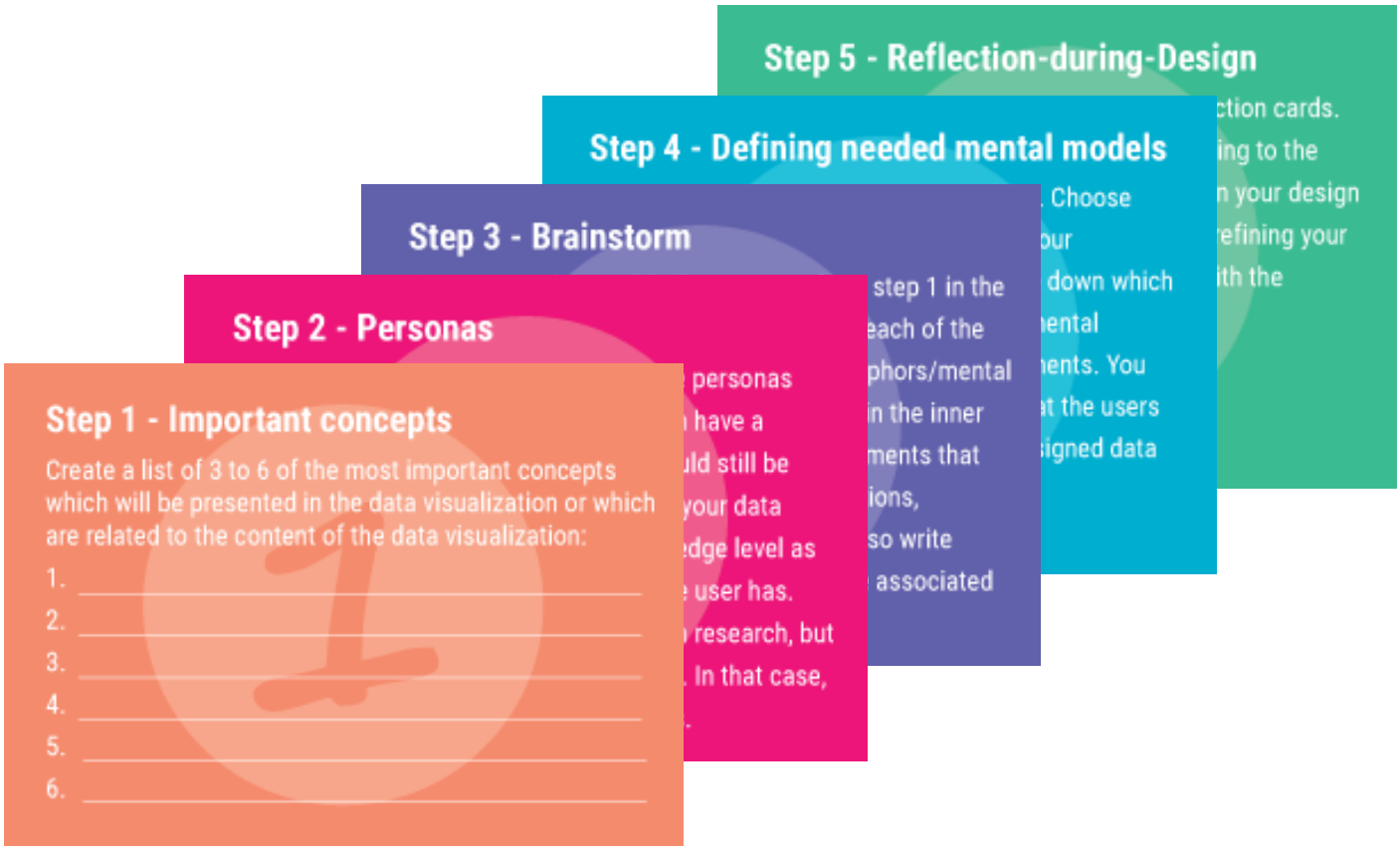
DESIGNING THE HEALTH DATA COMMUNICATION IN MENSTRUATION TRACKING APPLICATIONS

Users' challenges and the role of design in the visualization of health data



Master Thesis
03-04-2023
Industrial Design Engineering &
Communication Science
DPM 2007
Marije Pott

UNIVERSITY OF TWENTE.

Designing the Health Data Communication in Menstruation Tracking Applications
Users' challenges and the role of design in the visualization of health data

This thesis study was supported by the University of Twente DesignLab Research Fellows Fund under the project titled 'An Exploration into Designerly Ways of Knowing Digital Personal Health Data.'

Master Thesis
Marije Willemien Pott

Faculty of Engineering Technology
Department of Design, Production and Management
Industrial Design Engineering
Human Technology Relations
&
Faculty of Behavioural, Management and Social Sciences
Communication Science

DPM 2007

Examination Committee:

Prof.dr.ir. G.D.S. Ludden	(chair)
Dr. A. Karahanoğlu	(1st supervisor IDE & 2nd supervisor COM)
Dr. T.J.L van Rompay	(2nd supervisor IDE & 1st supervisor COM)
F. Toso	(IDE member)

Acknowledgements

In February of 2022 while in search for a master thesis assignment, I came across a LinkedIn post from Armağan Karahanoğlu. While the assignment from the LinkedIn post was not a match for me, she proposed the project 'An Exploration into Designerly Ways of Knowing Digital Personal Health Data' to me. And now, a little more than a year later, I am looking at my finished thesis for both studies of Industrial Design Engineering and Communication Science. The year flew by, and I had a lot of fun working on this project.

Therefore, I would firstly like to thank Armağan Karahanoğlu for the opportunity to work on the project, but also for the great discussions and progress meetings. These meetings always left me with a full to-do-list, which was honestly great and made the process so smooth. Furthermore, I would like to thank Thomas van Rompay as well for his guidance during the project. His knowledge and communication science perspective made that I really learned a lot during this thesis. I am really grateful that I had two very enthusiastic supervisors, thank you both!

Additionally, I would like to express my gratitude to the little Women's Health group that was formed during my thesis. Together we had great conversations and discussions on each of our own research projects. In particularly, I would like to thank Danique Hofstee for helping me with the design workshop, thinking along with me and giving great feedback.

Furthermore, I would like to thank the DesignLab for supporting the project and providing me with a space and materials for the design workshop.

Lastly, I would like to thank my friends, former flat mates and family for supporting me throughout this thesis. Not only by critically thinking along but also by listening to me and sharing their own experiences.

I hope that you enjoy reading!
Marije Pott

Abstract

Health tracking applications become increasingly popular, since they help people gain knowledge about self and promote empowerment and self-control. However, studies show that users of these apps sometimes have difficulty in understanding their data and consequently do not utilize their collected data effectively. Even though health tracking has many potential benefits, the difficulties users encounter may lead them to doubt the usefulness of the apps and disengage from tracking activities.

To address this challenge, this thesis reports the results of two studies conducted to answer the research question of 'What roles can design practice undertake to improve visual health data communication in tracking applications?' within the domain of menstrual health tracking applications. The first study, semi-structured interviews with users of menstruation tracking apps, identified challenges that users face during the interpretation of app data. The interviews revealed 6 causes for misinterpretation: (1) perceived similarity, (2) visual clash, (3) clutter, (4) overlooking of data, (5) clashing self-knowledge and (6) designer-user mismatch. The study also revealed that users try to make sense of data visualizations by attaching associations and employing their existing mental models to understand the visual elements they see in the data visualization. Results showed that sensemaking of a data visualization is a constant loop of looking at visual elements and assigning meaning to them. These sensemaking practices are presented in the data visualization sensemaking framework.

The interview study was followed up by a design workshop with the goal of exploring how designers help the users overcome the health data communication challenges. The design workshop showed that only knowledge of the users' sensemaking practices was not enough and the designs still contained flaws due to the participants' assumptions that the designed visual elements were clear to the users. Designers need more guidance and/or steps to reflect better on the visual elements in their designed data visualizations. In the end, this thesis proposes a reflection-during-design tool, which could help designers actively reflect on each of the visual elements that they put into the data visualization. The reflection-during-design tool consists of five steps that the designers will have to follow: (1) identifying important concepts that will be presented, (2) creating personas with different levels of self-knowledge, (3) brainstorm visual elements, (4) defining needed mental models for the interpretation, and (5) answer reflection questions about the design.

This thesis study was supported by the University of Twente DesignLab Research Fellows Fund under the project titled 'An Exploration into Designerly Ways of Knowing Digital Personal Health Data.'

TABLE OF CONTENT

CHAPTER 1
Introduction

CHAPTER CONTENT:

1 INTRODUCTION

The prevalence of health tracking apps in smartphones is rapidly increasing with an estimated 3.18 million users of fitness, meditation and nutrition apps in the Netherlands in 2022 [1]. Health tracking technologies give the users inferences about topics ranging from sleep [2] and daily physical activity [3] to diet [4] and symptom tracking [5], utilizing data from different wearable sensors, smartphone sensors and self-reports [6]. Health tracking itself has become an ubiquitous practice for many, as individuals can collect and reflect on diverse health-related data in daily life, from the type of alcohol consumed to the type and location of the physical activities that take place [7].

Health tracking proves to have multiple benefits [8, 9]. It helps people gain self-knowledge [10], facilitate self-reflection [10, 11], promote empowerment and self-control [12]. Despite these benefits, it has been observed that individuals may find it difficult to comprehend the data obtained through many health trackers (e.g., sleep score [13]) and the reasoning behind the predictions (e.g. the fertility window [14]). These difficulties sometimes result in a lack of understanding the reasons and the results of health behavior [15]. Furthermore, there have been instances where the tracking process itself proves to be futile, and the individuals do not utilize the collected data effectively [16]. This ineffectiveness may lead individuals to doubt the usefulness of the trackers and consequently disengaging from tracking activities [8].

Data is presented visually in health tracking applications. Health tracking applications take the collected pieces of information and render these into visual formats. Hereby, the pieces of information get certain properties such as shape, color, size, and position that convey the meaning of the information. This rendering of information into a visual format is also called a data visualization [17]. Data visualizations present the collected data to users in a clear and concise manner [18]. The primary goal of data visualizations is to make the data transparent and accessible to user [19]. However, Ajani et al. [18] found that many data visualization practitioner guides argued that visualizations are ineffective, confusing and even misleading. Although the data visualizations are the users' primary access means to the data itself [19], the question still arises as to why users may struggle to make sense of these visualizations and use the presented data effectively.

Multiple studies have already focused on proposing design principles or implications for the design of health tracking applications [8, 20-22]. However, when focusing on the users' comprehension of the presented data, there are no clear guidelines or requirements. One example of such recommendations is that of Rooksby and colleagues [28] which states that the designer should not expect users to be data scientists. This recommendation does not state what to do to prevent regarding the users as data scientists. The recommendations that come closest to the improvement of data interpretation are from Eschler and colleagues [5], they help to improve menstrual literacy in menstrual health tracking applications. Suggestions like assessing design assumptions about menstruators and adding more tips about self-care from evidence-based resources are defined to offer advice and hopefully increase self-knowledge, with the goal to improve menstrual literacy [5]. However, the improvement of menstrual literacy does not guarantee the improvement of the data interpretation, as the effect of menstrual literacy is still unknown [5]. That is why this thesis will focus on improving health communication with the goal to improve users' data interpretation.

1.1 Challenges in Data Communication

Franconeri et al. [23] suggests that low graphical literacy and ineffective design are two causes of the inability to understand data visualizations. But, even though the more graphical literate audience has more knowledge on common schema elements, for example the assumption that larger values are plotted upward, designers do not always respect these [23]. Therefore, effectiveness of visual representations can be improved by following visual design guidelines. Two well-known design guidelines in data visualization are that of declutter and focus [18], in which declutter suggests to remove unnecessary elements and focus suggests to provide highlighting that lead the user to focus on the proposed pattern in the data [18]. Ajani et al. [18] found that multiple practitioner guides state that these two guidelines improve the understanding and clarity of data communication. But declutter and focus are not the only guidelines, Franconeri et al., [23] also created multiple design guidelines, of which being aware of common visual illusions and confusions, and avoiding taxing working memory by converting legends into direct labels are two examples [23]. Furthermore, the gestalt principles are also an essential part of how users perceive visual design, well before applications were created [24]. Gestalt principles like similarity and proximity explain that people group data they perceive together when they have a similar color for example (e.g., similarity) or when they are closer to each other than other data (e.g., proximity). Visualizations that incorporate gestalt principles facilitate sensemaking because they exploit the users' predispositions to perceive related objects as a group [24].

Even though there are many design guidelines and principles for data visualizations, the design of the data visualizations is still not optimal [23]. One possible reason for this is that designers may still create ineffective visualizations because they assume that users have certain knowledge, when in actuality the user does not have this knowledge [25]. This psychological phenomenon is called the curse of knowledge or the curse of expertise [18, 25]. According to Xiong et al. [25] the consequences of this phenomenon are not studied well in the field of data visualizations, they found that the curse of knowledge did play a role in this field but they also did not study this effect during the design of the data visualization.

1.2 Aim, Research Questions and Scope of the Thesis

The goal of this thesis is to improve the way designers create data visualizations in health tracking applications with the purpose of improving health data communication. This thesis will first follow up on the discussions around self-trackers' data sensemaking practices, tackle what users understand from data visualizations, and what causes for misinterpretations are. After that, this study will dive into how designers create data visualizations, if the curse of knowledge is of influence and explore the benefits for designers of having insights in the users' sensemaking practices. These topics will answer to the research question of '*What roles can design practice undertake to improve health data communication in tracking applications?*' (RQ1).

To tackle this research question, the research is divided into two studies. In the first study has as goal to answer the sub question 1 of *"What are the challenges users face during the interpretation of data in tracking apps?"* (SQ1). In this study, in-depth interviews with users will be conducted. The goal of the second study is to answer sub question 2 of "*How can the design process of tracking applications be improved to limit the challenges users face during the interpretation of data?"* (SQ2). This is done through a design workshop, in which designers first obtain knowledge on the users' sensemaking processes and then are asked to design data visualizations for a health tracking app.

Since there are many types of health tracking applications, my focus in this thesis will be tracking of the menstrual cycle, it includes menstrual tracking and fertility tracking applications. Menstrual health tracking applications are part of Femtech, technology specific for females, which was created recently [26, 27]. People have tracked their menstruation for ages [12], and in many different ways [28]. Historically, women tracked their period in diaries, calendars or with beads [29]. Nowadays, tracking is done by remembering, noticing symptoms, writing down in diaries/calendars and following cues in birth control [28]. Furthermore, the use of phone applications for menstrual tracking has grown recently. In 2013 the first menstrual cycle tracking apps were created and in 2021 there were an estimated fifty million women who used an app for tracking their menstruation [30].

Menstrual health tracking is chosen as a case study since menstrual tracking applications become more popular [27], and because there is a growing movement to break the stigma of menstruation which is also reflected by more and more people sharing their experiences and appreciating their menstrual cycle [31]. A good understanding by the users of their own experiences can help with this movement.

1.3 Contribution of the Thesis

Motivated by these reasons, I conducted two studies in which first I reflected on the users' data sensemaking practices of menstruation data during in-depth interviews with users and following, I conducted a design workshop to understand how knowledge of the users' sensemaking practices influences the design process of data visualizations. This thesis contributes to the literature four-fold: (1) common causes for misinterpretations and confusion during the interpretation of data from menstrual health tracking applications are defined, (2) the sensemaking process of users interpreting data visualizations is further defined, (3) the pitfall in which data visualization designers assume that users have a certain knowledge is discussed in detail, and (4) a reflection-during-design tool is proposed that will help designers become aware of the assumptions they make and adjust the design accordingly.

1.4 Structure of the Thesis

Chapter 2 – Data visualization and sensemaking in symptom tracking
The goal of this chapter is to reflect on gaps in the studies about data sensemaking, especially in symptom tracking. In this chapter important terminology in the fields of data visualization, sensemaking and menstrual health tracking are explained and discussed. The ways in which users misinterpret information in health tracking applications found in literature, are also presented.

Chapter 3 – Understanding users' interpretation of menstrual data visualizations
In this chapter, I will take you through the first study. The goal and the set-up of the interviews with users from menstrual tracking apps are explained. Interesting findings, like ways of misinterpretation and the users' sensemaking activities are presented in the results section.

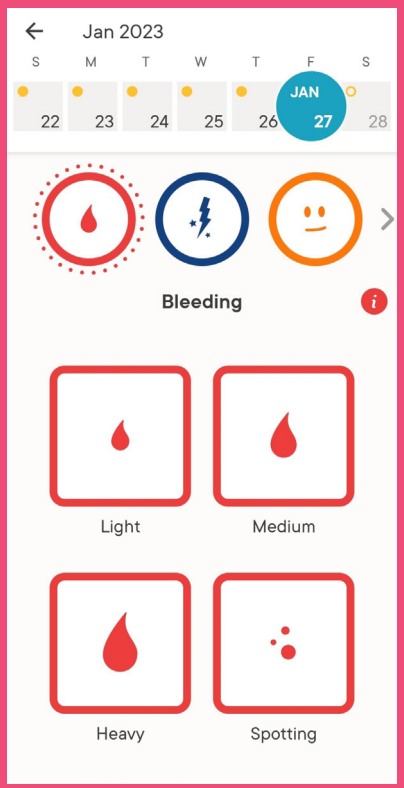
Chapter 4 – Reflecting on the roles of design in menstrual data sensemaking
Study two, the design workshop, is presented in chapter 4. In this chapter I will explain the goal, the activities of the design workshop, and the criteria for participating. Afterwards, the differences in the design processes will be discussed in the results section. It will conclude with the needs for a reflection tool for future design processes of data visualizations.

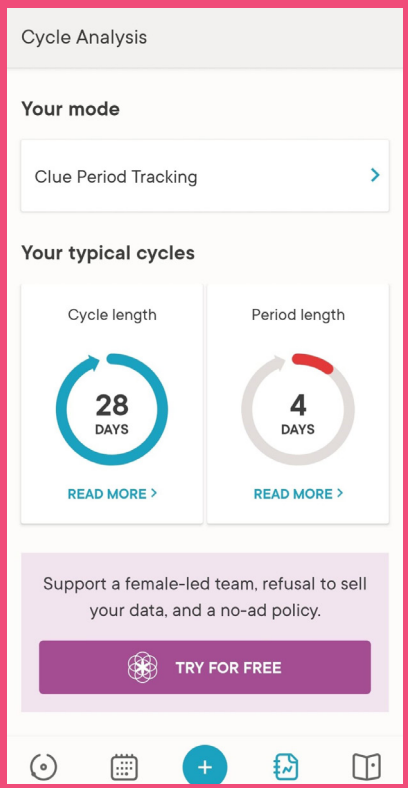
Chapter 5 – Design of a reflection-during-design tool
In this chapter I will take you through my design process of the reflection-during-design tool. Design choices are explained, and the final design is presented. It is concluded with a discussion of the reflection-during-design tool with two of the participants of the design workshop.

Chapter 6 – Conclusion and discussion
I will reflect on the research questions in this chapter. Here I will discuss the research activities that were done and whether the results answered the research questions. Additionally, the results will be reflected upon and points for future studies will be defined.

CHAPTER 2

Data Visualization and Sensemaking in Symptom Tracking





CHAPTER CONTENT:

2 DATA VISUALIZATON AND SENSEMAKING IN SYMPTOM TRACKING

In this chapter, the main concepts, and models regarding data sensemaking in health tracking will be discussed. In the first section data visualizations and their various aspects are explained. In the second section the users' activities when they try to make sense of the data visualization are discussed. Afterwards, I dive into the designers' practices and guidelines to create interpretable data visualizations in the third section. Some reasons for misinterpretations are explained in the fourth section and in the fifth section I will conclude with the effects of data visualizations and their design on menstrual health tracking.

2.1 Data Visualizations

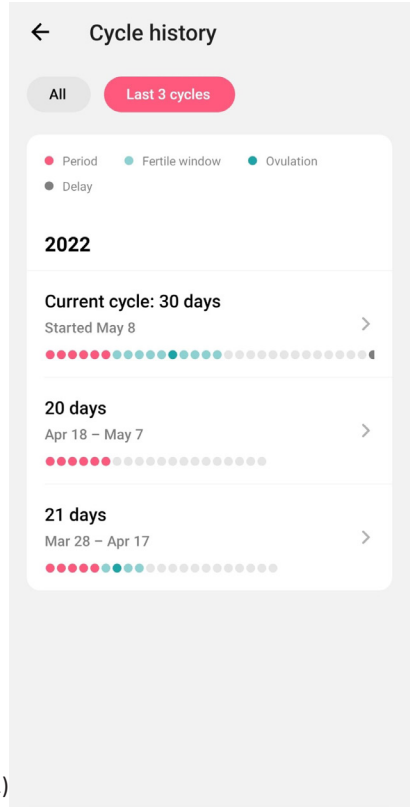
Data visualizations (or information visualizations) are representations of data using position, size, shape, color and text to facilitate analysis, by exploiting the human visual system which is good at spotting patterns [32]. A data visualization consists of visual elements or objects that convey information, in figure 1 you can see that there are many different types of visual elements. Although in both visualizations the same type of data; the dates, the cycle length and the timelines are presented, different visual elements are used. Additionally, data visualization 1 has a legend which data visualization 2 has not. The presented visual elements can convey information on content and on visual encoding [33]. The content of the data visualization explains the topic and data. The visual encoding is the format of the data visualization, and thus the way to interpret the visual elements. The reason why data is presented in visualizations is that it makes proposed patterns in data more clear and easier to spot [18].

2.2 Data Sensemaking

Part of health tracking is the exploration of data [15, 34]. The user does not have any understanding of what patterns, information or knowledge the data contains when exploring the data [24]. So, the primary task is sensemaking [24]. According to Baker et al. [24] sensemaking is the ability to understand complex information, assimilate it, create a structure, and develop a mental model of the situation before taking action on the situation. However, the concept of sensemaking can be defined differently depending on the domain [33]. In data visualization, it is explained as the conscious effort to arrive at an understanding of how to interpret visual elements and underlying content in a data visualization [33].

