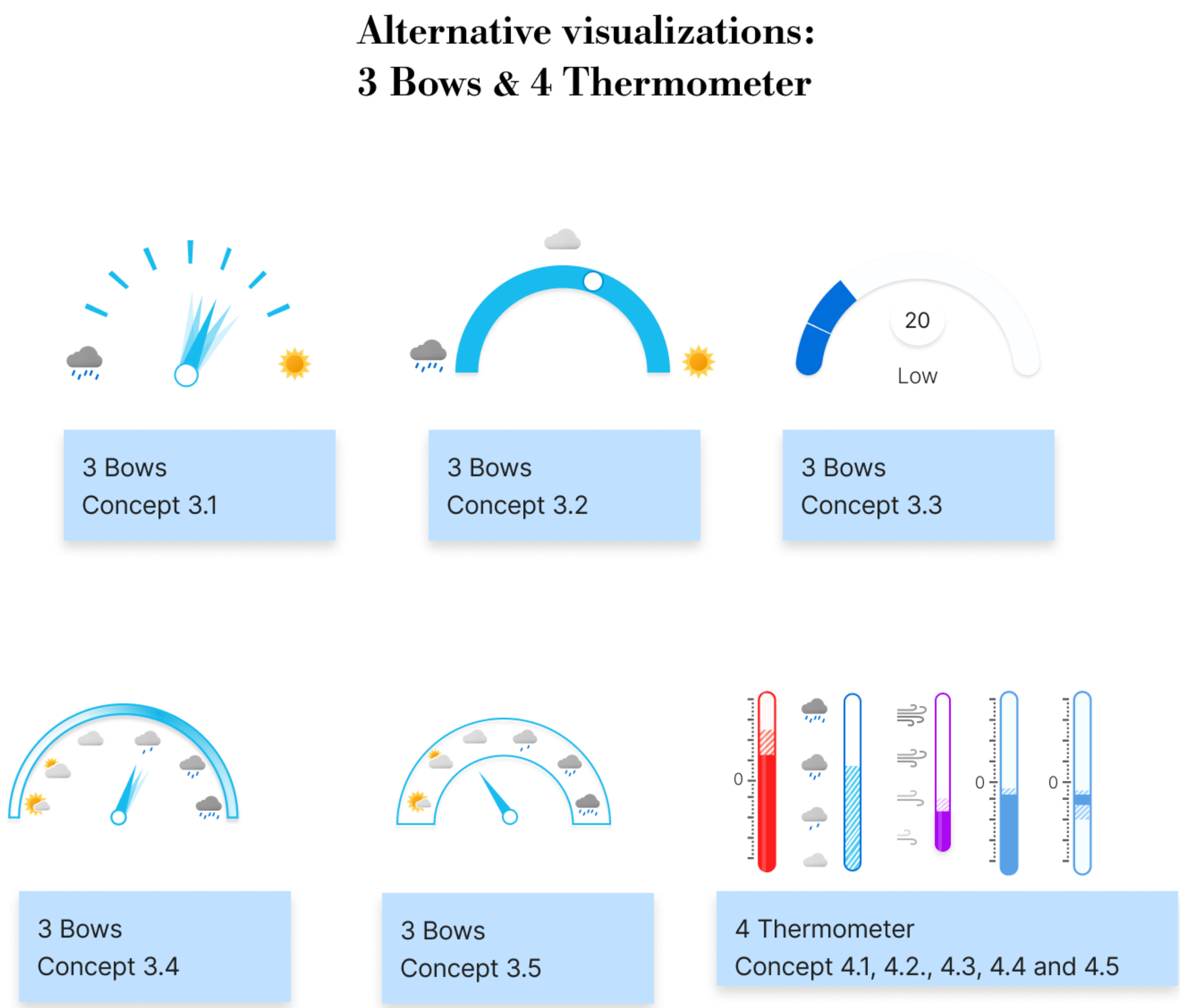


Fig. 5.42. Alternative visualizations chosen for user testing.

OTHER ELEMENTS FOR TESTING

The concepts presented on the previous page were intended to be tested with text, symbols, numeric values, and be placed in different interfaces, such as thermometers put in relation to a bow, in a hover function, and more, see Figure 5.43.

In addition to the visualizations presented; indicators, graphs, and alternative visualizations, other important elements to express or help understand uncertainty were prepared for user testing. These include:

<u>Filter options</u>
Both the graphs and alternative visualizations were presented by themselves and in a context where information could be filtered.

<u>"Details on command"</u>
Explanation and further information can be made visible through press/hover-function on graphs and by the indicators.

<u>Text</u>
Text in relation to visualizations was tested to provide users with explanations, in addition to expressing uncertainty through text.

<u>Context</u>
The indicators were presented with YR's table to create a weather forecast scenario, to provide users with context in order to analyze how they read the visualization in relation to the scenario, and how uncertainty could influence their actions. Additionally, a new context was designed where users could see an overview of a specific day or time of day chosen with the alternative visualizations and graphs.