According to Klein et al. [35] there are multiple sensemaking activities when making sense of external events; elaborating a frame, questioning a frame, evaluating a frame, comparing alternative frames, reframing a situation, and seeking anchors to generate a useful frame. Here, they define frame as 'a structure for accounting for the data' in other words a structure that explains entities by describing their relationship to other

(1)



(2)

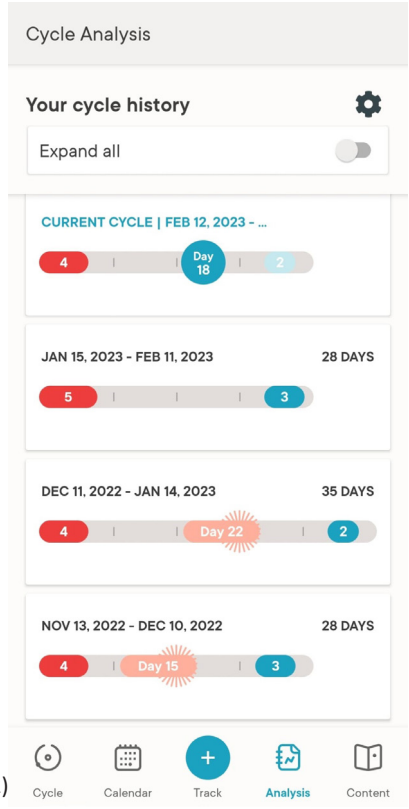


Figure 1 - Two data visualizations on cycle history, data visualization 1 (left) from Flo and data visualization 2 (right) from Clue (Important to note: the same type of data is presented, not the exact same data)

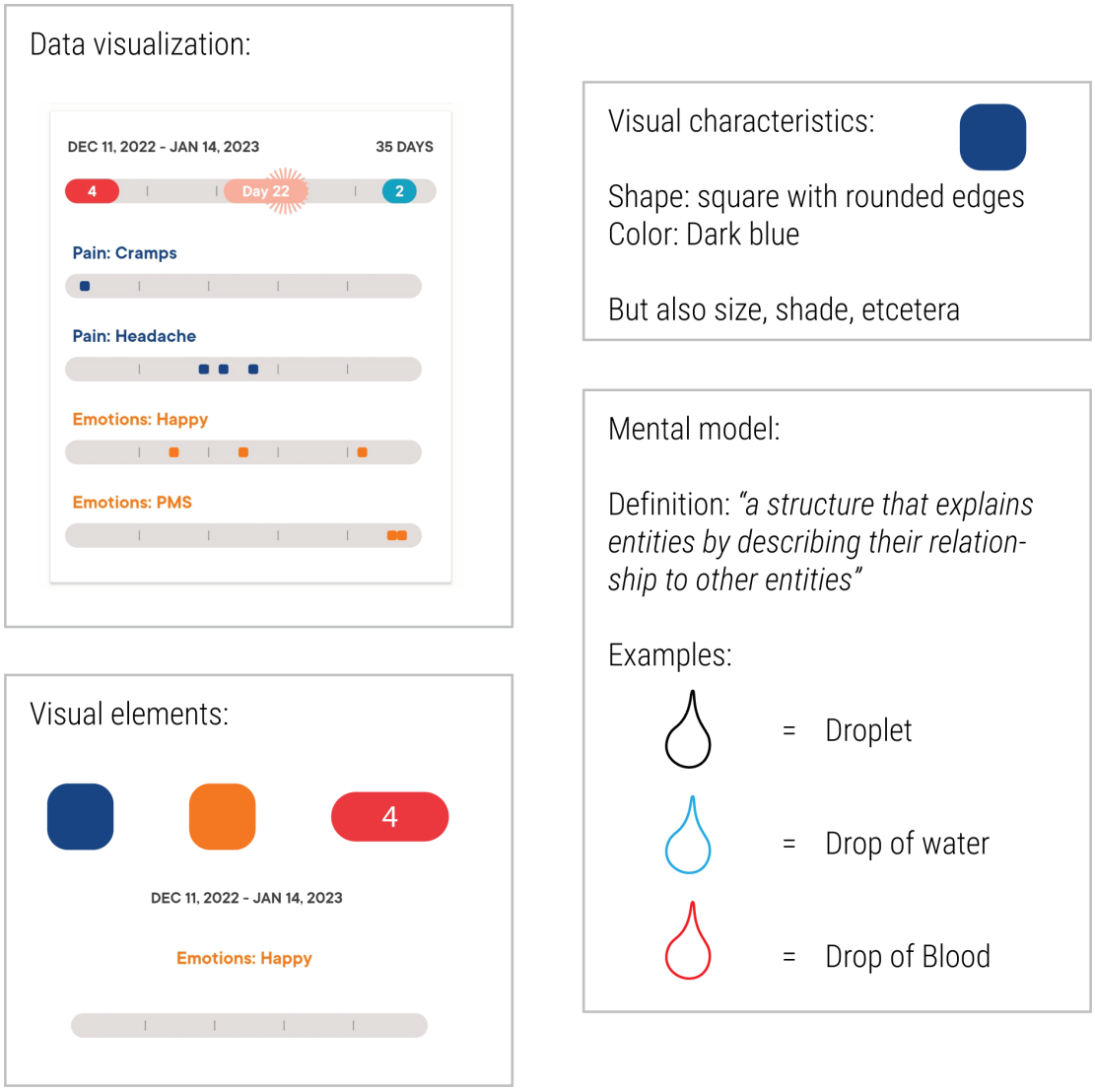


Figure 2 - Overview of the recurring concepts; data visualization, visual elements, visual characteristics, and mental model

entities [36], but frame is also referred to as schema, internal representation, mental structure and mental model [37]. A frame can also be a metaphor, as a metaphor can also be defined as “something regarded as representative or suggestive of something else” [38]. In the current thesis I refer to frame as mental model or metaphor, see figure 2 for examples. In Kleins and colleagues [35] data/frame theory of sensemaking, they divided sensemaking activities into two cycles, (1) the elaboration cycle, where the people build upon the existing frame, and (2) the reframing cycle, where people construct a new and better frame. Lee et al. [33] based their novice’s information visualization sensemaking (NOVIS) model on the data/frame theory of Klein et al [35]. In the NOVIS model there are five activities; (1) encountering a visualization, where the user first looks at the data visualization as a whole image, (2) constructing a frame, where the user tries to create their first understanding of the visualization, (3) exploring visualization, where the user interacts with the visualization and discovers facts and insights from the visualization, (4) questioning the frame, where the user doubts the constructed understanding or tries to verify the understanding, (5) floundering on visualization, where the user does not know what to do with the visualization because he did not construct a reasonable understanding [33].

During health tracking, there are different activities. These activities are defined in different stages in the stage-based model of personal informatics systems [10]. The stages are preparation, collection, integration, reflection, and action. The activity of sensemaking happens during the reflection stage because that is the first time that the user looks, explores, or interacts with the data visualization. However, according to Epstein and colleagues [39] the personal informatics model from Li et al. [10] does not represent the actual way people track information. It is rather a process where multiple stages happen at the same time. So, Epstein et al. [39] defined the lived informatics model of personal informatics which consists of the activities of (1) deciding, making the decision to track, (2) selecting, deciding the tool with which to track, (3) tracking and acting, the ongoing process of collecting, integrating and reflecting, (4) lapsing, stopping with actively using the tracking tool, and (5) resuming, revisiting the decision to track and the selection of the tracking tool. In this model, the sensemaking

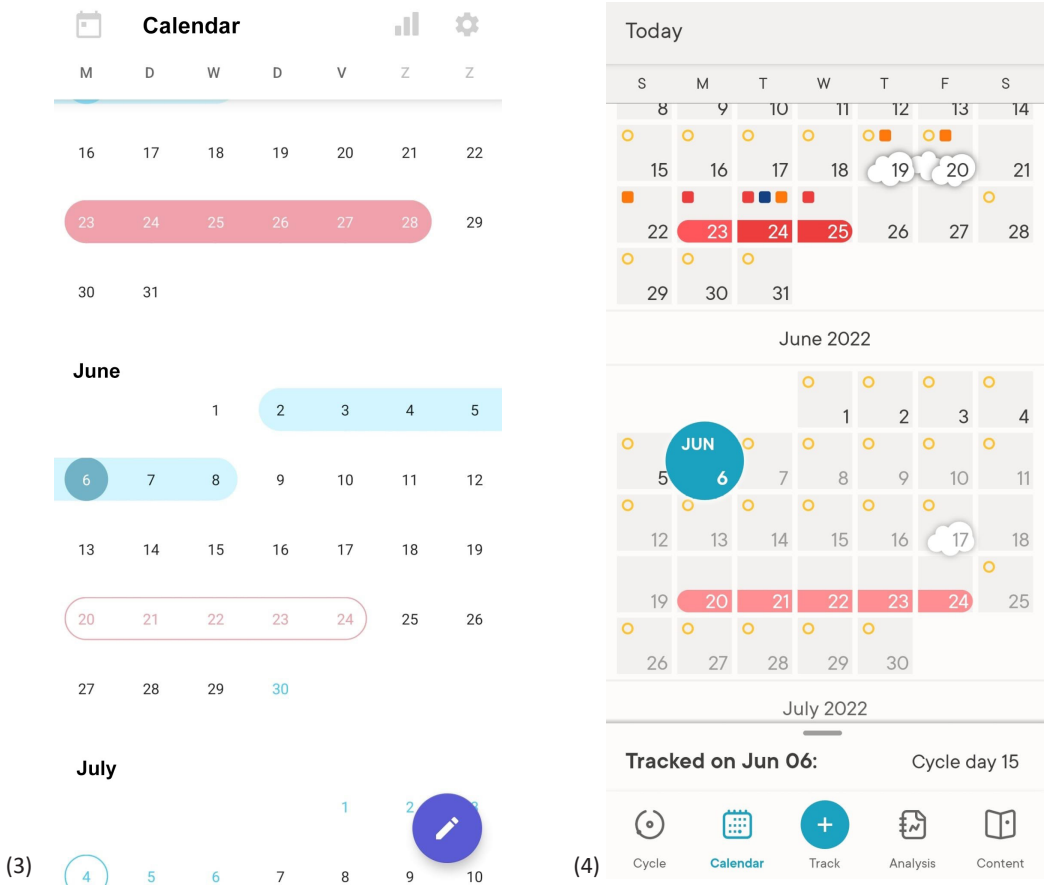


Figure 3 - Two data visualizations from menstrual tracking apps, data visualization 3 (left) from ‘Clover’ and data visualization 4 (right) from ‘Clue’

activities happen during the tracking and acting stage, because here the user first looks at the data coming from the tracking tool.

Both models have a reflection stage, in which the tracked data is reviewed. However, for this study it is important to note that collection, integration, and reflection can happen simultaneously. In line with this notion Epstein et al. [39] argues the users can learn something about their behavior and practices when they collect and integrate data, and thus are already busy with reviewing their data. Whooley et al. [40], mention the cycle seat which is a device that tracks the cycling of a user sitting at a desk. When the user stops cycling for a longer period a red light will be going on, this makes that the user is instantly aware of and reflecting on the fact that (s) he stopped cycling. This is also called reflection-in-action [40]. Sensemaking activities therefore do not only happen in when the user actively reflects on their data, it also happens during the collection and integration of data.

2.3 Designing Interpretable Data Visualizations

In figure 3, you can see the difference between two data visualizations which communicate data on the period and the fertile window from two menstrual tracking apps. These data visualizations are calendars but present information in a unique way. The main difference is that the data visualization 3 contains less data than data visualization 4, because the data in data visualization 4 also communicates on symptoms and PMS days, which data visualization 3 does not present. Both app layouts are still called data visualization because they communicate data through visual elements.

Another difference is that data visualization 3 uses more visual elements to convey the same data. See the difference in how the days are presented, in data visualization 3, the days are presented with their numbers and their position. Data visualization 4 also has a grey box around each day besides the numbers and the position. Experts in the field of data visualization says that more visual elements add more clutter and make the visualization more difficult to interpret [41]. However, in this case data visualization 4 which has more visual elements also presents more information. The question lingers of which data visualization is better designed.

The two guidelines of focus and declutter have the purpose of making data visualizations, understandable, effective and not confusing in communicating data and information [18, 41]. Ajani et al. [18] found that multiple data visualization practitioner guides recommend replacing visualization legends with labels, and removing gridlines and extra visual elements, e.g. excessive colors and 3D effects. However, visual elements can help with making the data visualization more memorable and engaging [42]. Still, there are benefits and limitations to adding visual elements to the data visualization. How do designers know how many visual elements is too much? Other guidelines, e.g. make data interpretable at a glance [32], also do not facilitate the designer in the design process of a data visualization.

There are many types of tools created for the design of data visualizations, so called Information Visualization (InfoVis) tools [43-45]. There are tools for data abstraction, visualization creation and visualization programming [43], in which the difference between visualization creation and visualization programming is mainly that in visualization programming there is more flexibility but more programming skills are necessary [43]. These tools however do not facilitate designers with minimum programming skills to create advanced data visualizations [44]. Bigelow et al. [43] found that designers preferred the manual design of the data visualizations and thus not using visualization creation and visualization programming tools, because the manual design process is flexible and rich, and there is no need to have programming skills. However it was also noted during that study that the designers' assumptions on the data behavior were often incorrect, which was the cause for the need for redesigns [43]. Besides, despite the available tools, research shows that designers prefer to manually design data visualization so sketching and constructing the visualization by hand (using paper or tools like Adobe Illustrator), because there will be less limitations because of the tool [43]. And because of designing manually, the design relies on interpretations and knowledge on the data of the designer [25, 43]. This can have negative effects in two ways, when the designers make incorrect assumptions about the data [43] and when the designers make incorrect assumptions of the knowledge of the user [25]. The incorrect assumptions on the data causes the need for redesigns, and thus it might lead to ineffective designs if these mistakes are not spotted during the design process [43]. And the incorrect assumption on the users might cause the designer to assume the proposed pattern in the data is clearly communicated when in fact the user's interpretation might differ from the designer's intention. When the audience focuses on a different pattern in the data visualization, it creates the potential for miscommunication between the data visualization designer and the user [25]. This discrepancy creates misinterpretations and subsequently possible abandonment of the tracking app, when it comes to menstrual health tracking.

2.4 Data Misinterpretation in Health Tracking

According to studies in the field of health tracking, there are two ways specific to tracking in which users might mis-interpret data. The first way is when users are over-accepting to the systems interpretations and when users feel that the data visualizations are more 'real' than their own bodily sensations [17, 20]. They might also blame their body and lifestyle for the menstrual irregularities, while trusting the applications' data [46]. This wrong way of interpreting data is especially likely when the data interpretation is about emotions or personality [20]. This might be the case in tracking emotions/mood in menstrual tracking apps. Karlsson [47] states that in an ideal world the user would make their own system in which data is collected, processed, and interpreted, however the average user does not have all those skills. So, the user must trust the system to some extent and therefore also the app provider. This could be a reason some users are over-accepting to the

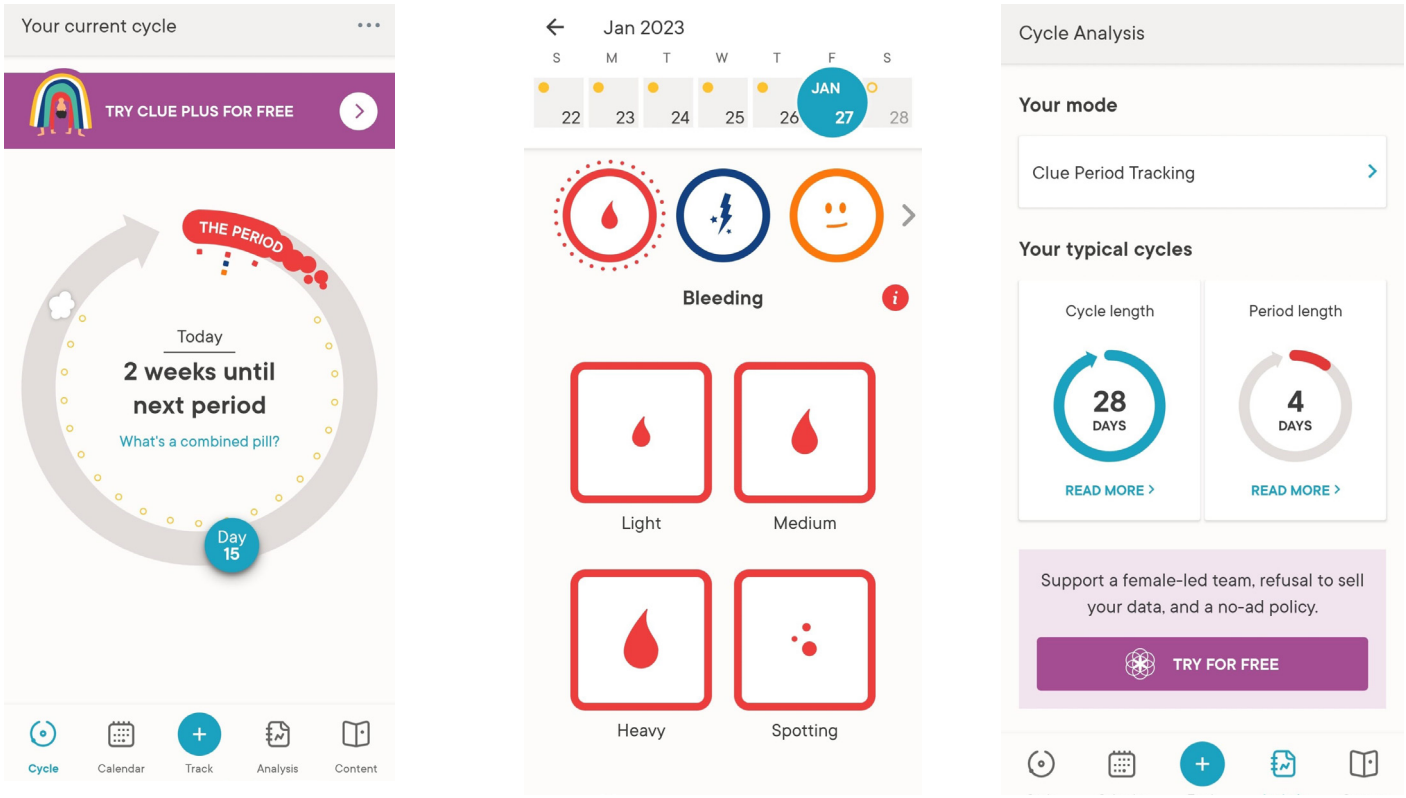


Figure 4 - Three different screens in the menstrual health tracking application 'Clue'

system; they maybe trust the system too much. It might also be because the body data is often seen as ordered, controlled and unemotional as opposed to the contingencies and the uncertainties of the body and its ills itself [48]. Therefore, it is viewed as neutral, scientific, and a direct measurement of the body's state [48, 49].

The second way of misinterpretation is through obsessive engagement with data. The user might interpret symptoms of their body wrong. An example from Costa Figueiredo et al. [49] is that women with the goal to get pregnant, became obsessive and started to interpret symptoms of their body as a sign that they had conceived and thus had gotten pregnant. However, these symptoms were not pregnancy symptoms, and they were in fact not pregnant. Thus, it is possible that because of obsessive engagement, the user interprets the symptoms of their wrong.

Besides misinterpreting the data, there is also the case that users interpret the data correctly but do not know why it should be interpreted that way. For example, Bretschneider [50] found that all five of their participants could correctly interpret the way the app presented their fertility window. However, the participants did not know why that time was their fertile window. The participants processed the data from the application into information, which Rowley [16] states is when the data becomes relevant for a specific purpose or context. In this case the participants saw with the applications' data representation that they were fertile on certain days. Arguably, the participants did not have the knowledge on the fertile window, since they did not have the information why on some days a person is fertile and other days not. So, in future cases they cannot predict their own fertility and thus completely trust the app, even when there is a possibility that the app makes a mistake. Additionally, when the user does not have the complete knowledge, the information might not be used to its full potential. As stated previously, not using the full potential of presented information can lead to abandonment of the application [8].

2.5 Effects of Sensemaking in Menstrual Health Tracking

Often, in health tracking the main purpose for tracking is trying to change behavior [39]. However, in menstrual health tracking, changing behavior is not the goal since people cannot change their menstrual cycle and their symptoms. According to Epstein and colleagues [28], the goals for menstrual tracking are (1) being aware of how the body is doing, (2) understanding the body's reactions to different phases of the menstrual cycle, (3) being prepared, (4) trying for or avoiding pregnancy, and (5) informing conversations with healthcare providers. These several reasons might cause the users to look at various aspects in data that is presented to them.

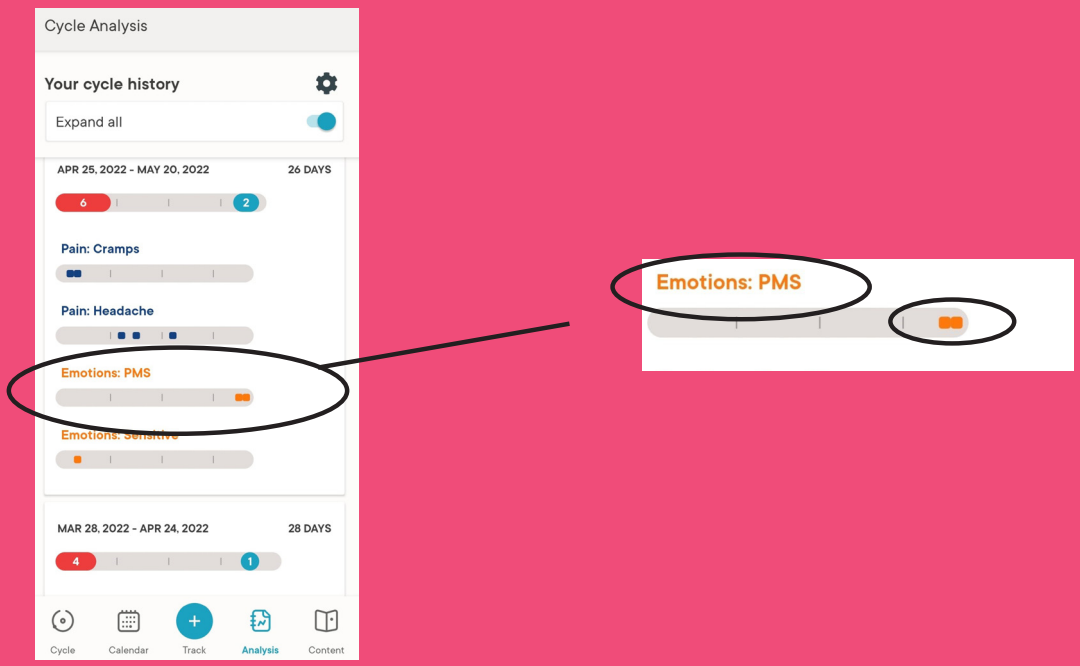
Menstrual tracking applications work like symptom tracking tools. Just like some other symptom tracking [51] applications, they rely on users' self-reports. The user must manually fill in their symptoms and mood. Patel [51] states that symptom tracking could be considered a self-care activity. The study also revealed that the activity of symptom tracking could make the users more aware of their needs to manage symptoms at home and how to communicate this to clinicians.
When using a menstrual tracking app, often the first thing the user must do is fill in the date when they last started menstruating, fill in their average cycle length and their average period length. After that, the application gives a prediction for the next period and often also the time of ovulation, see figure 4. for an example of a menstrual tracking application. When the user has set up the application, the user can begin to track. Mood, symptoms, temperature, weight, and occurrence and frequency of sexual intercourse are all things the user may be able to track with the application [52]. Next to that, some apps have features like irregular cycle support, pill reminders, personal diary and educational information [52].

When the purpose for tracking from the user is not fulfilled, this might result in the user abandoning the health tracking application [39]. Other reasons for possible abandonment of menstrual tracking apps, are that tracking can be overwhelming, time-consuming and in some cases useless when the tracked data is not being used [8]. People might not use the data because the data does not fulfill the purpose of tracking [8] or there is no new information to be interpreted from the data [39]. When the purpose for tracking cannot be fulfilled and users will abandon the application, it will cause the users to miss out on many benefits [8-12].

Therefore, the data visualizations in the apps and the users' sensemaking have on impact on the use of tracking applications. Although there are some studies that focus on the use of information coming from the apps. There are few studies that focus on the interpretation of data in tracking apps. Additionally, there also lack practical guidelines for designers for the design of data visualizations, the existing guidelines do not facilitate designers much. For example, designers still need to 'guess' what they think is the right number of visual elements. Therefore, two studies are conducted to create a better understanding of the users' sensemaking activities in menstrual health tracking and to facilitate designers better in the creation of data visualizations for tracking apps.

CHAPTER 3

Understanding Users' Interpretation of Menstrual Data Visualizations



CHAPTER CONTENT:

3 UNDERSTANDING USERS' INTERPRETATION OF MENSTRUAL DATA VISUALIZATIONS

The primary objective of the first investigation is to gain insights into the way the users of menstrual health tracking apps perceive and interpret data visualizations. Of particular interest is the identification of instances where users exhibit misinterpretation of data and the underlying causes of such misinterpretations. To achieve this objective, I employed a qualitative research methodology, which involved conducting in-depth interviews with users of menstrual health tracking apps. Next, I will explain the details of the participant study.

3.1 Aim of the Study

The aim of the first study is to gain insight into the sensemaking practices of the menstrual tracking app users. Of special interest are the challenges the users face during the interpretation of data visualizations in the apps, but also the underlying causes of these challenges. Therefore, the goal of the interviews is to answer sub question 1: *"What are the challenges users face during the interpretation of data in tracking apps?"*.

3.2 Study Method

I conducted semi-structured interviews to address the challenges users face during the interpretation of menstrual data. As the study involved users, I applied for and received ethical approval from the faculty of behavioral, management and social sciences (BMS), ethical request number 220916.

Each interview consists of five parts, see table 1 for the interview structure. Most of the interviews took place at the University of Twente, a private room was booked for each of the interviews. The data visualizations were printed on paper, so that the data presented in the visualizations did not change. One of the interviews took place online via Teams. In the case of the online interview, the visual platform Miro was used to present the images of the data visualizations, the participant could zoom in and out like she wanted.

The conditions for the participants were that they had to use a menstrual health tracking application for at least three months, and they needed to have a menstrual cycle. The participants were recruited through snowball-sampling and through an online platform where students get participant credits which are required for their studies.

3.3 Participant Characteristics

In total 16 participants completed the study. One of these participants were excluded from the sample as the participant indicated that they do not have enough experience about using a menstrual tracking app (duration of use: one month). The average age was 21,8 and the ages ranged from 19 to 27. Generally, older people that were asked to take part did not use a menstrual tracking app. However, there is also the bias of the recruitment methods, where I (23 years at the time) asked contacts of myself to participate and through the online platform only students were recruited.

All participants lived in the Netherlands at the time of the study. Most participants were from the Netherlands (n=6) and Germany (n=5), but there were also participants from Moldova (n=1), Romania (n=1), Vietnam (n=1) and Italy (n=1). The level of education was relatively high, as all the participants studied or had studied at university or university of applied sciences (Table 2).

Table 1 - Interview structure

Part	Topic	Activities
1	Introduction	Inform the participant about research goal, discuss informed consent, verify conditions for participating
2	About the user	Questions about age, the country of origin and eHealth skills
3	Menstrual health tracking app	Questions about use of menstrual health tracking app
4	Interpretation data visualizations	Interpret 9 data visualizations while thinking aloud, see appendix A for the data visualizations. Questions about attention and elements that make interpretation easier or more difficult
5	Ranking data visualizations	Rank and sort the 9 different data visualizations on diverse topics

Table 2 - Participant characteristics

Participant	Age	Country	Interview Language	Level of education
1	21	Netherlands	Dutch	Student at university
2	27	Netherlands	Dutch	Graduated university
3	20	Netherlands	Dutch	Student at university of applied sciences
4	22	Netherlands	Dutch	Student at university
5	20	Netherlands	Dutch	Student at university
6	23	Germany	English	Student at university
7	20	Italy	English	Student at university
8	22	Moldova	English	Student at university
9	21	Germany	English	Student at university
10	21	Romania	English	Student at university
11	23	Germany	English	Student at university
12	23	Germany	English	Student at university
13	24	Vietnam	English	Student at university
14	21	Germany	English	Student at university
15	19	Netherlands	Dutch	Student at university

3.4 Data Analysis

The interviews were transcribed and coded using inductive coding. The interpretations were coded into categories of interpretation, remarks on visualization, comparison to own application, and reflection on presented data. Then, in the category of interpretations, interpretations of which the participant was not confident were marked in orange and misinterpretations were marked in red. Other remarks on the data visualizations when answering the other questions on the data visualizations, were coded in categories of aspects of the data visualization. The aspects are content, visual encoding, application layout, number of data/visual elements, irrelevant visual elements, style of visualization, visual in comparison to text/numbers, and colors. See table 3, for examples.

Table 3 - Codes and examples

Interview part	Codes	Additional	Examples
Interpretation of data visualizations	Interpretation	Misinterpretation is marked in red	*"The first header is like 14 days of waiting, so you have to wait, I think, till your next period. Yeah, this must be the 20th then. And it's like a separate box, like above the paper and a different color and blue. And there's also like an image next to it of a rabbit. And yeah, there you can see like what, what happens today. And then you can click on the calendar, I think underneath it. And then you will see Yeah. On the bottom how much the chance of a pregnancy is. So, from high to low, I would say. And this is also in a separate section. And the date as well."* – Participant 11
		Not confident in interpretation is marked in orange	*"Um, that's a list of symptoms that could happen during, before or, I don't know, after you get your period or like during the cycle in general. And I think that's like how you can keep track of that. It says abdominal cramps three times, headaches two times, good feeling one time, and all of the other symptoms it says zero times. So, I would guess that maybe within one cycle."* – Participant 12
	Remark on visualization		*"I do not find this very clear, because, as I already said, if I see dates, I need to see them on a calendar, otherwise I do not know the connection…"* – Participant 2
	Comparison to own application		*"As in, in my application it says about halfway you are going to ovulate and then a bit later, you are going to be on your period."* – Participant 1
	Reflection on presented data		*"But I find these red and blue dots a bit weird, because to my knowledge you will not ovulate directly after your period."* – Participant 1
Questions about data visualizations	Content		*"And I find it also clear that you, just, just see the months, and the dates."* - Participant 1
	Visual encoding		*"I think with the dots, it's kind of easier to understand as well."* – Participant 11
	Application layout		*"Um, I think that all the things are separated, which makes it easy to, like, interpret. You have different subheadings."* – Participant 6
	Number of data/ visual elements		*"Yes, clear, just not too much information."* - Participant 1
	Irrelevant visual elements		*"Yes, I find the bunny very confusing."* – Participant 4
	Style of visualization		*"It is also just a fun, happy app, or something. As in, the pink and colors, that is just also a bit fun. That makes it even better."* – Participant 5
	Visual in comparison to text/numbers		*"But also, clear. I like it when they put an image with it, that it is not only text or just a dot, but that it is written down, or a clear image or both."* – Participant 4
	Colors		*"Colors makes it easier, and they are chosen well I think."* – Participant 1

3.5 Results

3.5.1 Participants' App Use

The participants ranged between using their application from 3 months up to 6 years and ranged with using the application every day up to once per month. The most common apps that were used were Flo (n=4) and iPhone health (n=3). Other applications were Clue (n=2), Fitbit (n=1), Mijn kalender (n=1), My calendar (n=1), NuvaRing Circle (n=1), Period tracker (n=1), and social health (n=1).

3.5.2 Participants' Ways of Data Interpretation

After analyzing and coding the interviews, 6 causes for misinterpretation, no interpretation or confusion were found. Each of them is explained in the following sections. Additionally, examples from the interviews are given.

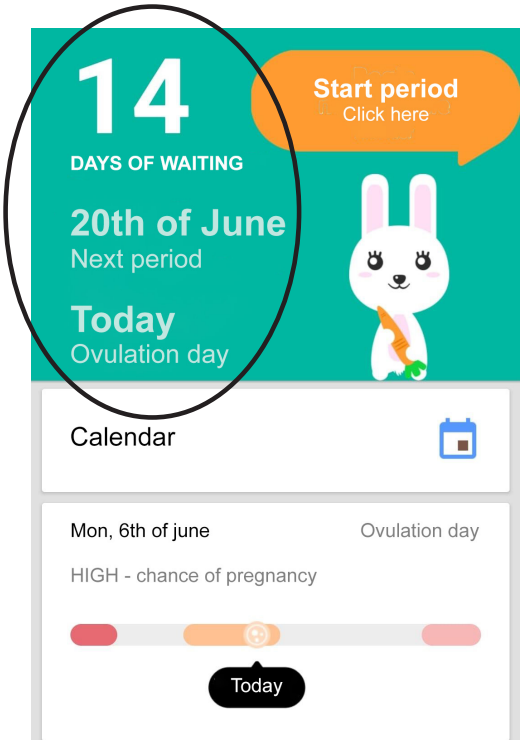
1. Perceived similarity: Different types of data were perceived as similar types due to similarity of visual elements.

- 1 out of 9 visualizations: Visualization 1
- 2 out of 15 participants: Participant 2, 12

In visualization 1, see figure 5, different types of data were perceived as similar due to the similarity of their visual elements by two participants. In the visual, there are multiple dates given and multiple days mentioned. The 6th and the 20th of June are mentioned, as well as '14 days of waiting' and 'today'. Since 'today' and '20th of June' are in the same style, and '14 days of waiting' is similar, there is some unclarity in participants. This can be deduced from the comment from participant 2: "Yes, I actually think that it is not very clear, because I see, fourteen, 20th of June and today, but it is not the 20th of June today and also not the 14th of June." Here, participant 2 even misinterprets the 14 days of waiting as the 14th of June. For participant 12 this caused confusion when the participant found additional elements that concluded that the data in fact did not belong together.

Table 4 - Participant characteristics results

Participant	Application	Application usage	Duration of use
1	Flo	1x week to 1x month	3 years
2	Fitbit	1x week	1 year
3	Flo	Every day	2 years
4	iPhone health	Every day (during period) to 2x month	2 to 2,5 years
5	Mijn Kalender	1x month	3 to 4 years
6	Flo	1x month	6 years
7	Clue	1x month	6 months
8	Flo	1x week	3 years
9	My Calendar	1x week	1,5 years
10	iPhone Health	1x week to 1x month	2 years
11	NuvaRing Circle	1x week	2 years
12	Period tracker	2x month	6 months
13	Social health (translated)	1x month	5 years
14	Clue	2x month	5 to 6 years
15	iPhone Health	1x week	3 months (current use) - 2 years (previous use)



2. Visual clash: Due to the similarity of two visual elements, they were perceived as one visual element when they collided.

- 1 out of 9 visualizations: Visualization 8
- 3 out of 15 participants: Participants 4, 5, 12

In visual 8, see figure 6, the day of today is presented with a grey circle around the date and the ovulation day is presented with a blue circle around the date. When this is the same day, it becomes a blue/gray circle. This circle creates confusion in multiple participants (4, 5, and 12). An example from the statements of participant 4: *"The dark blue would probably be the predicted ovulation day, or I don't know what day today is. Oh no, it would probably be the day of today."* and later *"No, I think that the dark blue is your ovulation day. But it is not clear what day today is, but the rest is clear, I think."*

Figure 5 - Visualization 1, in the black oval the visual elements that were perceived as similar

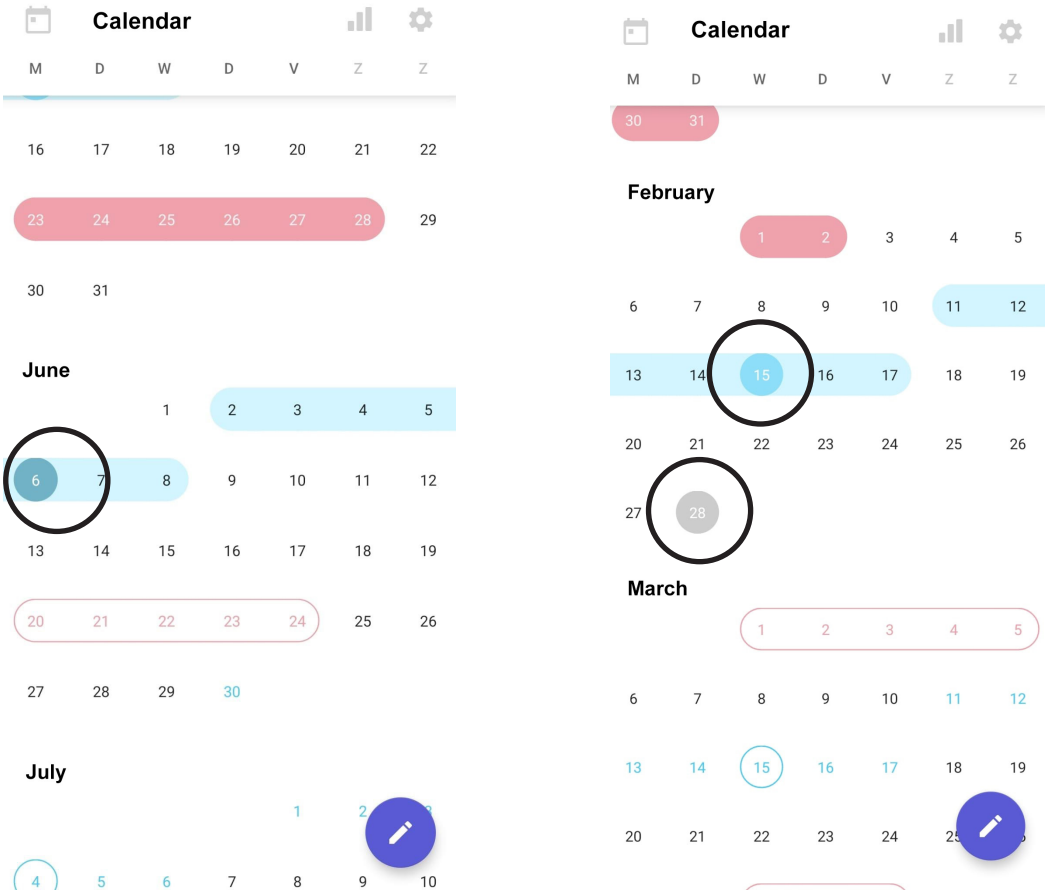


Figure 6 - Visualization 8 on the left, the same visualization with different data on the right, the clashing visual elements are circled

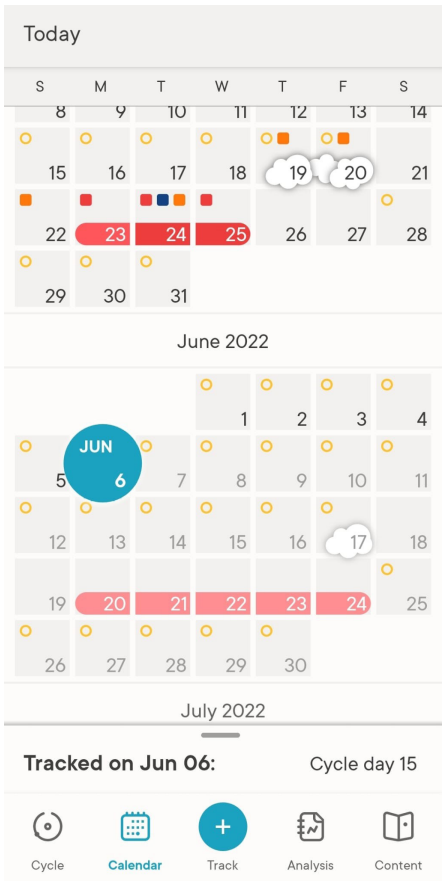


Figure 7 - Visualization 9, many visual elements: yellow circles, different colored squares, clouds, etcetera

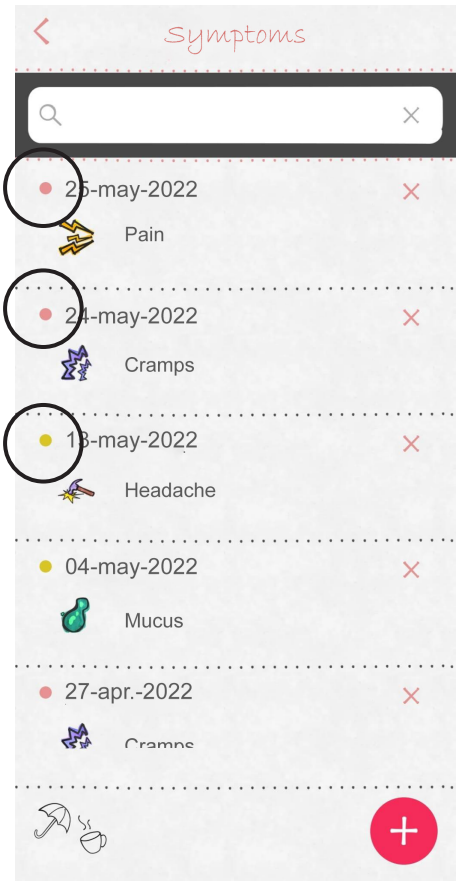


Figure 8 - Visualization 7, three of the five colored dots that were overlooked are circled.

3. *Clutter: Due to many different visual elements and many types of data, the correct visual element was not linked to the correct piece of data.*

- 1 out of 9 visualizations: Visualization 9
- 15 out of 15 participants: Participants: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15

In visualization 9, see figure 7, all of the participants misinterpreted elements or stated that they were confused with the interpretation. 5 of the 15 participants answered that the number of colors and icons to interpret contributed to making the visual more difficult to interpret. As an example, to the question of what makes the interpretation more difficult, the answer of participant 3 was: "*More difficult, that it is so busy, with all those circles, the bright colors, like that 6th of June is bright blue and the different shapes so, the clouds etcetera, that makes it quite busy.*"

4. Overlooking of data: Small visual elements were overlooked due to many visual elements.

- 2 out of 9 visualizations: Visualization 7 and 9
- 13 out of 15 participants in visulization 7: Participants 1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 15
- 2 out of 15 participants in visualization 9: 5, 6

In visualization 7, see figure 8, the dots that indicate whether the symptom happened during the period or not, are only interpreted by two of the fifteen participants (5 and 14). The other participants only noticed the dots when asked about it. Although in visualization 7 the participants did not mention that there were many visual elements, the reason for the overlooking of the dots might be because of the use of colors. The colors in the symbols are not conveying extra information, but the colors of the dots do. The use of many different colors might therefore impact the interpretation of the colors of the dots.