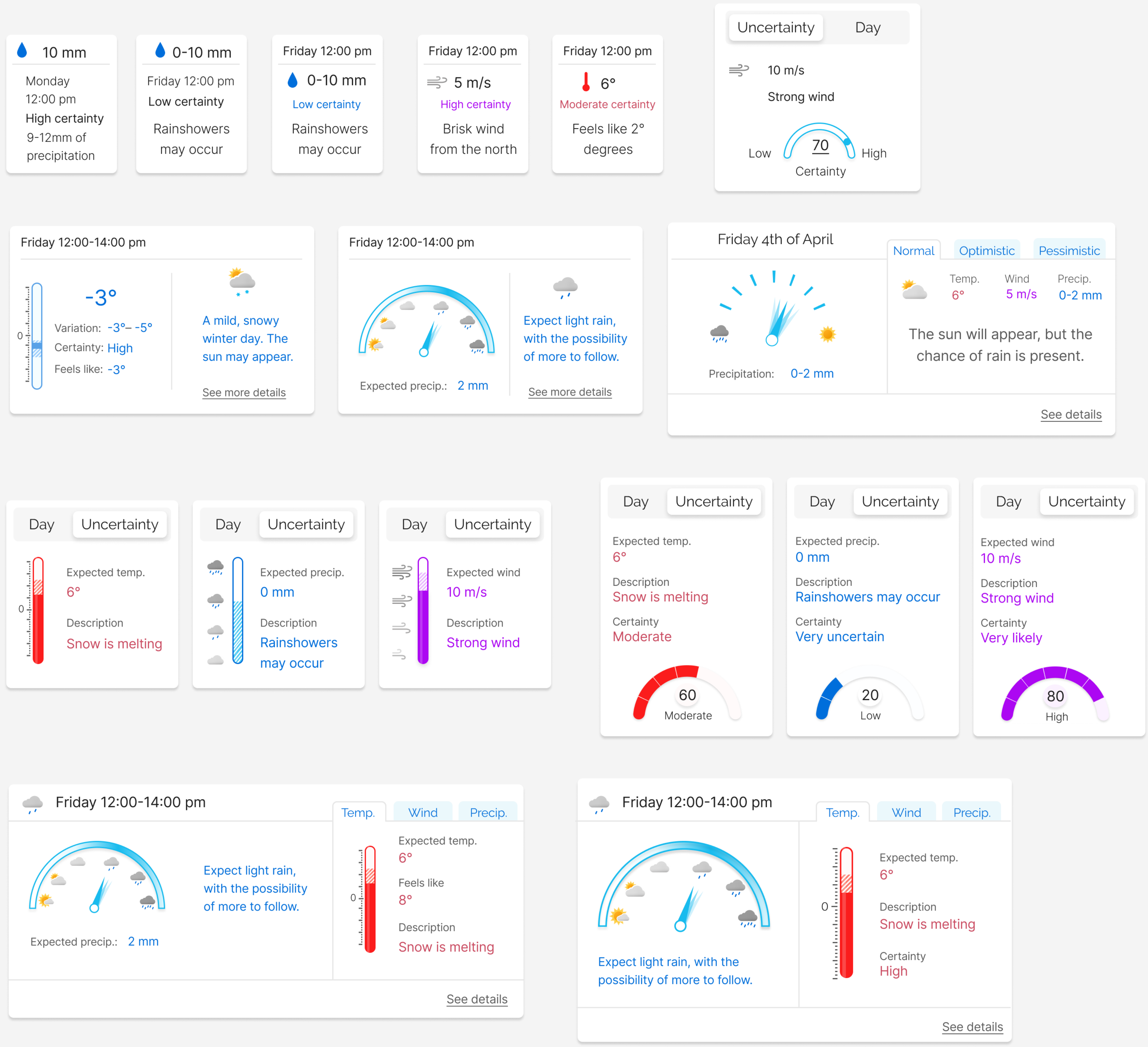


Fig. 5.43. Alternative visualizations in context explored for user testing

5.12 User testing

User tests were conducted with 6 participants in total. The main goal was to involve users from the risk group previously interviewed. 3 users from the risk-group previously involved had time and possibility to participate again. As most of the participants from this group were not as interested in conventional data visualizations, I decided to involve two users from the non-risk group: one with a physics background and one with an economic background with both an interest in weather and an understanding for graph-type visualizations.

The user test was created in Figma as a presentation, which participants accessed via a shared link, allowing interaction and control from their personal devices. Each test took between one to two hours.

The presentation started by sharing concepts of indicators presented in the context of a weekly table forecast by YR, intended as the first level of information. The following slides displayed graph concepts without context, to ensure focus on graph elements like symbols, colors, and uncertainty. Next, alternative visualizations were presented, including half-circle barometers, thermometers, and other user interfaces surrounding these. The final slides showed graphs and alternative visualizations in context. The participants were asked to share their thoughts and interpretations of the visualizations.

During the tests with the first three participants (Person 1-3), constructive feedback led to minor changes in the presentation. An additional page was added, asking participants to rate low, medium, and high uncertainty from 1-100, to understand their mental models.

The user tests with the full transcript of feedback are included in the appendix.

PARTICIPANTS

Person 1

Dog sled owner and outdoor enthusiast from the risk-user interviews.

Person 2

A new participant not involved with the project beforehand. From Finland, conducts seasonal work as snow scooter guide in Tromsø. Also an outdoor enthusiast, such as randonee.

Person 3

From the non-risk user group, fairly interested in weather and especially the uncertainty related to 0 degrees. An understanding and interest for detailed, graph visualizations.

Person 4

Part-time apple farmer from the risk-user interviews.

Person 5

A non-risk user interested in weather for outdoor activities like tennis and volleyball, with temperature interests and an economic background, helping to understand graph visualizations.

Person 6

Professional outdoor photographer also from the risk group.

5.13 User test results

When processing feedback from the user tests, the key findings were organized in a table. This approach was experienced as the most helpful for interpretation and comparison of results.

The table is included in the appendix, and displayed in Figure 5.44.

User tests: Key findings

Indicators	Most users correctly interpreted Concept 1.1, but required the hover functionality to be sure of its meaning. The additional explanation on hover received positive feedback. Mental models may have influenced user perception, as they expected forecasts ahead of time to be less certain. This meant that a solid line represented uncertainty and dotted line certainty, which was the opposite of the intention. Person 2 and person 6 mentioned how it might look like a mistake or glitch in the system. However, Person 4 mentioned that it facilitated quick scanning through the forecast, which was experienced as easy for quick information.	Most participants preferred the thermometer (Concept 1.2). It was described as clear and easy to understand. Person 4 suggested increasing the difference between low and moderate, to enhance clarity and make them less visually heavy. Person 5 and 6 also suggested adding color to help differentiate each level of certainty. When asked about colors, green, red, and yellow were mentioned without hesitation.	While I expected users to appreciate Concept 1.3, most mentioned that they still preferred the thermometer. Some participants were confused whether the bow was supposed to represent a half-moon or sunrise, while others shouted "banana!" at first sight. Person 4 appreciated the visual balance with the rest of the components in the table.	Concept 1.4 received comments mostly on issues with the target discs. Some appreciated the humor and creativity it held. Person 4 spent much time interpreting the forecast in relation to both the indicator and alternative outcome. As these illustrations were intended for quick information, the alternative outcome might have been presented in the wrong context. Other users also spent more time interpreting the whole forecast when presented with these two indicators side by side. Person 5 suggested that the alternative outcome could be used for a specific time of day.	Regarding decision making, the indicators led users to discuss how they would plan activities. However, as the first weather forecasts presented showed high uncertainty regarding rain early in the week, and certainty of sun later, their planning might have been the same without uncertainty presented. The forecast was adjusted for the last two participants, particularly to challenge person 6 with the planning. The participant started to argue the planning by referring to certainty. When certainty changed on the next page of the user test, the participant changed their plan due to the certainty indicators.
Graphs	The certainty line beneath the graphs in Concept 2.1 created clutter and unnecessary cognitive load for users. However, all users interpreted the solid color as certain and the shaded as uncertain. Person 3 appreciated the combination of symbols and numbers, which was contrary to the assumption that graph enthusiasts would find them unnecessary. Person 5 was unsure about using red color for temperature, due to its association with danger.	Most users found Concept 2.2 to be better than 2.1, due to the appreciation of displaying uncertainty on both sides. Person 5 mentioned that the graphs resembled standard finance graphs, making them easy to understand. Person 4 proposed only showing a single solid certainty line, but the graph enthusiasts enjoyed seeing more data and information.	All users except two expressed that they did not relate to graph visualizations, and one even asked to skip some of these visualizations. Person 3 and 5 enjoyed commenting and were interested in graphs. Person 3 appreciated the option to filter information (choosing which weather elements to be displayed), but suggested adding a timestamp on hover. Including the thermometer on hover was also debated, with mixed opinions.		
Alternative visualizations	Although some users commented on the "optimistic" forecast and personality choice to be amusing, it was not seen as beneficial. Person 2 stated, "I don't want to be the one making decisions". This comment was also related to Concept 3.1, as users preferred a range of weather symbols, like in Concepts 3.4 and 3.5. Furthermore, the density of the blue color in Concept 3.4 could be misinterpreted as precipitation amount, making Concept 3.5 the better option.	The majority of participants preferred the thermometer in Concept 4.5, due to its precise visualization. However, it was discussed that the solid area should be visible enough for users to see. Furthermore, it was also stated as important that users have the opportunity to be educated on the visualization, in order to learn how to use it.	Participants also liked the option to filter weather elements in alternative visualizations. Person 1 expressed: "The filter removes a lot of irrelevant information. That's a relief" However, it was important to have the opportunity to see all weather elements at once. Some also suggested that seeing less information could be beneficial on smaller devices like phones.	The combination of a bow presented together with Concept 4.5 affected users to start interpreting the forecast. If this is due to the combination of visuals or users getting used to them was not clear. However, most users interpreted the forecast as intended. Most users discussed the visuals before reading the accompanying text. Users also expressed appreciation for concise, functional text explaining the visualizations.	Presenting three illustrations at once caused confusion for the majority of participants. The test showed the predicted weather through a bow, a thermometer for possible precipitation amounts, and an additional certainty bow (Concept 3.3), for precipitation certainty. Person 2 said that it was easy to interpret the forecast, but several expressed that it felt like a lot of information.
Additional findings	Some participants did not notice the indicators initially, even those more visually heavy. This could be due to the users recognizing YR's table, and the expectation to read the forecast following the natural reading direction of left to right.	Person 4, 5 and 6 were asked to put a number on low, moderate, and high from 0-100, each answered similarly, where low was stated as below 30 and high above 70.	The surrounding elements were not meant to be analyzed, but rather provide users with context. However, users still focused on them. This could be due to the interface being new, compared to what they were used to. In contrast, the interface when using YR's table for context was not commented upon.	Users' preferences varied based on their visual preferences. The graph enthusiasts sought precise and extensive information, while others preferred simpler visuals with fewer elements.	

Fig. 5.44. Key findings and feedback from user test

Results

Concept presentation and discussion

6.1 Final concepts

INDICATOR

1st level of information

The final iteration of the indicator evolved from Concept 1.2. This concept was experienced as easy to understand, and received positive feedback during the tests. However, some constructive criticism was also expressed, related to color and visual weight. In response to this feedback, colors were added and the indicators' width were reduced. The "low" and "high" indicators were also changed slightly to better differentiate between levels. The term "medium" was also changed to "moderate" based on user feedback.

The indicator is designed to be accessible through three different visual elements: level, text, and colors.The chosen colors were suggestions by participants. Research also shows that a traffic light palette is suitable for showing uncertainty, and that green is most suited for representing certainty (Toet & Tak, 2014). However, further user testing could be beneficial to understand how they influence user perceptions and actions. The selected colors meet the WCAG AA contrast guidelines for graphical objects and UI-components. The colors were also added to facilitate quick scanning, enabling several users to understand the illustrations without needing to read the text.

Additional information was implemented through the small icon next to the title to help users learn and understand the concept. This could be a useful feature to include in the beginning of implementation to ensure correct data literacy. The indicator is intended to fit into various parts of a forecast, depending on the specific service's needs and user interface.

Fig. 6.1. Table (made transparent) is based on YR's existing table.

USER SCENARIO

A regular user visits her preferred weather forecast service and notices a new visual element. By seeing the headline, she understands that each illustration represents a degree of uncertainty.

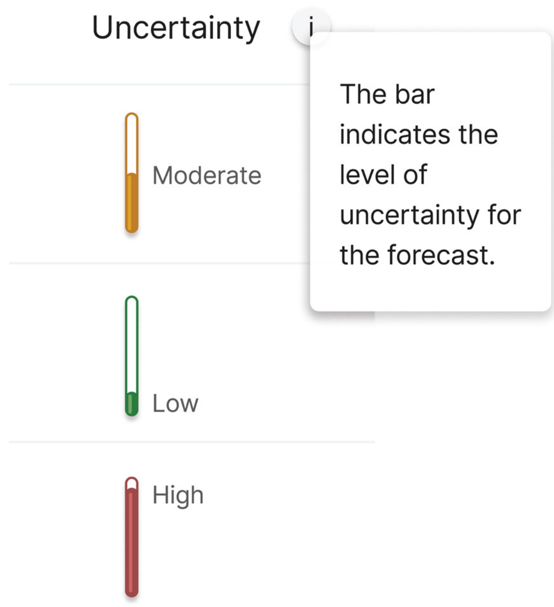


Fig. 6.2 Indicators with information

USER SCENARIO

She presses on the information button to validate her understanding. As the informative text confirms her interpretation, she is now confident in using the new feature further on.

Fig. 6.3 Final indicators

USER SCENARIO

Finding this new feature interesting, the user studies the colors, shape, and text of the visualizations, noting their differences to ensure quick recognition during future visits to the service.

BOW

2nd level of information

The bow was selected as part of the final concept due to its ability to show alternative outcomes. Many users liked the clarity it offered when showing the most probable weather and allowing for comparison between various weather scenarios.

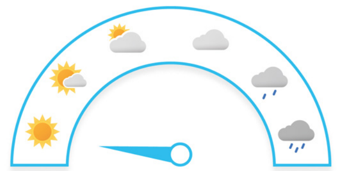
The bow has a range of weather symbols, adhering to users' preferences to see, rather than imagine, the symbols that fall in between two opposites on the scale.

The weather symbols are created by YR. These symbols are intended to be replaced based on a service's visual identity and own preferences. The concept allows for weather symbols changes based on predicted forecasts.

Each bow is intended to be accompanied with text to enhance understanding and incorporate information about uncertainty.

The sun will appear, but rainshowers may occur

Expect light rain, with the possibility of more to follow



Sun is expected with minimal cloud coverage

Varying temperatures may cause rain and snow

Fig. 6.4 Final bows

USER SCENARIOS

A user is interested in weather details for today, since she noticed the high uncertainty indicator on the services' first level of information. The arrow points between cloudy weather and partly sunny conditions. Reading the complimentary text, the user is informed about the predicted weather, and decides to bring an umbrella for her trip to town.

The user sees raindrops streaking her window the following morning. She had planned to hike, so she optimistically checks the weather hoping it will clear up. The bow and text suggest high certainty for rain, leading her to postpone the trip.

The sun is shining without clouds in sight. The user is hopeful as she checks the weather forecast. With a confirmation of the predicted high weather with low uncertainty, she can confidently set out for the hike she had previously canceled.