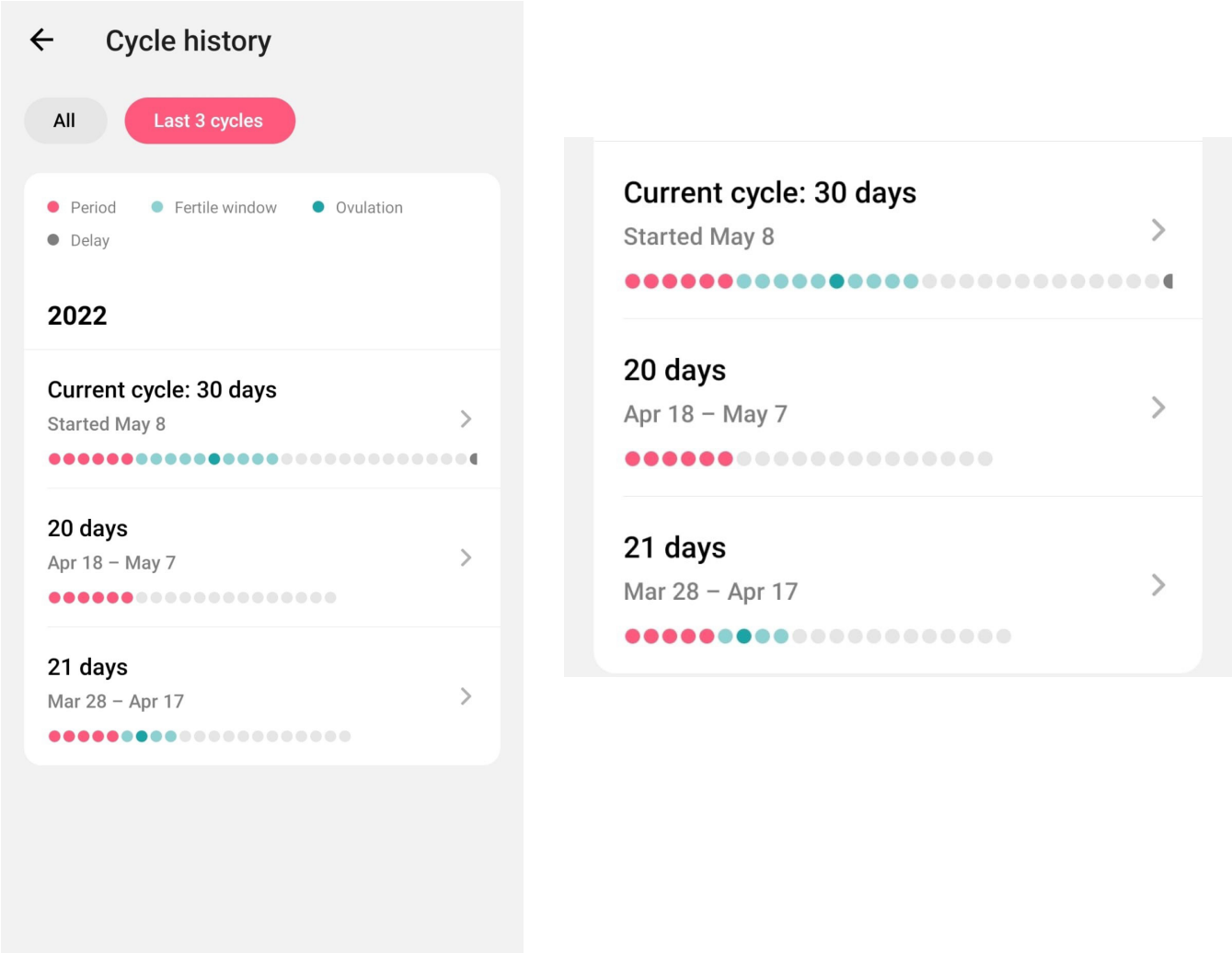


Figure 9 – Visualization 5 on the left, the different cycles with the fertile window are enlarged on the right

5. Clashing self-knowledge: Pre-existing knowledge that conflicted with the understanding of the visualization made the user unsure of their understanding and their pre-existing knowledge.

- 1 out of 9 visualizations: Visualization 5
- 4 out of 15 participants: Participants 1, 2, 3, 13

In visualization 5, see figure 9, there is some confusion because the fertile window and ovulation days are presented in different places each cycle. For example, participant 1 states *"But I find these red and blue dots a bit weird, because to my knowledge you will not ovulate directly after your period."* and participant 2 states "*But in the cycle of 20 days there would be no fertile days. That is a bit weird, but then it is more whether the data is right, or I interpret it wrong."*

6. Designer-user mismatch: The users associate visual elements with mental models different than intended by the designer.

- 3 out of 9 visualizations: Visualization 1, 2, 9
- 2 out of 15 participants in visualization 1: Participants 6, 11
- 6 out of 15 participants in visualization 2 (Timelines vs scales): Participants 8, 10, 11, 12, 13, 14
- 8 out of 15 participants in visualization 2 (Association blue and ovulation day): Participants 3, 5, 6, 7, 9, 10, 12, 13
- 5 out of 15 participants in visualization 9: Participants 6, 10, 12, 13, 15

There are different cases in which the user associates visual elements with mental models different than intended by the designer. In most cases this results in misinterpretation, but in some cases this wrong interpretation is questioned when seeing other visual elements, then it causes confusion.

- Blue is associated with ovulation/fertility:

In visualization 2, see figure 10, the blue numbers two and one, are often misinterpreted as days of ovulation or fertile window. When it actually is the number of days when the user experiences PMS symptoms. This interpreted as ovulation days by seven participants (3, 5, 6, 7, 9, 10, 12, 13) although in all but one (5) this is mentioned with confusion and uncertainty. For example: "*But the two and the one, I really don't know. Ovulation, maybe. I don't know."* (Participant 6). In visual 9, see figure 7, the blue dot on the 6th of June is misinterpreted as the ovulation day when it indicates that today is the 6th of June. This is done by five participants (6, 10, 12, 13, 15). The association with red and

blue is specifically mentioned by participant 15 (translated) *"and then red again is your period, and blue the most fertile day.".*

- Horizontal (time)lines are associated as a scale: In visualization 1, see figure 11, the timeline gets mistaken for a scale for level of chance of pregnancy. *"On the bottom how much the chance of a pregnancy is. So, from high to low, I would say."* - Participant 11. In visual 2, see figure 11, the timeline gets mistaken for a scale for the level of pain for each symptom. This is misinterpreted by six participants (8, 10, 11, 12, 13, 14). One example is: *"So you also have some graphs about different symptoms that you might have, pain, cramps, headaches, emotions, and it's indicating at what kind of percentage they are so low or high."* - Participant 8.

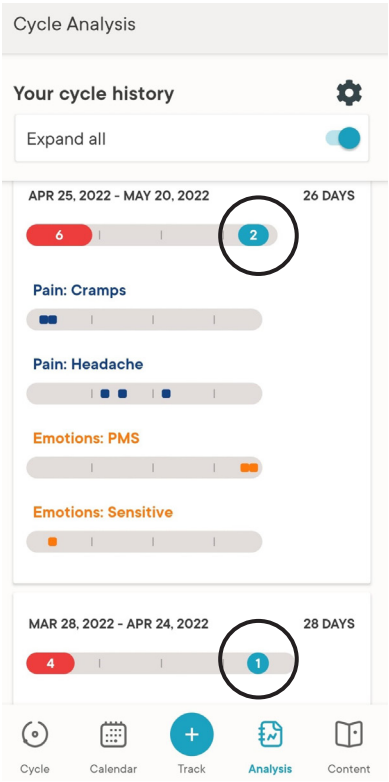
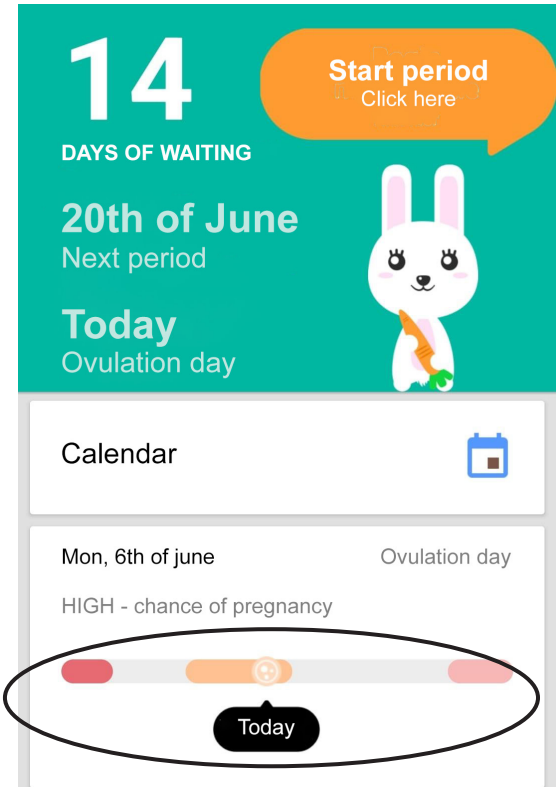


Figure 10 – Visualization 2, the blue aspects that are associated with ovulation are circled



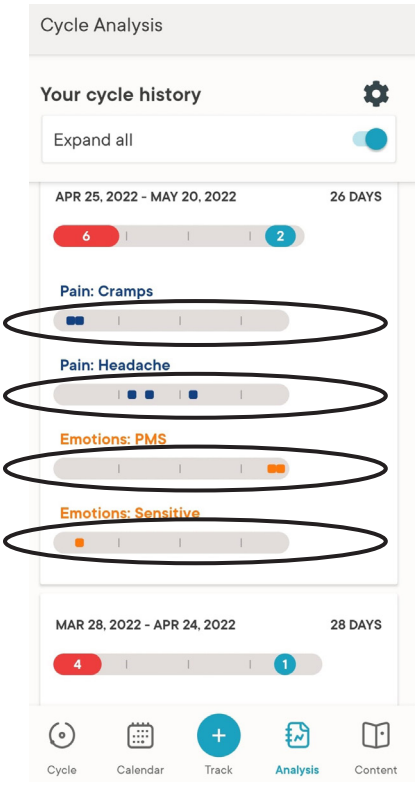


Figure 11 – Visualization 1 (right) and visualization 2 (left), the timelines which are interpretated as scales are circled

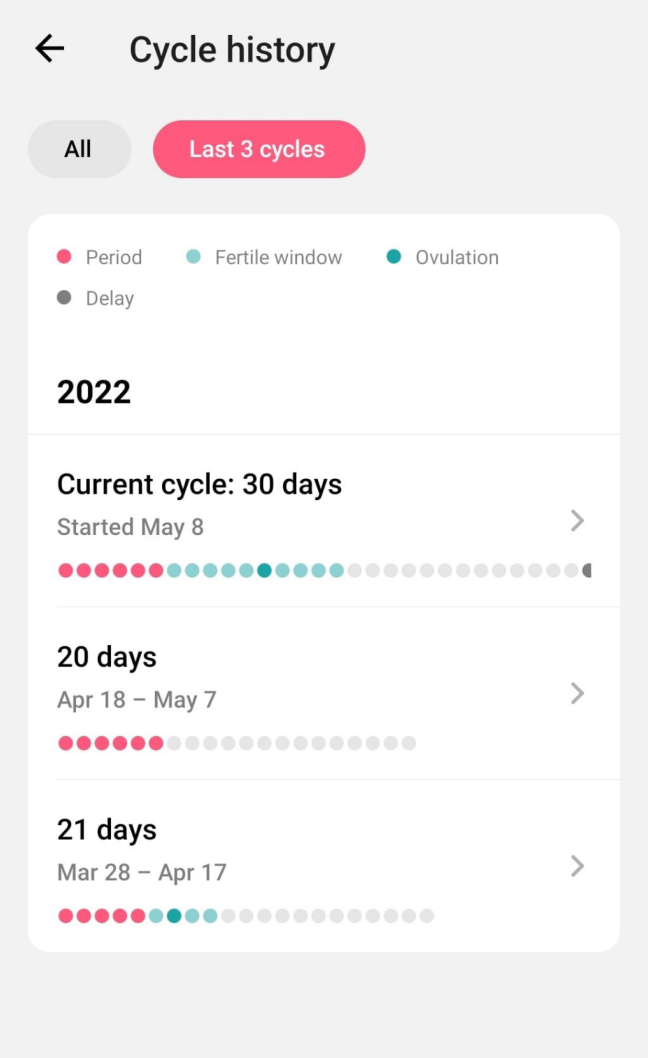


Figure 12 – Visualization 5

3.5.3 Sensemaking Practices

Results showed that there are few times when people had no existing mental models available to compare visual elements to, even though the participants saw (almost) all visualizations for the first time. In all interviews, the participants had some knowledge available, either on the content or the visual encoding to which they could compare visual elements to. The participants therefore always constructed their understanding based upon a first association with an existing mental model. This top-down approach of first having a broad understanding with the first association with an existing mental model and then building upon the understanding was used instead of a bottom's up approach where the participant constructs the understanding with the visual elements. This is explained with multiple interpretations of the fifth visualization, see figure 12.

> *"Yes, here you see the limit, I think well after three cycles, you kind of started. And then you can see… Yes, for example, that person started somewhere in March and then maybe they had their period from March 28 to April 17, I think…"* – Participant 1

> *"Yes, this is about your history so history of a cycle, last three cycles and here actually per cycle. You have got dots for your period, your ovulation day in the ovulation period where it can happen. Additionally, I have got dark grey dots for delay…"* – Participant 3

> *"Yeah. So, I think it's your cycle history. So, you have 2022. So, you have like your, um, yeah. Like your, your various cycle in all your 2022 time I'd say, so you have your previous ones and so now you have your, you're in your current one…"* – Participant 7

First participant 1, 3 and 7 start with comparing visual elements and try to see what can be recognized. With the knowledge that this is a data visualization from a menstrual tracking application, the participants quickly scan the overview and recognize that there are three cycles. In this moment, the participant chooses a mental model, an overview of

previous menstrual cycles, as their understanding of the data visualization indicating a top-down sensemaking approach. Then, the participants immediately continue with looking for additional visual elements. Participant 1 recognizes the cycle furthest in the past (see 21 days, in figure x) and interprets the dates as being dates indicating the time when the user had their period. Participant 7 sees 2022 and notes that these are all the cycles in the year 2022. The participants build upon the mental model of the data visualization that is created, even though not all interpretations are correct.

"…And the cycle lasted about 21 days and the second lasted from April 18th to May 7th. Then it lasted 20 days and the current cycle lasted then 30 days and it started on May 8th…" – Participant 1

"…But I only see that one, half here, so I don't know exactly what and also you can, I think, click on each cycle and get more information then I guess…" – Participant 3

"…And so, it shows in the red your yeah period in the in the blue one fertile window, ovulation in the dark blue one, delay is the dark one. I think it's pretty intuitive…." – Participant 7

With the mental model that the participant created of the data visualization, the participants look further at more visual elements and continues building upon her understanding of the data visualization. Participant 1 builds upon her understanding by interpreting each cycle and noticing the dates and duration. Participant 3 looks further in the visualization to see where the grey dots are and continues noticing the arrows to the side. Participant 7 continues by looking at the legend.

"…Oh, wait a minute, okay, these, dates are just per cycle…"– Participant 1

"…Yeah. And it's not 2022 fully. It's like last three cycles. That makes sense. It's only three cycles. Yeah." – Participant 7

When seeing the visual elements of 'Started May 8', probably in combination with the text participant 1 read before that; 'Current cycle: 30 days', participant 1 recognizes that the dates do not represent the start date of the period, but the start date of the menstrual cycle, see figure 13. She quickly questioned her mental model of the data visualization and subsequently corrects the misinterpretation and built upon her mental model. Participant 7 does this as well, but then with her understanding that these were all the cycles of 2022. But when reading the text 'last 3 cycles' in the red button, she questioned her and built upon her understanding that it is in fact only the last three cycles and not all the cycles of 2022. Participant 7 stops his interpretation of the visualization here, where participant 1 continues.

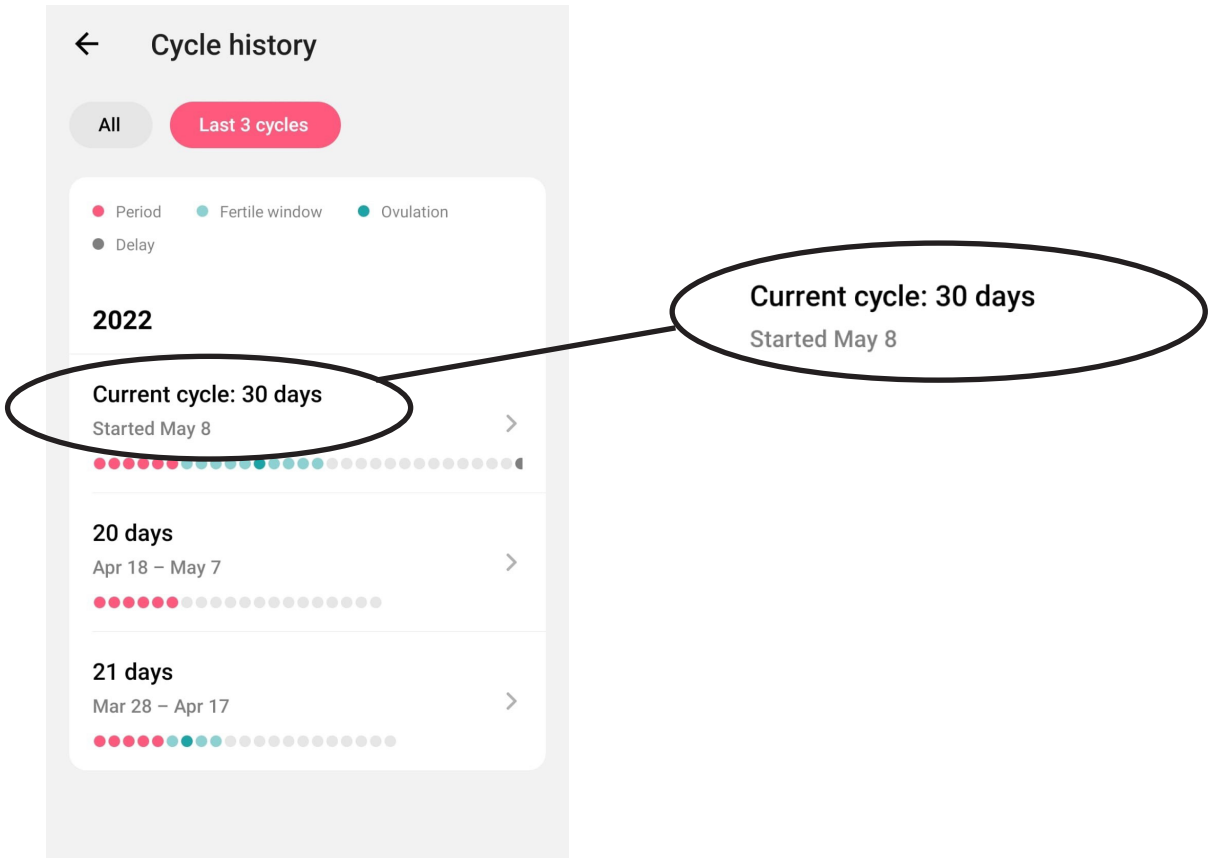


Figure 13 – Visualization 5 with the visual elements circled that helped participant 1 question and built upon her understanding

"…Yes, so you can therefore see when you got your period and when you approximately ovulated, but not how you are, with emotions or symptoms or that kind of stuff." – Participant 3

Participant 3 did not make an initial mistake during the interpretation of the visualization. She continues with interpreting the cycles and note that the visualization gives only information on the fertility and the period, and not about symptoms or emotions. Participant 3 stopped with the interpretation after this.

"…But I find these red and blue dots a bit weird, because I feel like you don't ovulate immediately after your period. I don't find that very logical. As in, my application says that around halfway, you will ovulate and then a bit later, you will have your period again. So, I don't know if that makes sense to me. Yes, that, I think." – Participant 1

Continuing, participant 1 compares more visual elements, the red and blue dots. Although participant 1, as well as participant 3, did not vocalize the moment, she understood the red dots represent the period and the blue dots represent the fertile window and ovulation, participant 1 interprets them. She also directly reflects upon the interpreted data, by mentioning that it conflicts with her understanding that the ovulation is halfway in the cycle and not as early as is presented. This participant ends her sensemaking of the data visualization by questioning the data visualization.

"Um, this one is also a cycle history. It has the options at the top that you could see either all cycles you've had kept track on or the last three and the last three is um. It's the option on and then. Yeah. You can see the last three. And with how many days it, uh, it included. So, the last one was 21, then it was. Um, 20 days and now it's 30 days. And yeah, you can see where the period, when the period was. Um, if there is delay, you can see the fertile window and ovulation and it's very different from cycle to cycle." – Participant 12

"Yeah. It's the cycle history, period, fertile window, ovulation and delay. So, we have like the current cycle. I think it's supposed to be like 30 days ago. I'm not sure. So then here was the period, the fertile window, the ovulation, and then the rest of the month. And then here like a delay. And then, uh. Here it was 20 days ago. I don't know, no, no. It's actually like, I think the timespan between cycles. So, like it was 20 days until the April 20 cycle and then 21 days. Like from late April." – Participant 10

Interpretation is quite different for each person. Just like participant 3, participant 12 interpreted the data visualization without questioning the understanding of the data visualization and stopped the interpretation without questioning the data visualization. She chose the mental model of a cycle history and then continuously compared more visual elements and built upon her mental model of the data visualization until she was content with her mental model. Whereas participant 10 did misinterpret something (duration of cycle '30 day' as time of cycle '30 days ago'), just like participant 7 she corrects her mistake and quits her sensemaking by being content.
This dynamic top-down sensemaking approach creates confusion when something does not 'fit' the understanding of the visualization. The participants start questioning the understanding and try to resolve the conflict by again comparing the visual elements to existing mental models. Often, this conflict is then resolved (like the example of participant 7 and 10) by noticing a wrong understanding of visual elements and correcting the mistake. However, sometimes this conflict cannot be resolved, and the participant stops the interpretation still being confused.

3.5.4 Biases in sensemaking process

Two of the causes for misinterpretation, that of clashing self-knowledge (cause of misinterpretation 5) and designer-user mismatch (cause of misinterpretation 6), are caused by attaching an association of knowledge, an existing mental model, to a certain visual element. In the fifth cause for misinterpretation, the interpretation coming from this association creates confusion because it conflicts with pre-existing knowledge, this can leave the user disregarding this interpretation (and therefore misinterpreting) or it can leave the user feeling confused (either on the data visualization or his/her self-knowledge). In the example of participant 1 (below), the information from the visualization 5 (see figure 12) conflicts with the information from her own application. Whether she will disregard the information from this new application and rely on the application she uses is not clear.