The user has plans to drive to the store for her weekly grocery shopping the next day. When checking the weather forecast, she finds that winter has arrived faster than anticipated. She has not had time switching to winter tires or harvesting the last cabbage from her vegetable garden. The user changes her plans for the day to ensure the shopping can be carried out the next day.

THERMOMETER

2nd level of information

The thermometer concept aims to offer a simplified alternative to graph visualizations. Several of the users interviewed were uninterested in graphs when reading the weather forecast. This insight led to the development of alternative concepts with the goal of differentiating from the traditional graph visualizations.

The thermometer was selected because most users understood and interpreted it correctly. While the feedback was mainly positive, some constructive comments led to minor changes in visualization.

The thermometers are designed to be less detailed than graphs, due to users' preference for simplicity. Many users would first interpret the thermometer before confirming with the supplemented text, suggesting that the visualization effectively conveys information.

Furthermore, the thermometer shares similarities with the chosen indicator and functions as a snapshot or summary of graphs. This allows users to easily recognize and associate it with information that they have previously been exposed to.

The thermometer is intended to be displayed together with other visual elements, and be used for showing uncertainties within a day's forecast or a specific time of day. Two examples of each weather element are displayed.

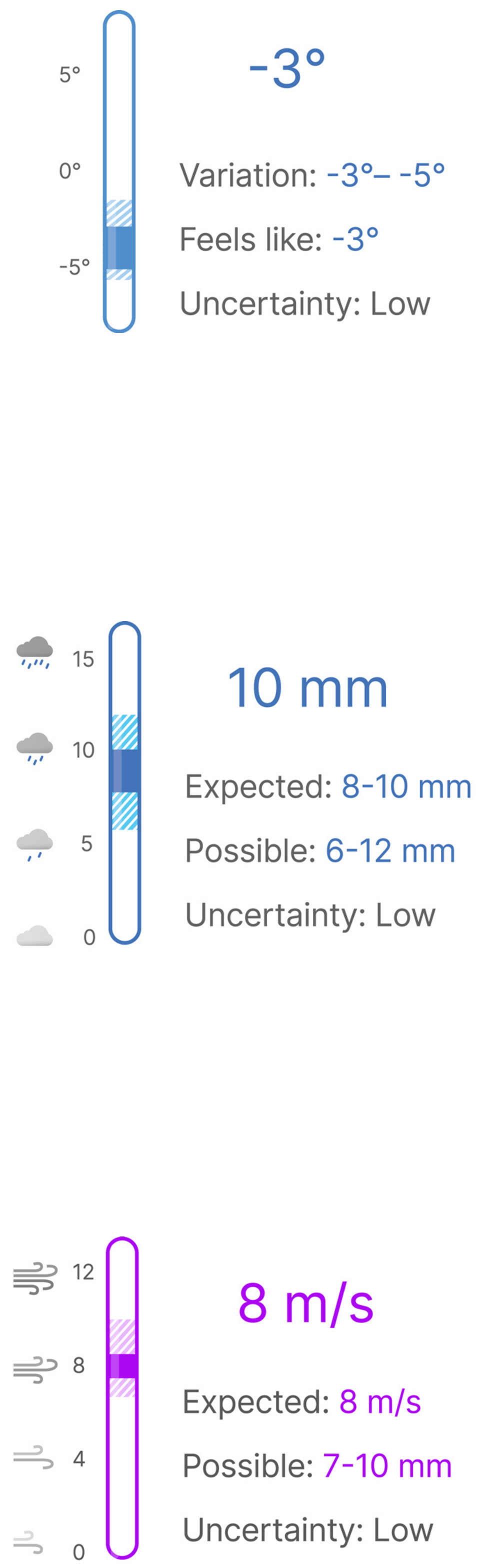


Fig. 6.5 Final thermometers

USER SCENARIOS

After weeks of precipitation and chilly temperatures, the snow has become thick despite warmer weather approaches. A user plans on skiing one last time before spring arrives, and checks the temperature forecast for the following day to ensure it is not too cold or hot. Seeing the forecast's low uncertainty, the user confidently invites the rest of the family to join the ski trip.

Several weeks later, the snow has melted, and spring has surely arrived. The user plans to hike up the local mountain as he usually does this time of year. Before finalizing his plans, he checks the precipitation forecast for the weekend. The user observes low uncertainty for rain during his preferred hiking hours, and decides to postpone his plans for safety reasons.

The user does not want to spend the weekend indoors, and considers other outdoor activities that are safer in rainy conditions. While checking the forecast for the weekend, he recalls the fun in surfing. Rain and chilly water will not stop him from going, and seeing low uncertainty for 8 m/s, he is satisfied to invite the rest of his surfing-crew to join him.

EXAMPLE OF CONTEXT

2nd level of information

Two “context” examples have been created to illustrate how the previously discussed visualizations could be implemented.

These examples serve as simplified overviews of a forecast, showing details related to a specific day.

The contexts showcase both the indicator, bow, and thermometer to demonstrate how they can collectively create and provide meaning and information.

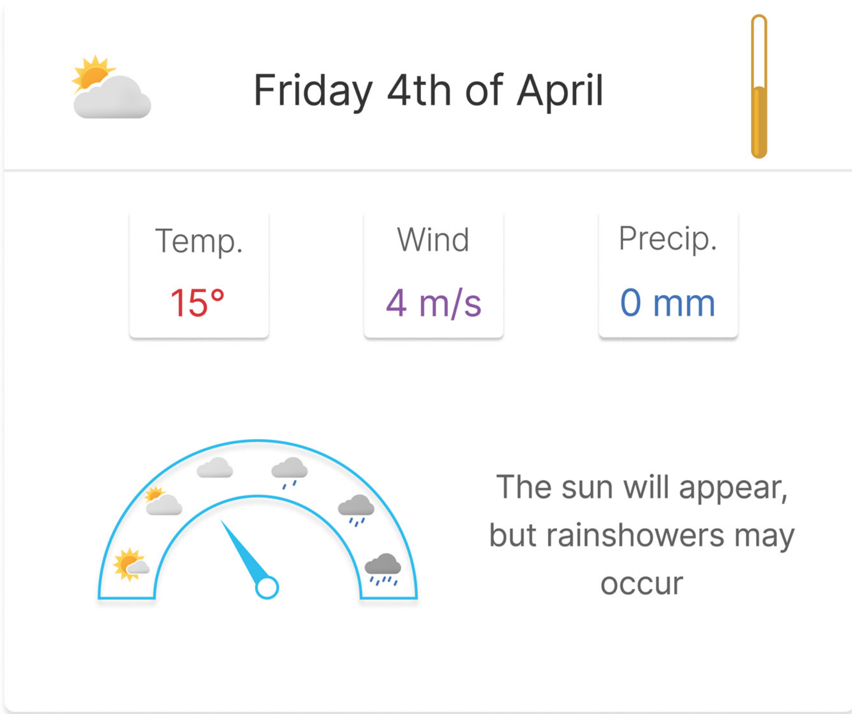


Fig. 6.6 Example of visualizations in context

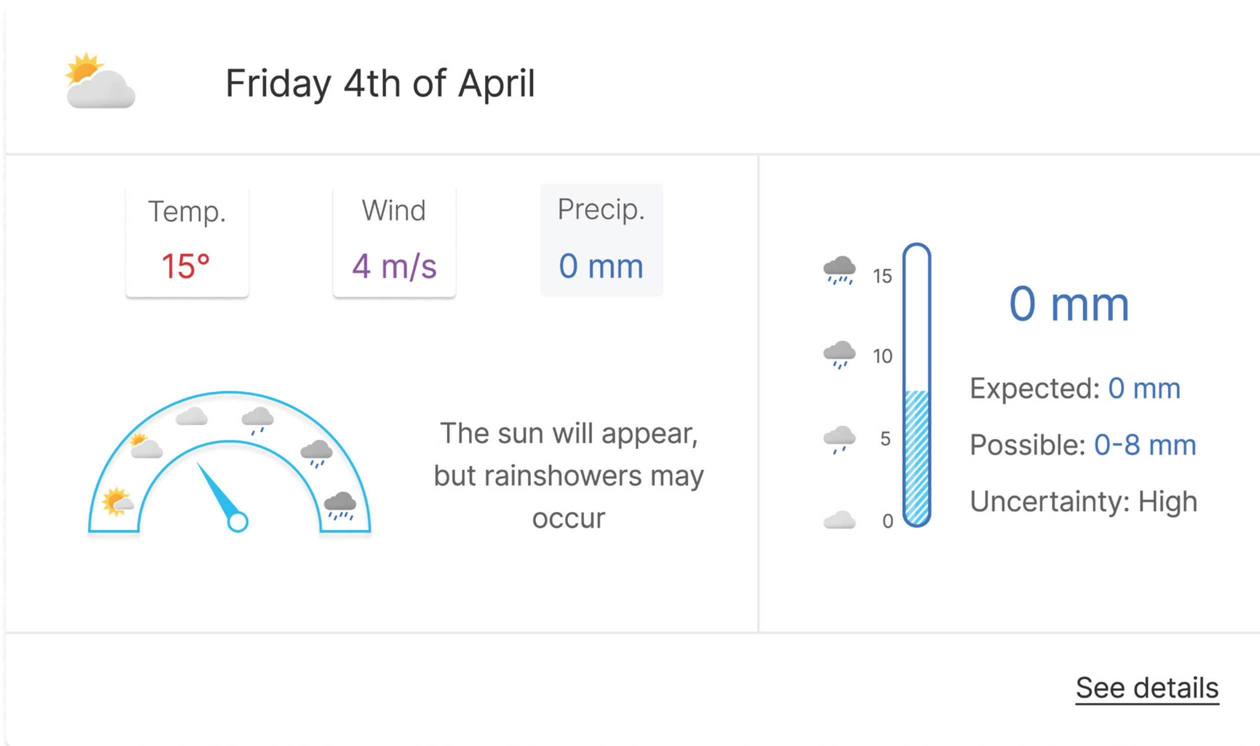


Fig. 6.7 Example of context with precipitation details

USER SCENARIOS

A user visits the forecast service to review predictions for Friday. The first level of information indicated moderate uncertainty, leading the user to explore further details. The detailed view reused the moderate indicator, confirming or reminding the user of the uncertainty. Observing the bow and accompanying text, the user understands that the uncertainty is connected to precipitation.

The user is interested in information about the uncertainty, and presses on the expected precipitation for more information. The visualization provides information about the high uncertainty considering precipitation, and the potential for up to 8 mm of rain. Alongside the thermometer, the user can again refer to the text to understand that rain showers may occur, but that it is quite uncertain. The user decides to postpone staining the balcony to avoid potential consequences of rain.

GRAPHS

3rd level of information

The final graphs were decided based on user feedback. The version presented was favored by most users, especially the graph-enthusiasts. The ability to see uncertainty on both sides of the expected outcome was important.

The graph and its legend has similarity to YR's current solution of displaying wind and temperature data, specifically the use of shaded areas and dual-sided uncertainty. The graph diverges from YR's when it comes to precipitation, width of solid color, the use of symbols, and the overall idea of maintaining the same graph structure across all weather elements. An additional focus is the aesthetic, particularly the use of white space to reduce visual clutter and cognitive load. This design choice is reinforced by the literature findings presented in Chapter 2 and from the expert interview from Chapter 3.3.

The symbols displayed beside the y-axis on the graph for precipitation and wind are designed to improve data literacy and enhance understanding for these variables.

Filtering options have been previously discussed and user tested. Providing such an option should be considered in order to provide users with the option to suppress irrelevant information. However, it is unclear whether users who typically prefer graphs value such a feature, and the proposed change should therefore be user tested.