"…But I find these red and blue dots a bit weird, because I feel like you don't ovulate immediately after your period. I don't find that very logical. As in, my application says that around halfway, you will ovulate and then a bit later, you will have your period again. So, I don't know if that makes sense to me. Yes, that, I think." – Participant 1

In the sixth cause for misinterpretation, the designer-user mismatch, the association to the visual element is not the association that was intended by the designer, a wrong association. There might be multiple reasons why, the user does not have the knowledge of the intended association, or the user disregards this association because his (wrong) association fits better with his understanding of the data visualization.
This last phenomenon is the confirmation bias. Confirmation bias is when information that agrees with pre-existing beliefs outweigh the information against it [53]. Thus, it can lead the user to prefer the association that is congruent with his mental model of the data visualization [54]. An example of this is the interpretation of visualization 2, see figure 14, of participant 12 (below). Participant 12 interprets the blue section with number 2 as ovulation days. However, she notices also the two boxes in the PMS section, she disregards that but focuses on the interpretation of the timeline which she is confused about.

"Um, so, first of all, it says your cycle history. Um. So, I guess this is about the so you can just see every cycle that you've

had. So, the first one says 26 days. So that was the duration of the cycle. It says in the first visualization here, it says six in a red box and two in the blue box. I would guess that the six means the days of the period, like how many days the period lasted, lasted for, the two may be for ovulation and then they are ranks about the cramps, the headache, PMS and how sensitive the emotions are. So, in pain and emotions, those two categories. And I think you can just like say how many times you experience those and then watch. Maybe. How heavily? Yeah. I don't know. I'm not sure about these. Like, if it's meant about, like, different days. Or if it's like ranked in like how heavily?" - Participant 12

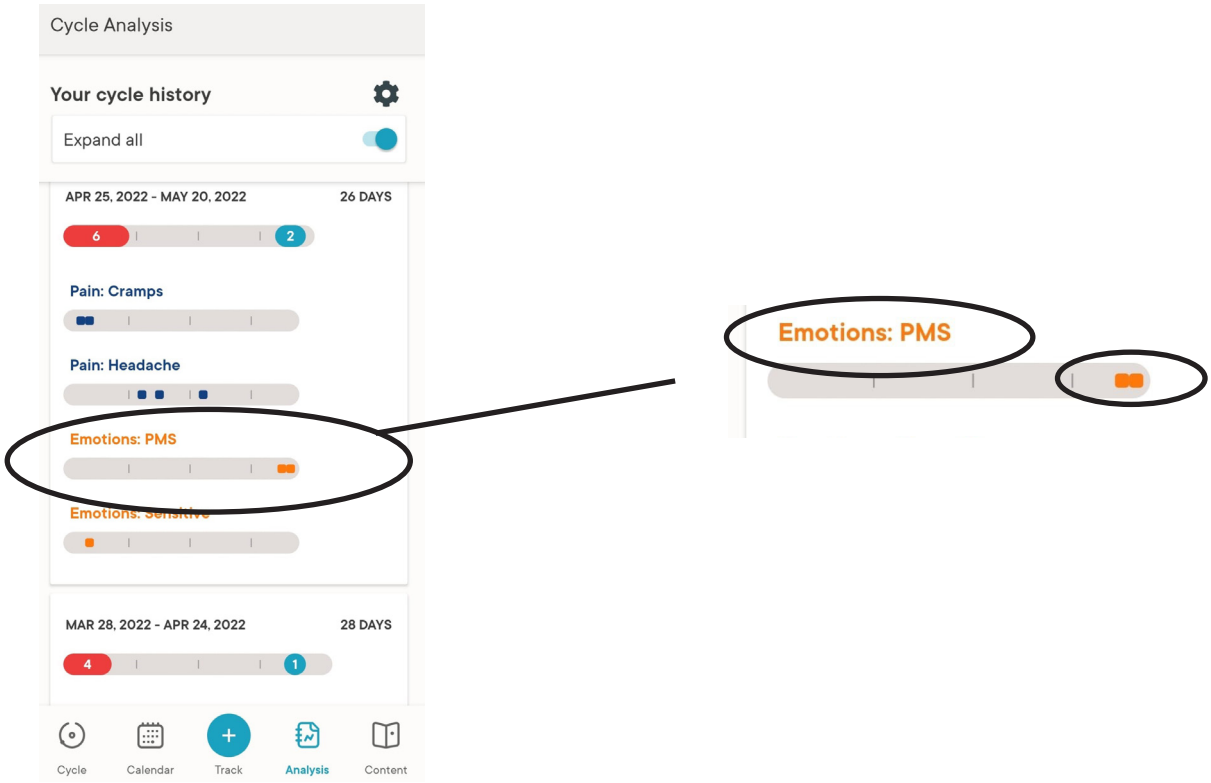


Figure 14 – visual 2 with circled visual elements that explain can explain the 2 representing PMS days.

There is also a second bias, besides confirmation bias, which can happen during the sensemaking of a visualization, which is the satisfaction of search bias. The satisfaction of search bias is when the user stops his search for additional information once a plausible result is found, this phenomenon is also called satisficing [53]. During the interpretation of a data visualization, the user stops sensemaking without having looked at all visual elements. So, the user stops looking for further visual elements to interpret and jumps to being content with the interpretation of the data visualization. This phenomenon was observed quite a lot in visualization 7. Multiple participants stopped the interpretation of the data visualization without mentioning the red and yellow dots, which represented whether the symptom was experienced during the period (red) or not (yellow).
The participants were content with their interpretation and stopped interpreting more visual elements. So, this can explain why certain elements are overlooked, the fourth cause for misinterpretation. An example of this, is the interpretation of visualization 9, see figure 15, of participant 15 (to the right). Participant 15 does not notice or ignores other visual elements that are in line with June 6th being the date of today and not the most fertile day, like the different color of numbers before and after June 6th and the texts 'Today' and 'Tracked on Jun 06, see figure 15.

"And then red again is your period, and blue the most fertile day" – Participant 15
"But then again, that June 6 is the most fertile day, that is clear, that catches your attention that you think okay that is it"- Participant 15

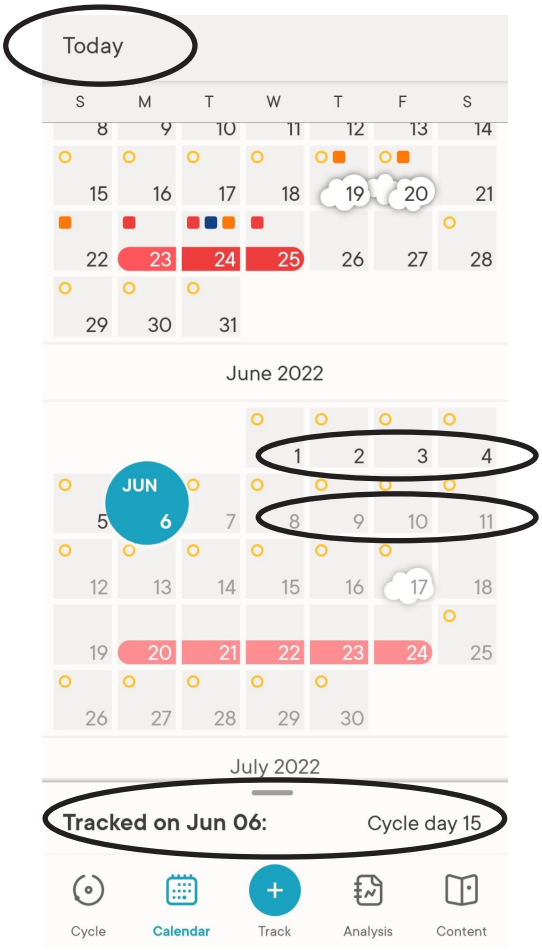


Figure 15 – Visualization 9 in which visual elements are circled that contribute to the understanding that June 6th is the day of today

3.5.5 *Data Visualization Sensemaking Framework*

From analyzing the sensemaking practices of the participants reported in section 3.5.3, I noticed that although the participants did not see most of the visualizations before, the participants always had some mental models to compare visual elements to. So, the data visualization sensemaking framework was created. All observed activities and outcomes are combined in the data visualization sensemaking framework, presented in figure 16. In total, I identified three sensemaking activities during the interviews:

1. *Comparing visual elements to existing mental models* – During this activity users looked for visual elements and then compared them to mental models in their heads trying to see they recognized some elements. When the users did not recognize elements, they continued looking at more visual elements and thus staying in this sensemaking activity. When the users did recognize elements, they continued with one of the following sensemaking activities.
2. *Building upon understanding* – During this activity, the user recognized elements from existing mental models and attaches that meaning and association to the visualization and adds this to his/her understanding of the visualization.
3. *Questioning the understanding* – Here, the user questions his/her understanding of the visualization because (s) he recognized an element from an existing mental model but that meaning, or association does not fit into the understanding that is made until that moment.

Here the understanding refers to the mental model being constructed of the data visualization but to avoid confusion the word 'understanding' is used. After comparing visual elements to existing mental models and the resulting sensemaking activity (building upon understanding or questioning the understanding), I noticed that either the participant continued sensemaking by starting to compare more visual elements (so going back to sensemaking activity 1) or stopped sensemaking while being content or confused with the understanding of the data visualizations. So, sensemaking is a constant loop of comparing visual elements to existing mental models and recognizing or not recognizing elements and continuing comparing more elements. This loop ends with two possible outcomes: 1) satisfied with understanding or 2) confused with understanding/data visualization.

The sensemaking activities and the possible outcomes are presented in the data visualization sensemaking framework, see figure 16. Based upon the data/frame theory and the NOVIS model [33, 35], the activity of constructing the understanding is also added to the framework when the user does not recognize any elements from existing mental models. When this happens, a bottom's up sensemaking approach is used, where the user constructs the understanding by combining visual elements in the visualization to create an understanding of them.

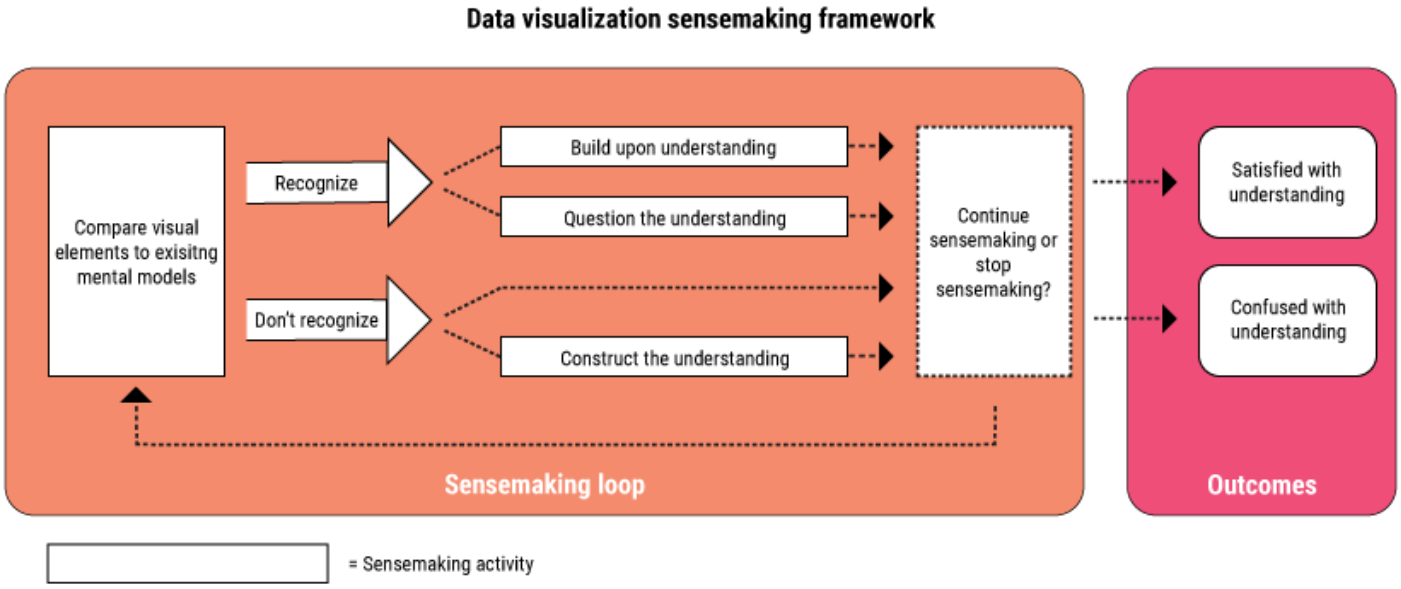


Figure 16 – Data visualization sensemaking framework

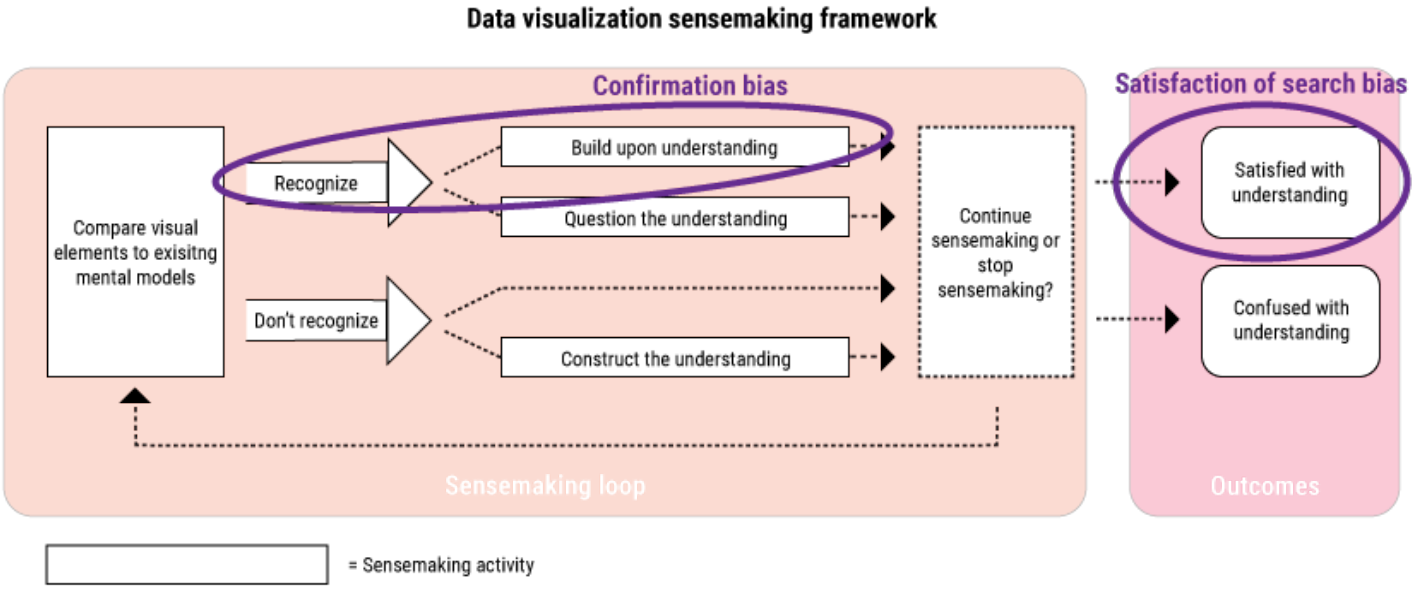


Figure 17 – Places where biases take place in data visualization sensemaking framework

In figure 17, the place where possible biases take place are presented in the data visualization sensemaking framework. With the understanding of the users' sensemaking practices, the causes for misinterpretations and the activities where possible biases take place, the next step is to study how designers could use this information in the design process. In the next chapter this study, a design workshop, and its purpose is further defined and explained.

3.6 Conclusion

The interviews were held with the goal to understand the challenges users face during the interpretation of data and to define how and why misinterpretations happen. The interviews revealed 6 causes for misinterpretations, no interpretations and confusion with the interpretations. These are (1) perceived similarity, (2) visual clash, (3) clutter, (4) overlooking of data, (5) clashing self-knowledge and (6) designer-user mismatch. The first two causes for misinterpretation arose because the visual elements of different types of data looked too similar. In the first cause, the data was seen as a similar type and in the second cause the data was not recognized as two separate pieces of data but one. Both causes can be resolved by following the design guidelines of the gestalt principles. The gestalt principle of similarity, where people perceive visual elements that are similar to be part of a group is the reason the data is perceived as similar when it is not.

The third and fourth cause of misinterpretations can be resolved by the declutter and focus guidelines. If there are fewer visual elements presented than these misinterpretations can be prevented. The third cause for misinterpretation happens when too many unknown visual elements and too many variables are presented. It becomes difficult to attach the right variable to the right visual element. This can be prevented by presenting fewer visual elements or provide annotations to let the focus go to certain explaining elements. In the fourth cause for misinterpretation, where visual elements are overlooked, it will probably also help to present fewer visual elements. To let the user focus more on the visual elements that are presented. However, it is difficult to define when there are too many distinct types of visual elements presented.

The fifth and sixth causes for misinterpretation have both to do with knowledge and sensemaking. Certain knowledge and associations came to mind during the sensemaking process, this caused confusion when the knowledge/association conflicted with the presented data, or it caused misinterpretation. Since there are no clear guidelines on these causes for misinterpretation, these two causes for misinterpretation and the sensemaking process should be studied further.

This study continued focusing on the sensemaking process and defined this in the data visualization sensemaking framework. The framework shows that users try to make sense of data visualizations by attaching associations and mental models that they already have to the visual elements that they see in the visualization. Additionally, the framework shows that sensemaking is a constant loop of looking at visual elements and figuring out what their meaning is.

CHAPTER 4

Reflecting on the Roles of Design in Menstrual Data Sensemaking

CHAPTER CONTENT:

4 REFLECTING ON THE ROLES OF DESIGN IN MENSTRUAL DATA SENSEMAKING

The goal of the second study was to understand how the data visualization sensemaking model is interpreted and used by designers and see if it influences their design process by making the designers reflect more on each visual element that they choose. To reach this goal, designers are invited to a design workshop in which they design a data visualization for a menstrual tracking app.

4.1 Participants

In this study, the condition for a person considered to be a designer is defined as the person needs to have obtained a bachelor's degree in a design related study program, such as Industrial Design Engineering or Creative Technology. The participants were recruited through a call for participants on personal social media accounts, social media accounts of the DesignLab of University of Twente and on a relevant study program page. Later, the participants were recruited through snowball and convenience sampling. There were six participants, of which two completed their master's degree in Industrial Design Engineering. The other four participants completed a bachelor's degree in Industrial Design Engineering. There were two male and four female participants. When the participants were divided into two groups of three, each group had one male designer.

4.2 Study Procedure

As the second study also involved users, I applied for and received ethical approval from the faculty of behavioral, management and social sciences (BMS), ethical request number 221382. The design workshop started with an introduction to the topic and the purpose of the workshop. The participants were asked informed consent for recording purposes in the introduction. Afterwards, a knowledge session was held in which the participants learned about data visualizations and how users make sense of them according to the data visualization sensemaking framework. Before designing a data visualization of a menstrual tracking application with this new focus on the user's interpretation, there was a warm-up session in which the participants together produced various metaphors (mental models) and visual elements for three menstrual tracking related terms: menstrual cycle, fertility, period.

After the warm-up session the designers were divided in groups. Male and female designers were spread evenly over the groups to spread knowledge/experience of the menstrual cycle. The designers were given a set of requirements for which data needs to be presented in the data visualization, but they were free to choose their own target group. The designers had about 1,5 hours to produce a design concept. After the designs were completed, the designers explained their design and design choices to each other. Then, as a group we reflected upon the design process, the design choices, and the design. The focus of the reflection session was whether the designers felt that they could make informed choices and whether the focus on the sensemaking framework was beneficial for the design. Also, the use of the data visualization sensemaking framework was discussed. To see an overview of the structure of the whole design workshop including the duration of various parts, see table 6.

Table 5 – Participant characteristics

Participant	Gender	Group
D1	Female	1
D2	Female	2
D3	Male	2
D4	Male	1
D5	Female	1
D6	Female	2

Table 6 – Structure of design workshop

Part	Duration	Content
Introduction	10 minutes	• Introduction to the topic and purpose of the workshop • Taking consent for recordings
Knowledge session	20 minutes	• Explanation on data visualization terms • Explanation on benefits and limitations of the number of visual elements • Explanation on the data visualization sensemaking framework (see appendix B for the earlier version of the framework that is presented during the workshop)
Warming-up exercise	20 minutes	• Brainstorm metaphors on the concepts of period, fertility, and cycle
Explanation assignment	5 minutes	• Explanation on assignment, goal of the assignment and requirements
Break	10 minutes	
Design assignment	90 minutes	• Divide into groups of three • Design a data visualization
Reflection session	60 minutes	• Groups present design • Groups explain design choices • Discuss the design process • Discuss the data visualization sensemaking framework

4.3 Venue and Equipment

The design workshop took place at the DesignLab at the University of Twente. A private room was used where a big screen, design materials like papers, pencils and markers, and whiteboards were available. See figure 18 for the set-up of the room. The whole workshop was audio and video recorded. For the audio and video recordings two cameras on tripods were used, these were set up at two group tables.

4.4 Data Analysis

There was a total of around 5 hours and 10 minutes of recording. The cameras were turned on right before the warming-up session. However, during the break, it was discovered that camera 2 was not recording. Luckily, the warming-up session was recorded on the other camera. Camera 1 stopped recording during the reflection session, but camera 2 did continue recording. Camera 1 had a total recording of about 2 hours and 30 minutes, and Camera 2 had a total of 2 hours and 40 minutes. The recordings and transcripts were stored on the personal UT account storage during the duration of the research. The recordings are deleted after the research is done. The transcripts which contain no personal data will be deleted when the UT account will be deleted.

The audio recordings were transcribed and the different activities in the design process were inductively coded. Remarks on the framework and the design process were marked as well, both during the design and the reflection session. These remarks on the framework together with the differences between the two groups in the design processes were analyzed and will be discussed in the results.