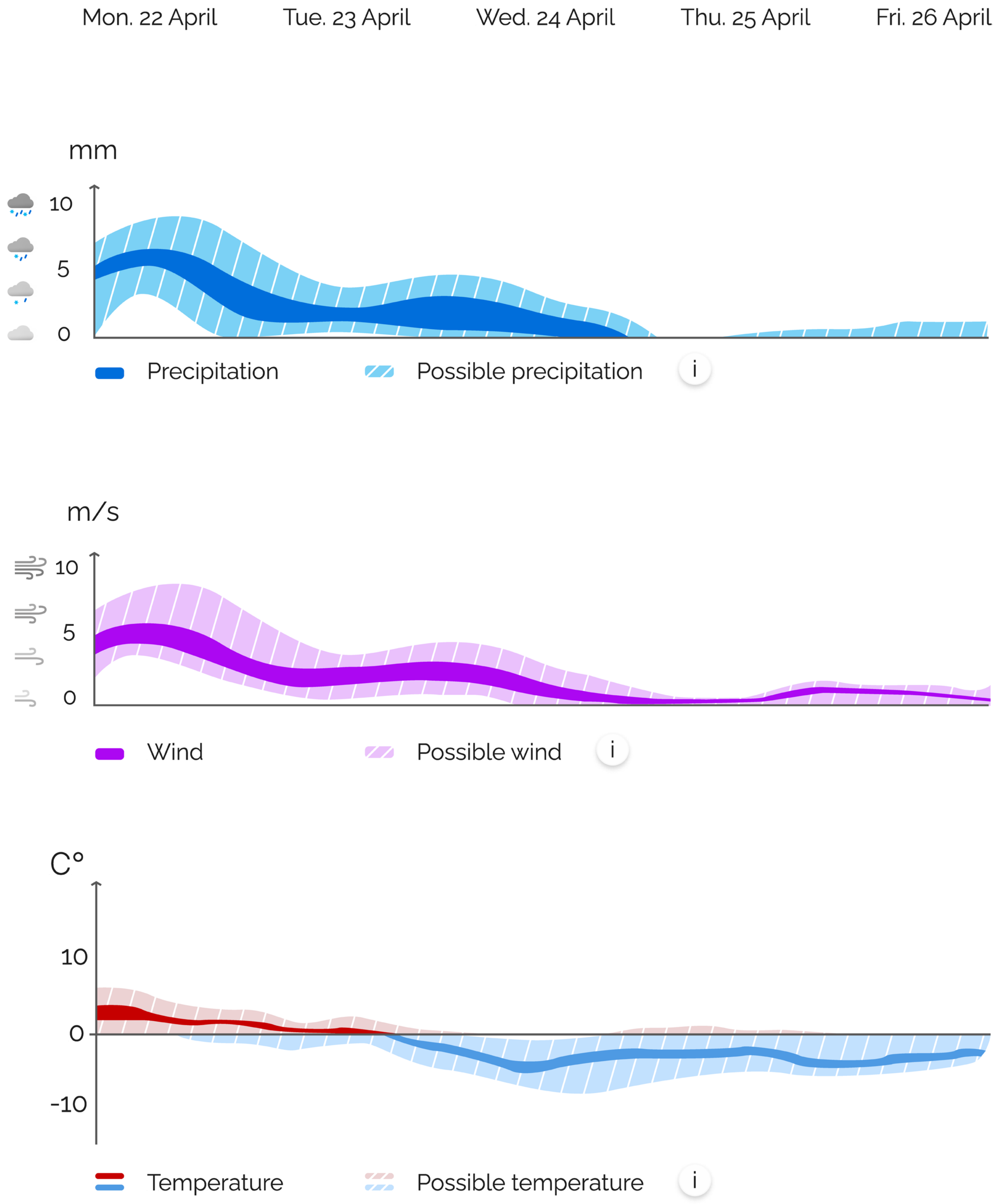


Fig. 6.8 Final graphs

USER SCENARIO

A user is planning a ski trip during the week. The weather has been warm recently, but with December approaching, she hopes for colder temperatures. The user is quite comfortable with using graphs to obtain a better overview of the week's forecast. She notices expected precipitation on Wednesday, and a shift in temperatures, indicating potential for snowfall. She observes uncertainty regarding precipitation on Friday, but given the forecasted low temperatures, any precipitation will likely be snow. This forecast makes her optimistic for a weekend ski trip, due to low temperatures and snowfall earlier in the week.The forecast suggests minimal wind, and the width of the solid colored line confirms the prediction's high certainty.

GRAPH DETAILS

3rd level of information

The information that pops up on hover was modified based on user feedback. One of the graph-enthusiasts expressed that the thermometer, which was previously visible on hover, could be redundant and too small to be useful. It was therefore removed. Users appreciated the precise information concerning expected and possible precipitation. Additionally, information regarding uncertainty was also added to provide more detailed information. This element could use the indicator instead of text, but both options should be tested in order to understand user needs, as the graph itself shows levels of certainty:

The solid presents certainty, and the shaded area shows uncertainty. The extent of the shaded area will impact how certain a prediction seems. If the hover function expresses moderate to high uncertainty, users could be affected to pay more attention to the shaded area and consider the likelihood of alternative outcomes.

Finally, an information button was added to clarify the legend, particularly the term "possible wind". This phrase differs from YR's current term "80% probability wind", which may not be understandable to all users. The text is designed to help users interpret the data presented, but the effectiveness of the formulation should be user tested.

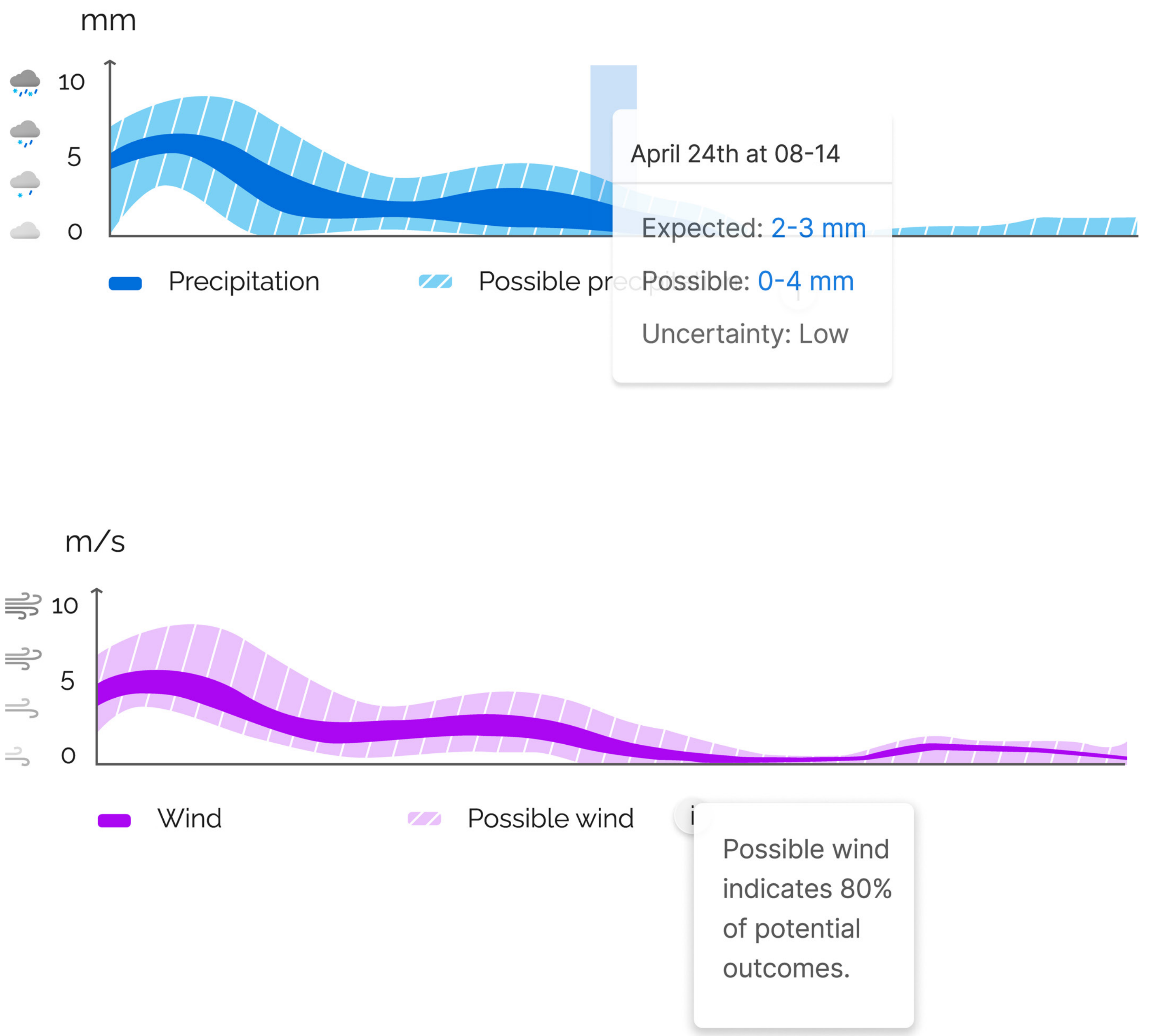
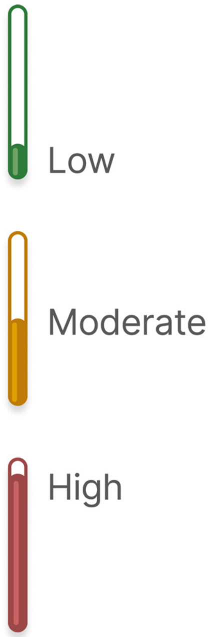