Figure 18a – Pictures of design workshop

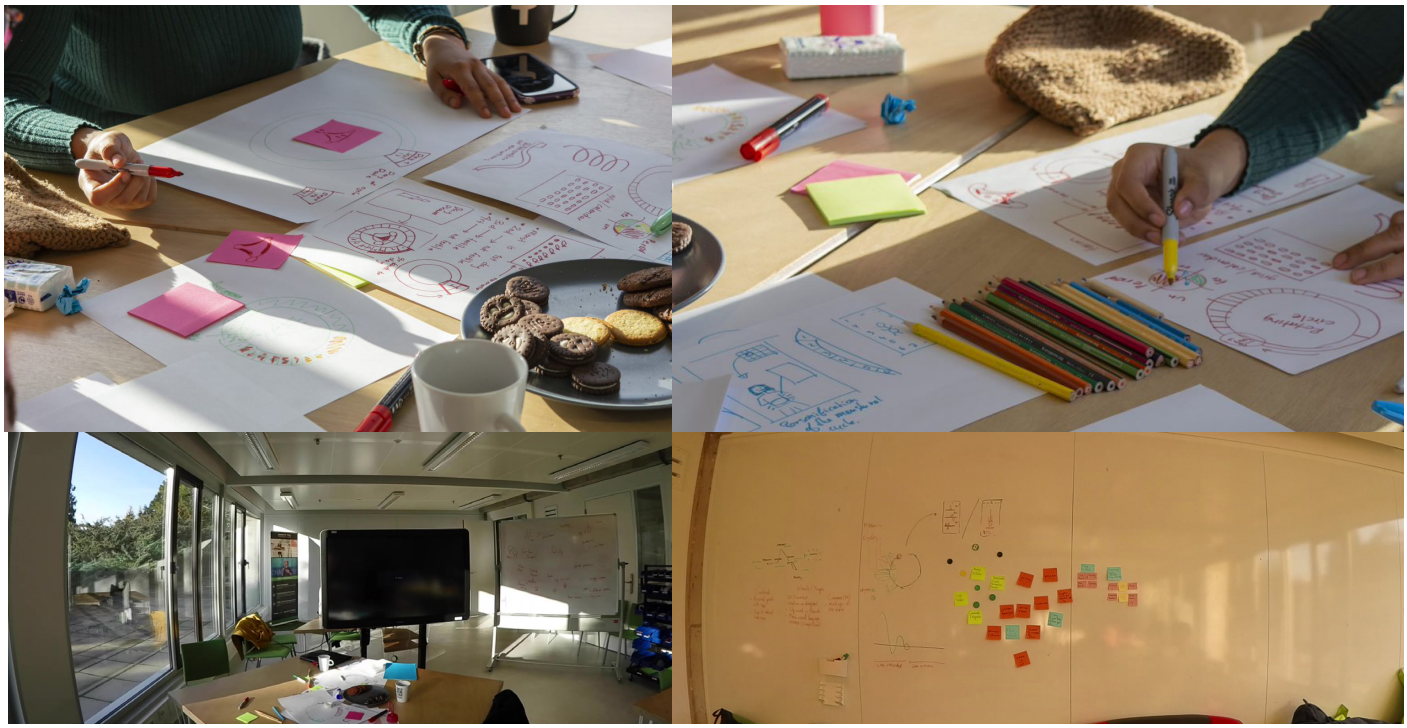


Figure 18b – Pictures of design workshop

Table 7 – Codes and examples of the design workshop

Topics	Codes	Examples
Design activity	Choose target group	Participant D1: *"Uh. I always go for the Dutch user. I always go for the Dutch user. For you."* Participant D4: *"Yeah. Or the American could also be. But this is sort of like a it is archetype with this career tiger."* Participant D1: *"Career tiger. It's like a tiger, Mom, do you know that one?"* Participant D4: *"Yeah, Tiger. It's just like someone, who really goes."* Participant D1: *"But do you know the phrase tiger Mom? It's like a mom that really pushes your child to do everything. Like, oh, you have to learn how to do piano and I can do an extra lessons."*
	Define target group needs	Participant D6: *"First couple of periods. Yes, first year, maybe first year."* Participant D3: *"Really explaining what is happening. Reassuring. So maybe also cues on what to do when."* Participant D6: *"Like guiding."* Participant D3: *"What to do when."* Participant D2: *"I think in this case, especially if you just start that you have to give the app a lot of information still. So, to make that easy for them. Like, for example, if you have a a timeline or during the day and then that you can give input to the app like, okay, today I feel like this or that. It probably has to learn still."*
	Brainstorm metaphors	Participant D4: *"That could be, uh, I was kind of thinking of this a sort of anonymous large group. First metaphor I came up with was a city with neighborhoods or flats. Flats are, of course, a sort of collective, anonymous thing. This could also be just to build your city map."* Participant D5: *"Yeah, it can be a city in the dark and I you see some lights and then where the lights represents other people that are also experiencing it."* Participant D4: *"And then you can have the, the, the personal cycle overhead. Like maybe if we have, uh, somebody like. Can be like, you have this indicator of your own cycle, uh, that can be sort of simplified in this collective overview. So maybe the moon goes from sort of this, uh, maybe from green to red to, to, to yellow, I don't know. And as you can sort of see all these little, uh, dots in the city with similar colored lights."*

Continuation of: Table 7 – Codes and examples of the design workshop

Topics	Codes	Examples
Design activity	Look at (visuals from) existing menstrual tracking apps	Participant D5: *"I'm going to look for some existing visuals as well. So, this one is also just to circle, it is not that difficult."* Participant D4: *"So where is the user?"* Participant D5: *"But where are they right now? I don't know."*
	Choose metaphor	Participant D6: *"Or I mean, it could be a full cycle or full circle. And then the guy here in the middle, you know, like, yeah, kind of showing like right now."* Participant D2: *"Yeah, it's like you click on the day and then it usually shows like the current day, but then if you click on another day, that day would show."* Participant D6: *"I mean, because this is also kind of educating how other models. Yeah. So, for example, like if you look at this one is like that is the circle. Like they're all, they're all like circles like, yeah."* Participant D2: *"I like the circle. Because it starts over and it's not really, I mean you can pick the date."*
	Define ideal path for user through the data visualization sensemaking framework	Participant D4: *"And then so the user constructs a model mentally there and then compare is further, while it's being built."* Participant D5: *"And then you, also the so then the things they want maybe and then build their own, uh."* Participant D4: *"And do we want our user to be content with the interface? I think so."* *Participant D1: "This is basic, right."* Participant D4: *"Not necessarily you could make an app with the explicit purpose of people not being content with it."* Participant D1: *"So that they build it themselves?"*
	Create concept	Participant D3: *"Then you can fast forward to that day. And then for that day, Sonya is. I don't know. She's feeling she's feeling a bit, uh, not so good. Um, and this is the reason why then you can have a bit more or something like that. She doesn't have any hands. But no problem."* Participant D6: *"She doesn't need them."* Participant D3: *"Maybe something like that."* Participant D2: *"I like that for the human aspect."*
	Define app layout	Participant D5: *"Yeah, but like, when you open the app, it can be that a store that just gives an example and then layer by layer builds it up for me."* Participant D4: *"Okay, so in that way we are, uh, making sure that the initial comparison is flat. And then later comparisons once that model is known, it becomes multilayered."* Participant D5: *"Yeah."* Participant D4: *"Okay, that's nice."* Participant D5: *"Maybe you can even have, like, a legend where you can just tap which things you want to see."*
	Create final design	Participant D2: *"Yeah. So, then we need to write the stuff that rotates on that one. And then we have to put the smaller circle on top. Or we cut."* Participant D3: *"Or we write a circle below it and we cut a hole in there. I can rotate over Circle But then you can't see the other day."*
Remarks on data visualization sensemaking framework	Remarks on data visualization sensemaking framework	Participant D4: *"I must say. I am having a little bit of difficulty of designing through the model provided by [researcher], because it starts with encountering a visualization. But now we're tasked with making a visualization. So, the model really describes what a user is doing."* Participant D1: *"Yeah."* Participant D4: *"But it doesn't really describe what the designer is doing. It's not like we take an app, we encounter visualization and we kind of change it or."*

4.5 Results

The two groups had unique design approaches and results. The first group looked further into how the user would go through the framework and thus how the user would interpret their visualization. The second group focused more on the needs of the user and creating something recognizable and less on the framework that was given. These different processes are shown in figure 19 and explained in detail in the following sections. The theme of group 1 where they discussed the ideal path of the user to follow is discussed in the first section. In the second section the process of group 2 where they proposed that elements must be recognizable is explained.

4.5.1 Designing the Ideal Path through Framework

Group 1 (participants D1, D4 and D5) started by defining the target group, which was part of the assignment left to be decided by the participants. The group decided to design for a young person who lives in a conservative environment in which women's health is very individual and not talked about openly. They started brainstorming about the app being a place where the user could learn about periods and learn what people could experience during the menstrual cycle.

During the brainstorm session, the group produced multiple metaphors which they could use to present the data. Eventually they produced a metaphor which was the summary of Spotify wrapped, which gives the user a summary of statistics of their music listening of the year. The participants wanted to have a similar way of presenting experiences from other users. However, after this initial idea, they struggled to come up with designs using the framework. One of the participants states the following:

> *"I must say. I am having a little bit of difficulty of designing through the model provided by [researcher], because it starts with encountering a visualization. But now we're tasked with making a visualization. So, the model really describes what a user is doing, but it doesn't really describe what the designer is doing. It's not like we take an app, we encounter a visualization and we kind of change it or."* – Participant D4. Here the model refers to the data visualization sensemaking framework, see figure 16.

Group 1 proceeded by describing the path they want the user to move through the framework. This path is (1) encountering the visualization, (2) compare visual elements, (3) construct a mental model, (4) compare more visual elements, (5) build upon the mental model, (6) being content. Before being content, there is a recurring loop of the steps of comparing more visual elements and building upon the mental model, for the path see figure 20. With this ideal path for the user, the participants created the idea to set-up the data visualization in an interactive way where the first time the user sees the data visualization, it is basically empty. After some time, the data visualization will add more elements and features automatically so that the user only must interpret a new element one element at the time, see figure 21. This way the participants argue that the user will build upon the mental model one element at the time. According to them this will limit the possibility of misinterpretation or questioning the mental model.

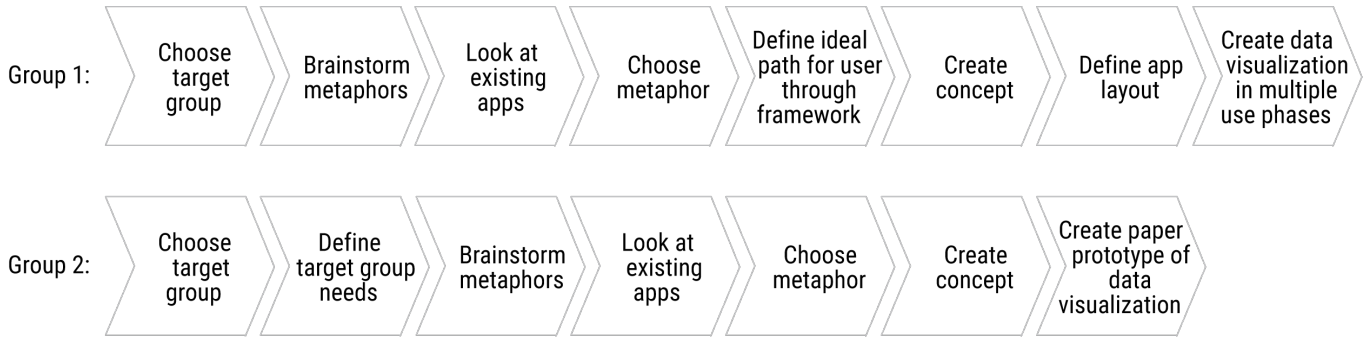


Figure 19 – Different design processes of both groups

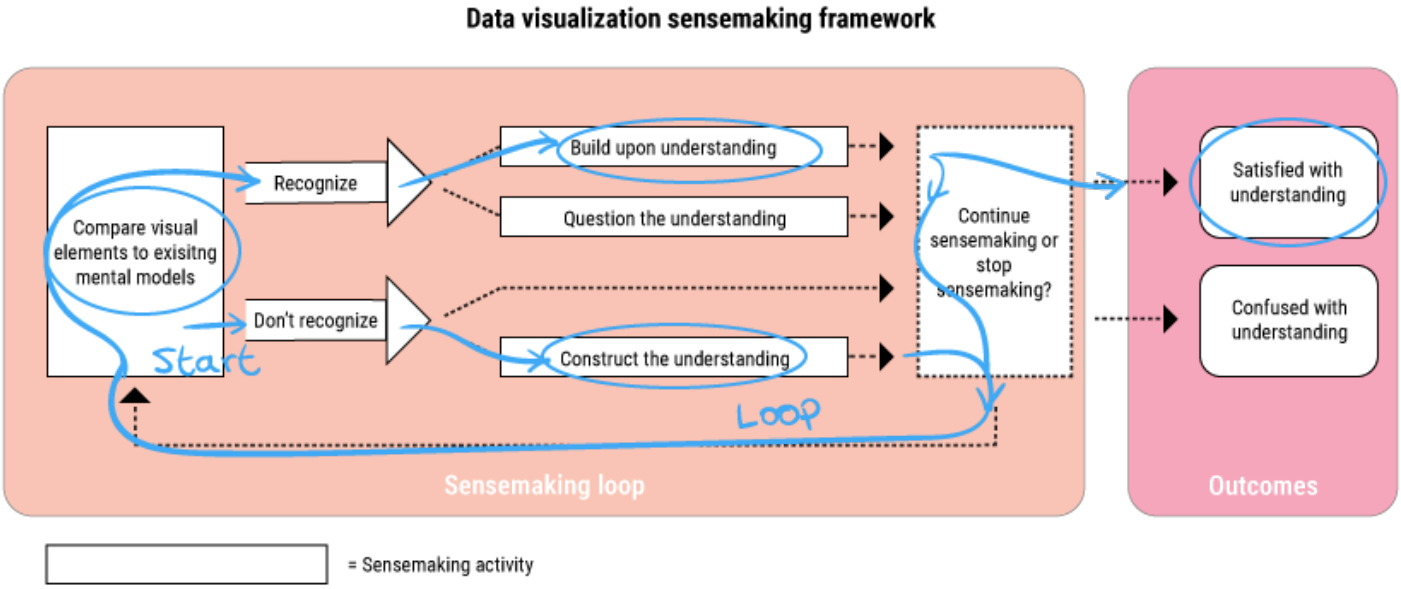


Figure 20 – The ideal path through the framework defined by Group 1

Figure 21 – The concepts of group 1, building the data visualization one element at the time. The left is the start screen, the middle shows the 'empty' data visualization, and the right shows the built data visualization.

During the reflection however, the Group 1 mentioned that their design is actually "very ambiguous and artistic". One participant answers the question whether there are visual elements that could be understood differently or overlooked with:

> *"Yeah, we made the visuals very ambiguous. So, I think it's difficult to point to something exact because it should be so over personalized and artistically. So, I don't think that the app will explain how it's drawing the picture. So that's this element is causing it to be purple and this element is causing it to be a circle. I think that will be obfuscated, to make it, uh, mysterious."* – Participant D4

Unintentionally, while designing the data visualization and wanting the data visualization build upon the mental model of the user one element at the time in a personalized and artistic way, the participant lost the focus of making the data visualization easy to understand, which was one of the goals set at the beginning of the design assignment.

4.5.2 Designing Using Recognizable Elements

Group 2 (participants D2, D3 and D6) designed the data visualization differently, see figure 19. They started the same as Group 1, with deciding what the target group would be. They decided upon the people who menstruate for the first time. For this target group, the designers want the data visualization to also explain what is happening in the menstrual cycle. With this goal in mind, the participants start brainstorming different ideas and features, see figure 22 for a part of their brainstorm of metaphors.

After a while, the participants of Group 2 concluded that they wanted to have a calendar type overview of the separate phases in the menstrual cycle and a view with a character that explains what happens in the uterus during those phases. When brainstorming for the calendar type overview and thus different calendar metaphors, they begin with looking at other menstrual tracking applications and overviews of the menstrual cycle. They note that almost all overviews are circles and choose to do a circle as well. Later they explain this choice by saying:

> *"I think that we decided to go with a circle, partially because of your model, because then it was recognizable and that was something that we liked because it was new situation. And then this is something you recognize, but I'm not sure if we wouldn't have come to that decision without the model, so I'm not sure. But I think it nudged us a little bit to go to something recognizable."*– Participant D2. Again, the model refers to the data visualization sensemaking framework, see figure 16.

In the end, Group 2 designed the data visualization by choosing visual elements based upon the fact that they were already used by other data visualizations, or the participants of Group 2 had seen them before. See figure 23, for the paper prototype of their data visualization. With this focus on interpretation, they concluded that making something easy to understand can be achieved with using recognizable elements in the design. However, as one participant said they did not know if the framework was the main cause for this conclusion.

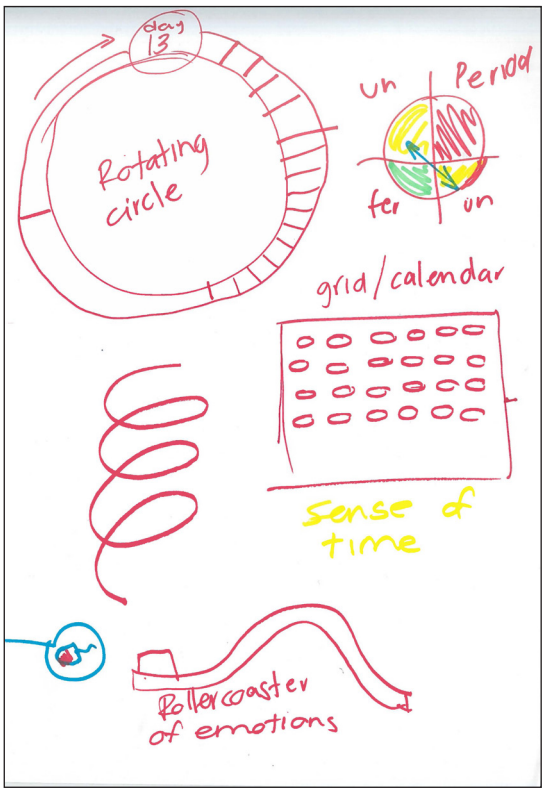


Figure 22 – Brainstorm of Group 2

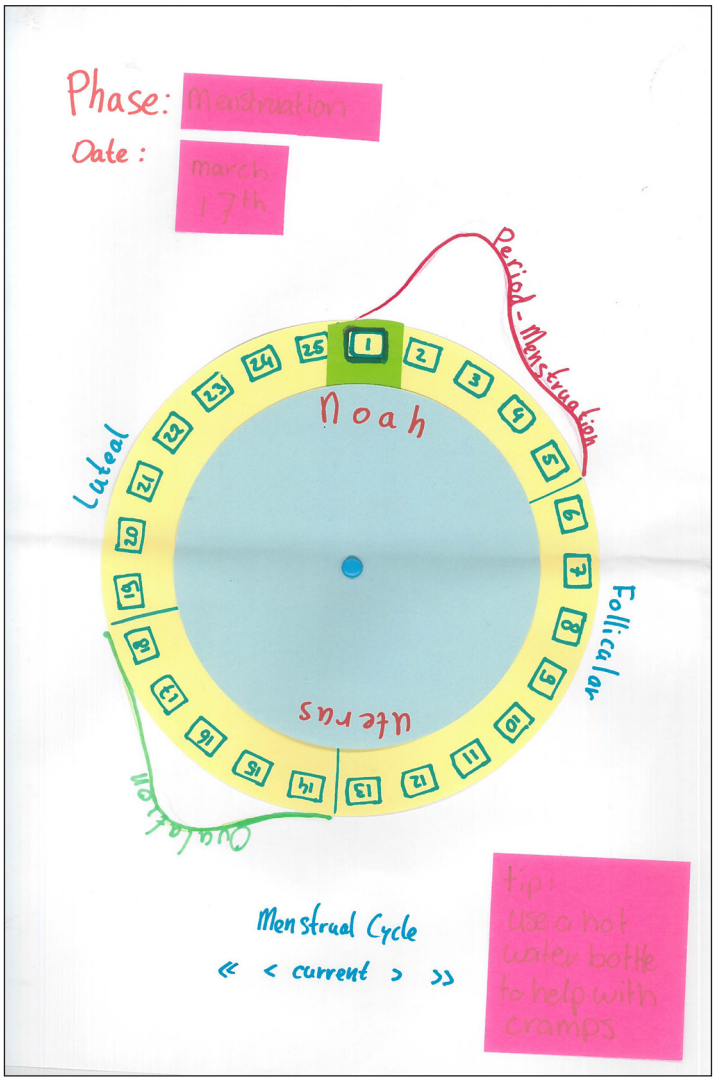


Figure 23 – The paper prototype of Group 2

During the reflection session, Group 2 became aware that the users of their data visualization needed to know quite a bit, before being able to interpret each element in their design. This is reflected in the answer to the question what the user should know before being able to interpret the data visualization:

> *"I think that they even able to relate that the circle represents an ongoing cycle. This cannot really go to the base of, of that metaphor. And of course, with the flows that flow can represent intensity. So, when I go out sort of more intense, when it goes down, less intense, color association maybe as well."* - Participant D2

Since the second group decided to design for new menstruators, they wanted to make it as easy as possible to understand. The group started to take elements from other existing menstrual tracking applications but forgot that new menstruators (probably) have not looked at other menstrual tracking applications and thus will not recognize the same elements that the participants themselves recognized. So, they ended up using metaphors and mental models which the users may not have and therefore making it more difficult for the new menstruators to understand the data visualization.

4.5.3 Framework as a Reflection Tool

As mentioned before the participant D4 found it difficult to design with the knowledge of the framework, also participant D3 mentioned that the framework gave a proper insight in the user at the start of the design process, however during the design it was not used anymore. In the reflection session this could also be noticed since both groups became aware that their users needed to make certain associations and therefore needed to have more knowledge than the groups defined. Participant D1 stated that the reason for the struggle to start designing with the framework in mind since they were forced to think from a users' perspective and not the designer perspective. Participant D4 agreed to this and stated that it was difficult to design with the framework, because the framework starts when the user encounters a visualization, whereas when designing there was no visualization yet:

"Well, I think with the model, it just made the user interpretation like, differently than how I would normally come at it. And I think also, like, it made it easier to sort of imagine what parts of the app would relate to the mental model of the user and how they experience it. So, I think was nice in that way. But at the beginning it was a bit of a struggle to understand how to make use of it because you're thinking from the designer perspective. So, it really forces you to have to imagine that you're the user itself." – Participant D1

"Yeah, I suppose the, the, the thing we found difficult was that because the model starts with the user seeing something and then doing something with that information, uh, but we had nothing. So that made it difficult to, uh, apply the model from the get-go. Uh, in a way, the model is a little bit reflective because it can show you what will happen when someone looks at the thing you've created. And in that way, it didn't give a lot of handholds for that initial step." – Participant D4

Without the framework, the participants mentioned that they would be thinking more on the users' activities and needs. During the design process with the framework, the participants thought more on the ways the user was thinking and the steps needed to understand the visualization. Participant D4 continued on this, when stating that this could be seen in the interfaces they designed. Their focus was really on explaining something that without the structure maybe could not be understood by the user:

"I think that's expressed in the fact that we have from all the interfaces we made. Almost all of them are about explaining something to the user instead of really focusing on like sort of assuming that the user understands. Right. And maybe that's also nice because now we could make something that the user cannot understand, but we make a structure around it. Whereas this would be a weird concept if you don't have that support." – Participant D4

Although Participant D4 mentioned that they focused more on explaining their concept and building knowledge with their users, they lost track of the goal to make it easy to understand. As stated before, they stated that they made it ambiguous and quite mysterious on purpose. Participant D1 mentioned that part of their idea was that the users did not have to fully understand it the first time but understanding things over time is part of the engagement, and it gives a sense of accomplishment to find out little details over time.

Additionally, Group 1 felt forced to think of visuals with this framework before thinking of the features of the application. Participant D4 stated that thinking visually in the beginning could be good, but it could also force certain design choices later in the design process which could affect the design negatively. The framework did not have the intention to force the participants to think only visually, but instead it should raise awareness in the participants that visual elements have an impact on the users' understanding of the data visualization.

In the end the participants agreed upon the fact that the framework gave proper insights in the users' understanding but it should have more guidelines or clear steps for designers to follow to help them apply this insight in the design process. The participants also felt that requirements and needs of the user should come before the looks. However, the discussion also revealed that there is a need for reflection during the process of making visual design choices or when the visualization was already made. Participant D3 connect these needs to the assignment of the design workshop:

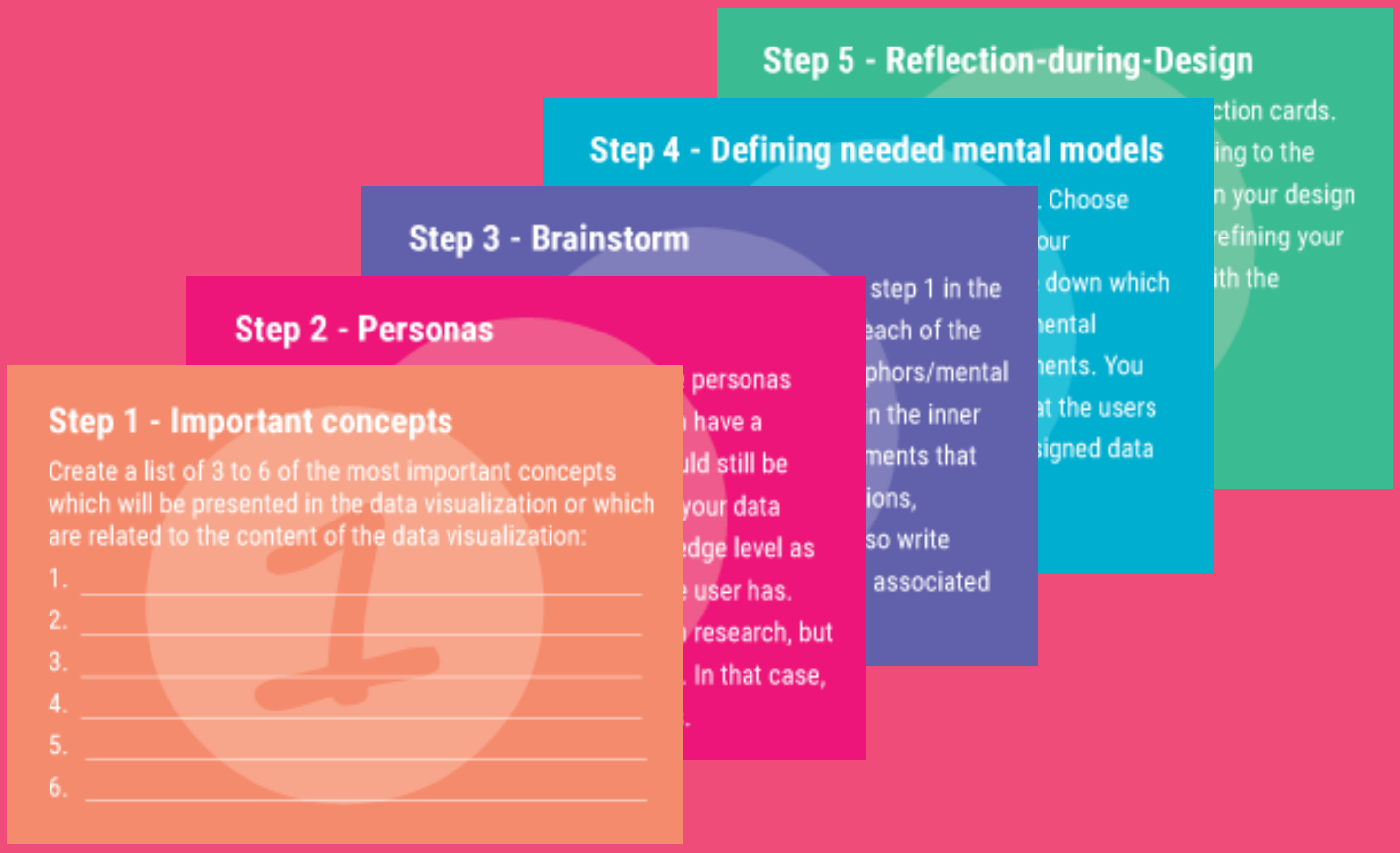
"We did really have to take some time for what is our target group and what is our target group need, because that was something that was still left open. But the other than that, there were quite clear requirements already. So maybe you have requirements or goals then to possible visualization that relate to that. Uh, what is their connection between them, what are different options? And then that was what we did. Are we going for circles or calendar, a farm, whatever, and then you make decision then so you're going into the diamonds, like this moment where you're going to explore all the different visual elements or connection that you could relate to requirements or needs, and then go back into a sort of reflection phase like, okay, um. What if we take this model? We already did this reflection part or now you can do the other way around. What information do they need and what possible biases could be related to that? So maybe then you have like to two-fold it in that sense. Yeah. Okay." – Participant D3

4.6 Conclusion of the Design Workshop

The goal of the second study was to figure out whether knowledge on the sensemaking process in the design process could prevent the 'Designer-user mismatch' misinterpretations. The participants were explained the data visualization sensemaking framework and were asked to design a data visualization that was engaging and easy to understand, however during the design process they had difficulty using the framework since it was from a users' perspective. Additionally, during the reflection session the participants found flaws and limitations in their own designs. The curse of knowledge, where during the design process they assumed that the users could understand their design, played a role since after reflection they found that the users probably did not have the knowledge to interpret the visual elements they designed. The design workshop therefore revealed that to make the participants think more about the design of each visual element in a data visualization, some guidance or steps for reflection were needed instead of just knowledge of the users' sensemaking practices.

CHAPTER 5

Design of the Reflection-During-Design Tool



CHAPTER CONTENT:

5 DESIGN OF THE REFLECTION-DURING-DESIGN TOOL

The design workshop revealed that there was a need for guidance or steps that facilitate design for good interpretability. It is difficult to design for various kinds of users and understand how they make sense of the design. The curse of knowledge, where the designer assumes that the user will interpret the visualization as intended, also plays a role. Therefore, in this chapter I will explain the design of a reflection-during-design tool that guides designers during the design process.

5.1 Purpose of the Reflection Tool

The design process of a data visualization starts when there is a need to present certain data. The data that is needed is defined by what the users need. As a first step, these user needs are further explored and as a result requirements and/or wishes are defined. After knowing what to present in the data visualization, the designers will make different concepts and designs. As noted in the design workshop, little is reflected upon each visual element. The designers will often choose their design based upon what they like or what they think is best. Especially with little visual elements the designer does not actively think about why they choose a certain visual element. Studies where users will interpret the data visualization and answer questions about the data visualization, can define pain points in the design. This is shown by the interviews that were conducted. Based upon the results from the interviews the data visualizations could be improved. However, involving users in the design process is time-consuming and costly. So, letting users actively reflect upon the designs, especially during the design process is not often done.

Therefore, there is a need for a tool that does not necessarily need to involve users but does help the designer reflect on how different users interpret the designed elements. Only the knowledge of the users' sensemaking practices does not help the designers reflect upon their design. So, a tool is needed that has the purpose of facilitating reflection on each of the visual elements during the design process.

5.2 Design Process of the Reflection Tool

The design of the reflection tool started with defining reflection questions, since reflection is the goal of the tool. The first questions were based upon the data visualization sensemaking framework, where for each sensemaking activity and outcome connecting questions were made:

Comparing visual elements:
- What is the first thing the user sees?
- What attracts the most attention in the visualization?
- What mental model is the first thing the user will reflect upon?
- Which visual elements can be overlooked?
- Which visual elements look like each other but mean different things?

Construct the understanding:
- What knowledge is needed to construct an understanding?
- What visual elements will lead to this knowledge?

Question the understanding:
- What visual elements can be associated with other mental models?
- What combination of visual elements can be associated with other mental models?
- What is knowledge/mental models than a user might have which is incorrect?

Building the understanding:
- Which knowledge/association/mental model is needed to come to an interpretation of each visual element?
- Does the average user have all this knowledge?
- What happens if a user does not have this knowledge? Can it be constructed by interpreting other visual elements?

Being satisfied with understanding:
- Is there anything that can be overlooked that might change the interpretation of the user?
- With what interpretation do you want the user to be content?

Being confused with understanding:
- Are there too many unknowns?
- Are there too many conflicts with existing knowledge/mental models?

However, while reflecting on these questions, the questions were not specific enough and the consequences of the answers were not clear. Take the last question for example, what is 'too many' and what does the designer need to do when there are too many conflicts with existing knowledge/mental models? So, these questions do facilitate reflection but do not guide the designer.

To guide the designer, the consequence needs to be clear, then the designer knows what to prevent. There, the causes for misinterpretations, no interpretation and confusion from the interview study came to mind. This was the basis for the reflection-during-design tool. For each of the causes for misinterpretation, a question or prompt was defined:
- *Perceived similarity:* Can different types of data be perceived as similar?
- *Visual clash:* Can different data still be distinguished from each other if the data collides?
- *Overlooking of data:* Are the sizes of each visual element according to the importance of the data that they present?
- *Clutter:* How many variables and visual elements does the visualization have?
- *Designer-user mismatch:* Do the users have the intended mental models needed for the interpretation?
- *Designer-user mismatch:* Consider all the associations that you have with a visual characteristic.

You might notice that the cause for misinterpretation of 'Clashing self-knowledge' is not presented in these questions and 'Designer-user mismatch' is presented twice. The reason clashing self-knowledge is not reflected upon, since there might

be dozens of reasons why a user has clashing self-knowledge. However, for this study we assume that the designer presents data that is factually accurate. Therefore, when there is clashing self-knowledge, the user has made the mistake of trusting information that is incorrect. The designer cannot change anything in the design to resolve this conflict except for presenting inaccurate information which should not be done. So, questions or prompts for clashing self-knowledge are not included.

There are two questions/prompts for the designer-user mismatch, since for the intended association of mental model to the visual element by the designer, the user needs to have this intended mental model but also needs to make the association to that intended mental model. So, the question is defined to evaluate whether the user has the intended mental model and the goal for the prompt is to make sure that there are no striking connecting mental models to the visual characteristics that might be noticed before the intended mental model.

After finalizing the reflection questions, there was still a lack of guidance of the designers. That is the reason, multiple steps to help guide the designers in the design process and help the designers answer the reflections questions were created. A total of 5 steps were defined, these are (1) identifying important concepts that will be presented, (2) creating personas with different levels of self-knowledge, (3) brainstorm visual elements, (4) defining needed mental models for the interpretation, and (5) answer reflection questions about the design. These steps and the tool are explained in the following section.

5.3 The Reflection-During Design tool

The reflection-during design tool consists of 5 steps that facilitate design and reflection. The designer will start with defining which data and concepts to present in the data visualization. The second step is to create three different personas, each with a different knowledge level. The third step is to brainstorm mental models/metaphors and visual elements that can be used in the data visualization. Each of the concepts of step 1 gets their own mind map with different associations. Lastly, the designer will create the data visualization. This can be done in the designers' own way, however, during the design process the designer needs to write down the mental models connected to the visual elements (s)he designs. And when finalizing the design, the designer needs to grab the reflection cards, answer them and will have to adjust the design according to the answers. The reflection cards will let the designer think of various aspects in the data visualization that can cause misinterpretations. See figure 24 for the explanation sheet of the reflection-during-design tool.

Reflection-during-design Tool

This reflection-during-design tool is created with the purpose of guiding designers to reflect more on the visual elements they put in data visualizations. The tool consists of 5 step cards, 3 persona templates, 6 brainstorm templates, a fill-sheet, and 6 reflection cards.

Step 1
This step is about defining the important variables and concepts that are going to be presented in the data visualization. What should be presented in the data visualization?

Step 2
In this step, you are going to reflect upon your user. What does your user know and where does your user gets his/her knowledge from?

Step 3
This step is the beginning of the ideation part of the design. You are going to brainstorm different visual elements that will represent your variables and concepts.

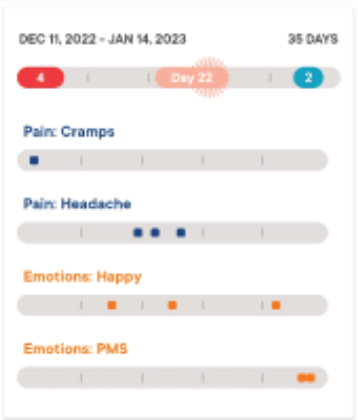
Step 4
You will start create your design of the data visualization. When you choose a visual element that you will use in the design, you will have to write down the connected mental models.

Step 5
In this step, you will refine your design of the data visualization. During the design process you will reflect upon your design with the reflection cards and adjust the design accordingly.

Defining requirements >>> Defining user needs >>>> Ideation >>>>>>>>> Create concept >>>>>> Finalize design

Explanation of recurring concepts in the reflection-during-design tool:

Data visualization:



Visual characteristics:

Shape: square with rounded edges
Color: Dark blue

But also size, shade, etcetera

Visual elements:

Mental model:

Definition: *"a structure that explains entities by describing their relation-ship to other entities"*

Examples:

= Droplet
= Drop of water
= Drop of Blood

Figure 24 - Reflection-during-design explanation sheet

5.3.1 *Step 1 – Important Concepts*

In this step, a list of 3 to 6 concepts which will be presented in the data visualization will be created. These concepts are related to the content of the data visualization. It is important for the designer to have a clear idea of what needs to be presented in the data visualization. As this fulfills the users' needs. A card is designed on which the designer can easily write these concepts down, see figure 25.

5.3.2 *Step 2 – Personas*

To get a clear idea of the various kinds of users that will look at the data visualization, the designers will need to investigate the users. Step 2 facilitates this, by having the designers create three personas with different knowledge levels, these can be defined using the personas template. See figure 26 for the step 2 information card and figure 27 for the personas template. By doing research into the users, the designers will define where the users get information (on the topic of the data visualization), what basic understandings they have and what full understandings they have. This will help the user reflect on which concepts and elements need more explaining in the data visualization.

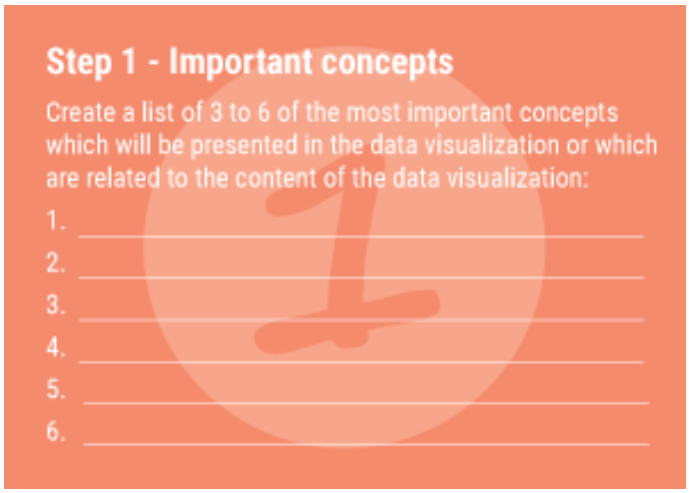


Figure 25 – Reflection-during-design card for step 1

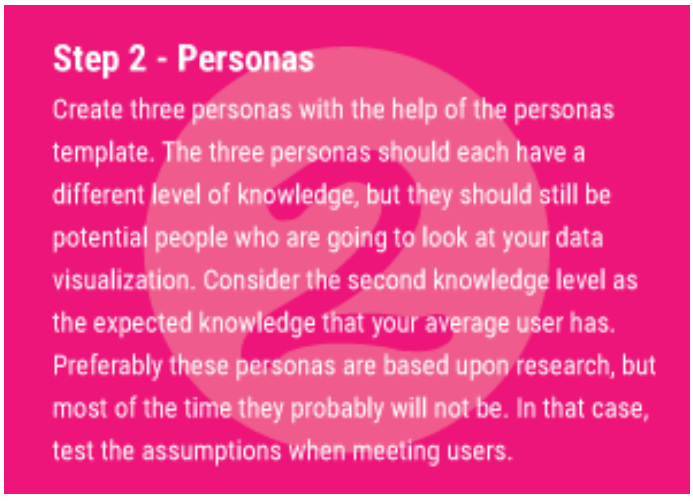


Figure 26 – Reflection-during-design card for step 2

Figure 27 – Personas template

5.3.3 Step 3 – Brainstorm

In the third step the designer starts with the ideation process with a brainstorm, see figure 28 for an explanation card. For each of the concepts that are going to be presented in the data visualization, the designer needs to come up with associations/ metaphors/mental models. All things related to that concept are going to be written down one of the brainstorm templates, see figure 29. Then in the outer ring, the associated visual elements are going to be drawn or written down by the designer. In the end, the designer has an overview of related mental models and visual elements. The designer can use this overview during the design process, by choosing visual elements from this overview to represent data in the data visualization.

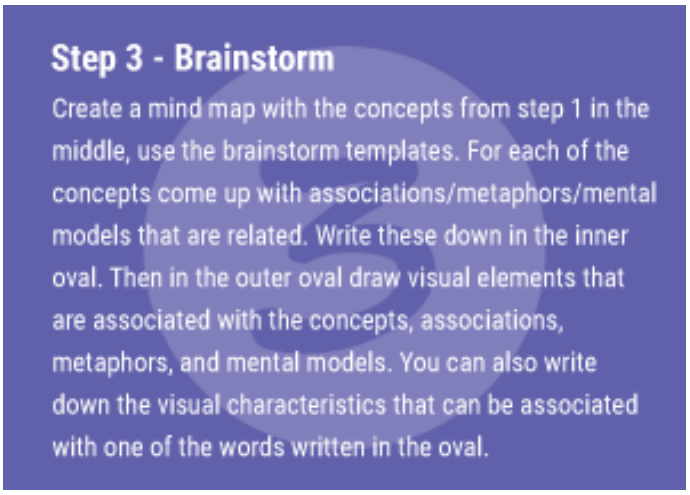


Figure 28 – Reflection-during-design card for step 3

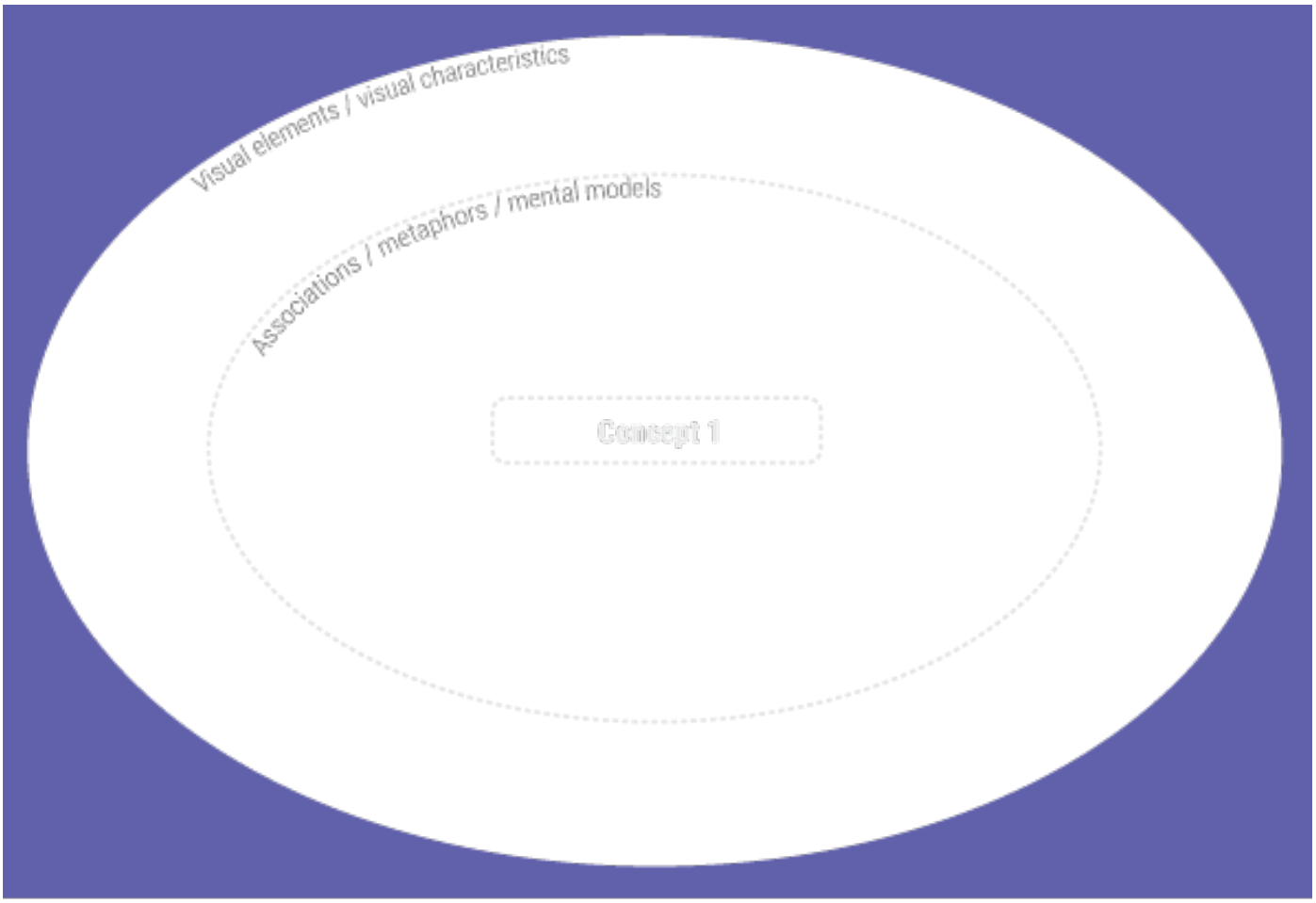


Figure 29 – Brainstorm template

5.3.4 Step 4 – Defining Needed Mental Models

After the brainstorm session, the designer can start the design of the data visualization. The designer can use visual elements from the brainstorm session and look at the personas to see what associations users can make. While designing the designer needs to read step 4, see figure 30, and thus write down the intended mental models connected to the visual elements. This can be written down in the template, see figure 31. When there is a complete concept of the data visualization, the designer will also have a complete list of mental models that the user may need for the interpretation of the data visualization. This list is useful to have during the reflection on the design.