Fig. 6.9 Final graphs with additional information

6.2 Presentation

INDICATOR

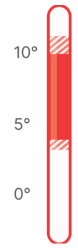
1st level of information



BOW AND THERMOMETER

2nd level of information

The sun will appear, but rainshowers may occur

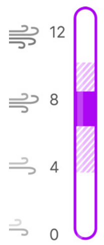


6°

Variation: 4°– 10°

Feels like: 8°

Uncertainty: Moderate

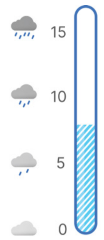


8 m/s

Expected: 6-8 m/s

Possible: 4-10 mm

Uncertainty: High



0 mm

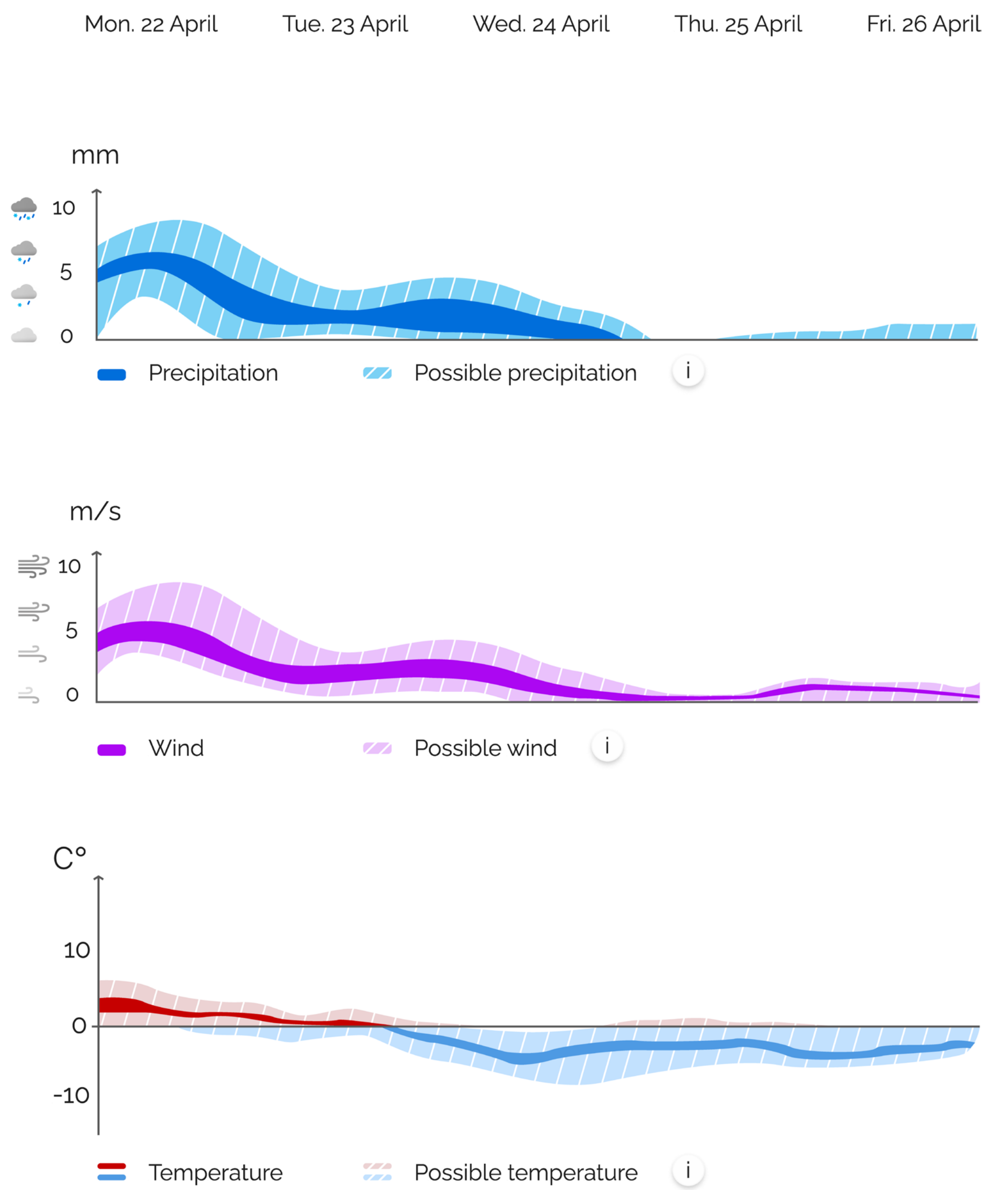
Expected: 0 mm

Possible: 0-8 mm

Uncertainty: High

GRAPH DETAILS

3rd level of information



6.3 Discussion

This research study led to several findings concerning the process, expert involvement, concepts, and user insights.

PROCESS

The project explored uncertainty in weather forecasting, but uncertainties were also present during the process. For instance, user involvement and participation was not always certain due to individuals' availability and time schedules. Therefore, having a flexible and dynamic approach to process planning and structure proved to be important.

The project was structured into several phases. Initially, my knowledge of the topic was limited, yet ideas for concepts emerged through all stages of the process. In retrospect, sketching ideas throughout the process could have been helpful, potentially resulting in interesting findings to reflect upon. At an early stage, concepts would not be influenced by theory and new knowledge, possibly leading to more intuitive, simple solutions. This reflection was triggered during concept development, as I noticed that the concepts were influenced by newly acquired knowledge about data. For example, I overlooked considering users' comprehension of precipitation measurements, as I had already learned about it during the process. At that stage, I felt a need to explore more innovative solutions.This realization led to the second workshop with Halogen, described in Chapter 5.9, which helped boost creativity. However, an internal ideation and sketching could have been introduced earlier in the process.

Using design methodology and principles provided user-centric perspectives, which is essential when designing solutions that directly impact users. The project revealed examples of how weather influences specific users and their activities, contributing to further insights. For instance, the outdoor photographer was asked to select a shooting day based on an indicator table. The participant altered their preferred day when the level of uncertainty changed. Furthermore, several of the participants from interviews shared how weather affects their decision-making process, and discussed how uncertainties could influence their planning, especially for long-term predictions.

User testing also revealed important information. In some cases, the designed context could distract users to focus on the user interface, rather than the uncertainty visualization. The users were used to YR's interface, and introducing a new interface did influence their feedback. For example, some users offered feedback on functionalities and adjustments to the surrounding visual elements, such as my design for a weekly forecast – which was only intended as an illustrative example to help understand the uncertainty visualization. To better guide users to focus on what was intended, adjustments could have been made to the context. This could involve adding transparency or further simplifying the interface elements.

EXPERT INVOLVEMENT

The importance of multidisciplinary collaboration was highlighted throughout the project. Conversations with YR, particularly with the meteorologists, were crucial for gaining data understanding and competence. Recognizing my role as a design student and others as experts was essential. This self-awareness helped me identify gaps in my knowledge, providing me with insights on what knowledge to seek for and how I could contribute to the research. For example, sharing concept sketches with meteorologists provided valuable feedback. This was crucial for understanding realistic visualization of data and areas where my solutions were lacking.

Other experts were involved in the early stages of the project, contributing to the exploration of the preliminary research question. Two interviews were conducted, one about data literacy and knowledge, and the other focusing on aesthetics. Their competence and professional experiences were important to confirm with literature findings, in addition to further understanding of the topics. For instance, the importance of data literacy and the potential of visualizing became clear. Additionally, the significance of aesthetics in user experience and its relation to functionality influenced my design approach. Insights such as the need to eliminate clutter and the value of iterating and testing ideas were beneficial during concept development.

CONCEPTS

The project showcased how mental models and interpretations influenced user feedback. My own and participants' biases and misconceptions were uncovered. It became clear that visualizing uncertainty could help enhance users' data literacy and planning, for instance by showing that forecasts ahead of time can be more certain than the ones closer to the current day. Additionally, insights from interviews showed that users do not search for information they do not know exists. These insights led to the concept of an uncertainty indicator, allowing users to delve deeper into information if desired. A services' navigation should facilitate easy access to further information, without having previous knowledge of where the information lies or having to actively search for it. The indicators were tested with users, and several shared how they would plan their week by referring to the indicator.

The colors used in concepts were primarily taken from YR's current palette. Each color was chosen as they align with existing associations; blue for cold temperatures and precipitation, and red for warm temperatures. Wind may not be associated with purple. However, the decision to adhere to YR's established colors was to strengthen the focus on uncertainty visualizations. As the participants in the user tests were used to YR, it was important to avoid confusion that might have arised from introducing new colors. Furthermore, the use of red, yellow, and green for the final indicator was based upon research showing its suitability (Toet & Tak, 2014), and feedback from user participants.

Conclusion

Project conclusion and future research

7.1 Conclusion

This master's thesis started as an exploration of data visualization. In the process, a visual map was created to better understand and foster learning of the subject. This exploration revealed some challenges, in which visualizing uncertainty was one of them. In parallel, I came in contact with YR, a weather forecast service, which expressed interest in the challenge of uncertainty. This marked the beginning of the main focus point of my thesis.

The exploration of uncertainty focused on literature insights which uncovered several challenges. These included issues of data literacy, such as the varying interpretations of probability when displayed as percentage (Burgman, 2015), and how the influence of users' prior experiences, cultural backgrounds, and local contexts affect interpretations (Sivle, 2016). Facilitating for user comprehension of data visualizations was at the center of this project. This was explored through methods such as user testing and interviews, and by designing solutions that provide clear meaning and alternatives. For instance, the use of text in addition to illustrations has been a valuable tool.

Despite the challenges presented in this thesis, the importance of visualizing uncertainty has become clear. Literature and previous studies have shown its usefulness for evaluating consequences and risks (Sivle, 2016), and for enhancing the audiences' trust in weather forecasts (Hanrahan & Sweeney, 2013). User tests and interviews further emphasized the potential of uncertainty information in relation to planning and decision-making. It is helpful for a range of activities, from minor risk evaluations, such as tire changes or planning for alternative travel routes, to larger decisions in professional fields and outdoor activities, where it helps reduce financial and life risk. For example, the vegetable farmer could adjust plans to secure crops against diverse weather conditions when informed about uncertainty in the forecast.

The final research question evolved to: "How can data uncertainty in temperature, wind, and precipitation within weather forecasts be effectively visualized to enhance user experience and comprehension?" This question helped guide the project to generate several concept ideas. These ideas were based on user insights, feedback, creativity, and further knowledge from literature. The competence that was built helped with structure, such as choosing three levels of information for concepts. The first level provided the uncertainty indicator, the second conveyed usable details, while the third aimed to offer in-depth data such as showing weather trends over time.

Interviews and user testing were key methods to enhance user experience. Additionally, the use of colors, clear language, and a focus on accessibility contributed to user comprehension. Both user experience and comprehension are closely related. It was crucial to reduce clutter and apply simplicity, while ensuring the information remained helpful. Nevertheless, further research and testing are needed to reach the full potential of the concepts. The visualizations are designed to be adjusted and integrated into systems or services, to ensure consistency with their own user interfaces, design systems, and identities. It is up to them to create the context surrounding the visualizations.

While there are still many areas to explore, this master's project has provided a foundation for understanding and visualizing uncertainty in weather forecasting, hopefully contributing to further development of the field of data visualization.

7.2 Future research

Moving forward, there are several areas that require further investigation, particularly in relation to user testing and involvement.

While the project primarily focused on uncertainty visualizations, it is important to ensure a visual balance and cohesion with additional designs and interfaces if the concepts are to be integrated into existing services. Additionally, considerations include thorough research and testing to ensure universal design principles are followed, thus providing a more inclusive user experience. For instance, making sure the service and features are accessible for those relying on keyboard navigation or users with visual impairments.

Furthermore, exploration of colors and testing should be conducted to understand their impact on users. While colors often impact associations to weather, they may also impact the comprehension of uncertainty. As mentioned in Chapter 2.2 under "Culture", cultural differences may impact the understanding and associations related to colors. When choosing colors, cultural differences need to be considered in relation to the platform's audience.

Moreover, observations suggest the importance for careful consideration of context in future user testing. One potential approach could involve testing solutions on a live service to observe how their existing user groups interact with new uncertainty visualizations. Another strategy could be to create stories based on individual users to enhance understanding of how uncertainty information could influence decision making. For instance, users could share their weather-dependent plans for upcoming weeks, and be provided with several weather scenarios incorporating uncertainties. This could facilitate feedback to understand how such scenarios could impact users' actions by using real-life situations.

The user interviews have provided valuable information about existing users of weather data, their typical weather-influenced activities, and their specific needs. These insights could serve as a foundation for future research. Stories based on these insights could be crafted to better understand needs and help both iterate and ideate concepts and designs.

The concepts that were explored followed a 2D format, which could limit their potential. Future research could benefit from exploring other methods of communicating uncertainty, such as videos, gifs, sound, and more. Such methods could increase user engagement and even involve younger audiences including children, fostering data literacy from an early age.

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Literature and photos

8.

8.1 Literature

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8.2 Photos and illustrations

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