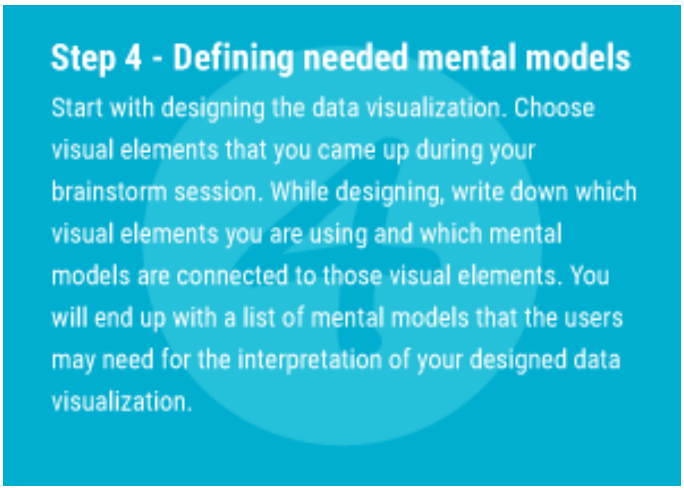


Figure 30 – Reflection-during-design card for step 4

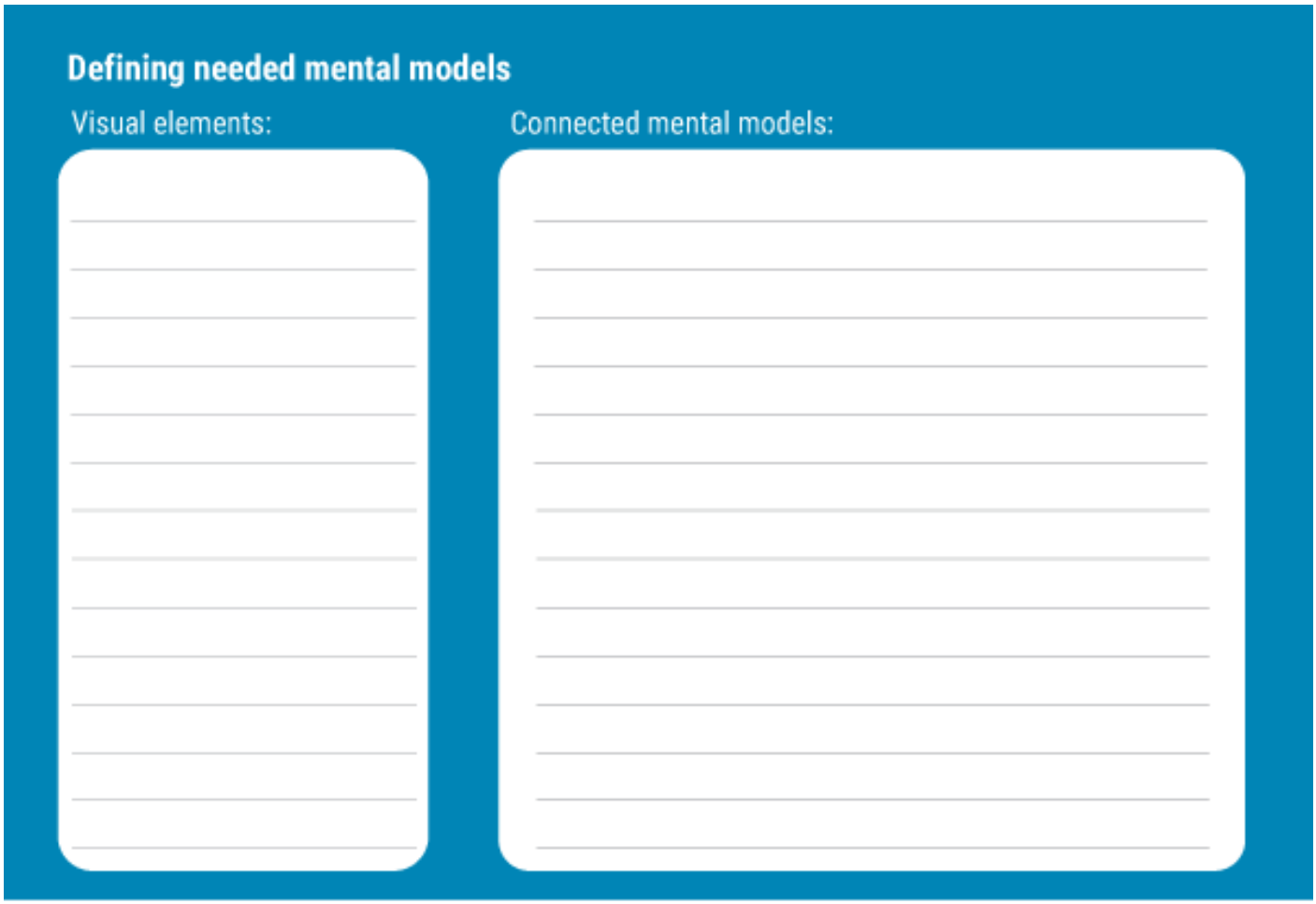


Figure 31 – Template step 4

5.3.5 Step 5 – Reflection-During-Design

During this step, the designer has a full concept of the data visualization and will start with refining the concept to a final design. See figure 32, for explanation card for step 5. While refining, the designer must grab the reflection cards one by one, see figure 33 for the reflection cards. The reflection cards let the users think about various aspects of the data visualization. There are cards that reflect upon each of the causes for misinterpretation found in study 1, the interviews with users. Additionally there is the card that lets the designer reflect on the mental models that the users have and the mental models needed for the interpretation of the visual elements which is connected to the 'Designer-user mismatch' cause of misinterpretation but also connected to the building upon understanding sensemaking activity in the data visualization sensemaking framework.

The designer can only stop with designing, redesigning, and refining the concept and the design when (s)he has reflected upon the design with all the reflection cards. Only then, common causes for misinterpretation can be prevented without reflecting upon the design together with users. Of course, reflection together with users might yield better results, however, time and money can be saved when the designer himself/herself has already properly reflected upon his/her own design.

Figure 32 – Reflection-during-design card for step 5

Figure 33 – Reflection cards

5.4 Discussions with Designers about the Reflection-During-Design Tool

After designing the tool, the tool was discussed with two of the participants from the design workshop and one other design student. The goal of the conversations was to see if the tool fit its purpose of letting designers reflect more on each visual element in the data visualization. Both participants mentioned that it facilitates reflection, with one participant even mentioning that he did not consider some aspects in a recent design. So, even though the tool was not yet used, the tool already encouraged the designer to reflect on a design.

However, during the first conversation it was clear that one step was missing. The definition of the needed mental models for the interpretation was not yet included. The participant mentioned that this meant that during the reflection there was not yet a clear overview of what mental models were actually necessary for interpretation. Therefore, step 4 was included in the reflection-during-design tool. Now, during the reflection the designer will have a clear list of the needed mental models for interpretation and can compare that to the personas where the knowledge of the users is written down.

Another discussion point, which was mentioned in all conversations, was the adoption of the tool by designers working for a company or brand. In the first conversation, one of the participants mentioned that connection to the design process was not clear. As a result, the connection to the design process was elaborated on in the explanation sheet. However, also in the second and third conversation the adoption by designers was discussed. In the second conversation this concern was expressed by explaining that all designers have their own way of designing and once a designer is confident in his/her own way, why would (s)he change? I argue that the adoption by designers should come when the reflection-during-design tool is proven to be effective in creating better data visualizations. However, first the designers should become aware of the fact that often times the data visualizations that they created are misinterpreted. So, I would propose the introduction of the tool in an educational setting, either in a workshop at companies or a lecture at a design education. In the session, results from studies need to be shown that misinterpretation happens often and what the common causes for misinterpretation are. This should make the designers/ design students become more aware on the commonality of misinterpretations. Afterwards, the tool can be introduced, where the reflection cards connect again to the common causes for misinterpretation.

The goal of the tool is to facilitate more reflection on each visual element. I would argue that when a designer uses the tool for a few times, the activities become more ingrained in the design process and will make the designer aware of the fact that each visual element should be carefully chosen. When the activities are more ingrained in the design process, the reflection-during-design tool probably is not necessary anymore since the designer can carry out the activities in his/her own design process.

The third design student expressed concern by stating that a designer for a company/brand has a certain visual style that needs to be taken into account. There is less freedom in the choice of visual elements. So, what would the tool be able to influence? I would argue that even though there is a specific style, there are still elements in data visualizations that are open to design. Besides, especially when there is a specific style of the brand, the visual elements should be reflected upon. For example, the colors of the brand can have associations on a specific topic (e.g., the brand Clearblue and the association between blue and ovulation) and those may have an influence on the interpretation of the data visualization when included in the style of the data visualization. So, even though there might be restrictions in the design, reflection is still necessary.

CHAPTER 6
Discussion and Conclusion

CHAPTER CONTENT:

6 DISCUSSION AND CONCLUSION

This thesis aimed at addressing the research question of *'What roles can design practice undertake to improve visual health data communication in tracking applications?'* with the sub questions of '*What are the challenges users face during the interpretation of data in tracking apps?*' (SQ1) and '*How can the design process of tracking applications be improved to limit the challenges users face during the interpretation of data?*' (SQ2). These questions are answered by conducting interviews and a design workshop. To narrow down the scope, menstrual tracking apps are chosen as a case study since menstrual tracking has recently become more popular [27] and people nowadays try to break the stigma by sharing more experiences with the menstrual cycle [31]. In the following sections, I tackle each question consequently.

6.1 Challenges Users Face

The goal for the first study was to answer SQ1; *'What are the challenges users face during the interpretation of data in tracking apps?'*. To answer this sub question, semi-structured interviews with menstrual health tracking app users were conducted. There were 15 participants who talked about their menstrual health tracking app usage and interpreted 9 data visualizations. The interviews showed that the data visualizations were not always clear, and that misinterpretation happens quite often. Six reasons for misinterpretations, incomplete interpretations or confusion with the interpretation were identified: (1) Perceived similarity, (2) visual clash, (3) clutter, (4) overlooking of data, (5) clashing self-knowledge , and (6) designer-user mismatch. Different guidelines to overcome these problems already exist [18, 24], however there were no existing guidelines on the last two causes for misinterpretation. Therefore, the analysis continued defining when and how existing mental models come into play in the sensemaking process. Here, the data visualization sensemaking framework was created.

The data visualization sensemaking framework shows that users try to make sense of data visualizations by attaching associations and mental models that they already have to the visual elements that they see in the visualization. In contrast to what Lee et al. [33] stated, that users always start with constructing an understanding. Additionally, the framework shows that sensemaking is a constant loop of looking at visual elements and figuring out what their meaning is, which is in line with the sensemaking activities defined by Klein et al. [35], which are part of the elaboration cycle. People attach meaning to the visual elements by making associations between the visual elements and existing mental models.

In the fifth cause of misinterpretation, clashing self-knowledge, the new attached meaning clashes with existing knowledge of the user. This often causes confusion because the user may not know what to trust, his/her own knowledge or the knowledge coming from the interpretation of the data visualization. The comparison between visual elements and existing mental models can also result in the designer-user mismatch, the sixth cause of misinterpretation, because sometimes the associations that the users make are not the intended associations by the designer. This can happen when the visual element in its context has visual characteristics that are too closely related to other mental models, or the user does not have the intended mental model. This top-down approach of attaching an existing mental model to the understanding of the data visualization therefore results into two causes for misinterpretations that do not yet have guidelines to help prevent them.

The top-down sensemaking approach is also where the confirmation bias and the satisfaction of search bias come into play. The confirmation bias is a cognitive bias that describes our focus on evidence that fits with our existing beliefs. When interpreting a data visualization, this bias causes the user to focus on mental models which fit to the understanding of the visualization. In the top-down sensemaking approach, this bias causes the tendency in the user to disregard mental models that do not fit the initial understanding, resulting in misinterpretations. The satisfaction of search bias can also happen in a top down sensemaking approach because the initial understanding might be satisfactory, resulting in the user not looking at all the visual elements.

In conclusion, the challenges users face are the unintentional cognitive processes that happen when users make sense of data visualizations and poorly designed data visualizations. Some guidelines like gestalt principles and focus and declutter exist to make use of the users' cognitive processes and adjust designs accordingly. However, for the top-down sensemaking approach of quickly attaching mental models to the understanding of data visualizations, there are no guidelines. The curse of knowledge is a contributing factor for the poorly designed data visualizations that do not facilitate the users' top-down sensemaking approach.

6.2 Improving the Design of Data Visualizations

The goal of the second study was to answer SQ2; *'How can the design process of tracking applications be improved to limit the challenges users face during the interpretation of data?'*. To answer this question, a design workshop was held to figure out whether knowledge on the sensemaking practices in the design process could prevent misinterpretations such as those caused by the designer-user mismatch. The participants, people with a design education, were explained the data visualization sensemaking framework, had a short metaphor brainstorm, and afterwards were asked to design a data visualization for a menstrual health tracking app.

During the design workshop, the participants had difficulty using the framework since it was from a users' perspective. The knowledge of the sensemaking practices of users, was not enough to let designers reflect more on each of the visual elements they chose during the design process. The participants did reflect on their concept, yet there were still flaws where the participants expected the user to have the knowledge to interpret certain visual elements which the users did not have. The design workshop therefore revealed that the curse of knowledge plays a role during the design process

and is an issue. Even when the participants were not experts in the field of menstrual health data, the participants made assumptions on the knowledge of their chosen target group and designed elements which could not be interpreted since the target group did not have the knowledge.

Xiong et al. [25] mentioned that the curse of knowledge was not studied well in the field of data visualization. This thesis therefore contributes to literature with the knowledge that the curse of knowledge is an issue in the field of data visualization and is prevalent during the design process which causes the designer-user mismatch misinterpretation. The phenomenon of the curse of knowledge, shows that designers need to reflect more on the design of each visual element without making assumptions on the knowledge of the user. Knowledge of the users' sensemaking practices was not enough to prevent the curse of knowledge, so the main conclusion from the design workshop that more guidance is needed.

Another important question regarding data interpretation came to light during the design workshop. Should the data visualization only include explicit data, or can the data visualization also be ambiguous? During the design workshop, one group wanted to design for all people who menstruate, not necessarily only women. They thought about including an ambiguous version of the gender variable but concluded to not include it in the data visualization. However, when including a gender variable that is explicit (e.g., only man and woman), it will exclude people who do not explicitly define their gender (e.g., genderfluid, non-binary etcetera). Ambiguity can in that case prevent exclusion, but ambiguity in data is often presented as a negative thing since it means that something is open to multiple interpretations.

Besides ambiguity, there is the case of the participants making assumptions on their users. One group wanted to make the visualization ambiguous. Although, the objective of the design assignment was to create a data visualization that was engaging and easy to understand, the group made the assumption that ambiguity in a data visualization was engaging the users. Whether users will actually find this engaging and whether the data visualization was still easy to understand still is a mystery. These assumptions about the user should always be evaluated since these assumptions affect the design and the satisfaction in the users.

6.3 Reflection-During-Design Tool

The design workshop revealed that there was a need for guidance and/or steps that help designers actively reflect on visual elements that they choose during the design process. So, the research question of 'What roles can design practice undertake to improve health data communication in tracking applications?' could not be fully answered. Yes, it is clear that more reflection needs to be undertaken, however there is not yet a straightforward way of how designers could reflect better. Therefore, the reflection-during-design tool was created. The reflection-during-design tool consists of 5 steps, (1) identifying important concepts that will be presented, (2) creating personas with different levels of self-knowledge, (3) brainstorm visual elements, (4) defining needed mental models for the interpretation, and (5) answer reflection questions about the design. The tool will facilitate the design process by letting the user define requirements, define user needs, and pursue a brainstorm session. But the tool will also facilitate reflection during the design process by asking different questions about the design. The reflection questions are based upon the causes of misinterpretation found in the interviews and the challenge of a top-down sensemaking approach. The tool will not only focus on reflection but also make the user aware of the cognitive processes that happen to make the designer aware of them.

The tool for reflection-during-design is discussed with two of the participants from the design workshop and another design student. These conversations revealed that the tool did already facilitate more reflection because it was mentioned by one participant that there were aspects in the reflection cards that he did not think about in a recent design. However, it also revealed that the tool should be more connected to the design process, the adoption by designers should be considered and the designer should define the mental models needed for the interpretation. So, some additions to the reflection-during-design tool were made; step 4 was added, and the explanation sheet was elaborated on.

In the end, the reflection-during-design tool should bring awareness to the designer that the visual elements (s)he includes should be interpretable by the user. Aspects among those which one of the participants mentioned, like the adoption by designers and the use over time, are still to be considered and therefore should be topics of future studies in the improvement of the reflection-during-design tool.

6.4 Limitations and Future Work

A limitation of the interviews is that the participants were all highly educated and relatively young. The e-health skills of younger users, namely use efficacy a health application and eHealth literacy, are higher than the older users of health tracking apps [55]. Where part of eHealth literacy is the ability to understand health information in apps [56]. More recently, de Boer et al. [57] found that problems related to data and strategic skills were more prevalent in older users and less educated users. Because of these differences in skills, causes of misinterpretations might differ for users who are older and less educated. Additionally, since problems related to data and strategic skill were more prevalent in older and less educated users, even more misinterpretations might happen when including older and less educated users in the study. Resulting in an even bigger need for better designed data visualizations, which take the users' sensemaking practices in account. For future studies, it is recommended that the common causes for misinterpretation and the data visualization sensemaking framework are assessed with a wider user group. More participants, from different countries, different levels of education, and different ages should be involved in the study, as it is proven that they have different eHealth literacy and data, app use and strategic skills [55, 57, 58]. Then, effects from age, the level of education and cultural differences could be studied.

The design workshop also included participants who were young and highly educated. The participants had limited experience in the work field since almost all were still students. This could have an influence on the results of the design workshop, but also on the reflection-during-design tool. Additionally, although the reflection-during-design tool was discussed with multiple participants, the tool is not fully evaluated or used in a design process. Future work should be conducted on the curse of knowledge in the design process with designers with relevant work experience and future work should be conducted on the reflection-during-design tool and whether better interpretable data visualizations are created with the tool.

Both the interviews and the design workshop had menstrual tracking applications as a case study. Menstrual tracking is similar to some other health tracking applications, namely symptom tracking applications. But menstrual tracking is tracking differently than other tracking applications, in the way that menstrual and symptom tracking requires manually inputting data, afterwards the application makes predictions. Other tracking applications mostly track automatically through sensors and give information about behavior, with the purpose of the user reflecting on their own behavior. However, although the method of generating data is not the same and the purpose is not the same, the definition of personal informatics as defined by Li et al. [10] fits both types of tracking tools, to obtain self-knowledge. After examining menstrual tracking applications, Epstein et al. [28] discussed that tracking experiences instead of behavior, can lead to important self-knowledge. And that menstrual tracking is similar to other domains where the user lacks control, like tracking pain and allergic reactions, where the user tracks the event rather than a behavior. Results like the causes for misinterpretations, the data visualization sensemaking framework, and the reflection-during-design tool can therefore be used also for other data visualizations presented in tracking applications.

6.5 Conclusion

The results of this thesis will hopefully also broaden the conversation that users have different knowledge, associations, and mental models than the designers and designers should be aware of the assumptions they make. Knowledge, eHealth skills and sensemaking skills differ depending on age, cultural background, education etcetera. Although this thesis study has not taken these differences into account due to time constraints, designers and researchers should use their ability and privilege to try to understand these users' different mental models, especially when designing/researching data visualizations accessible worldwide. Supporting users should be the main priority, whether that is through visual communication, explainability or accessibility.

References

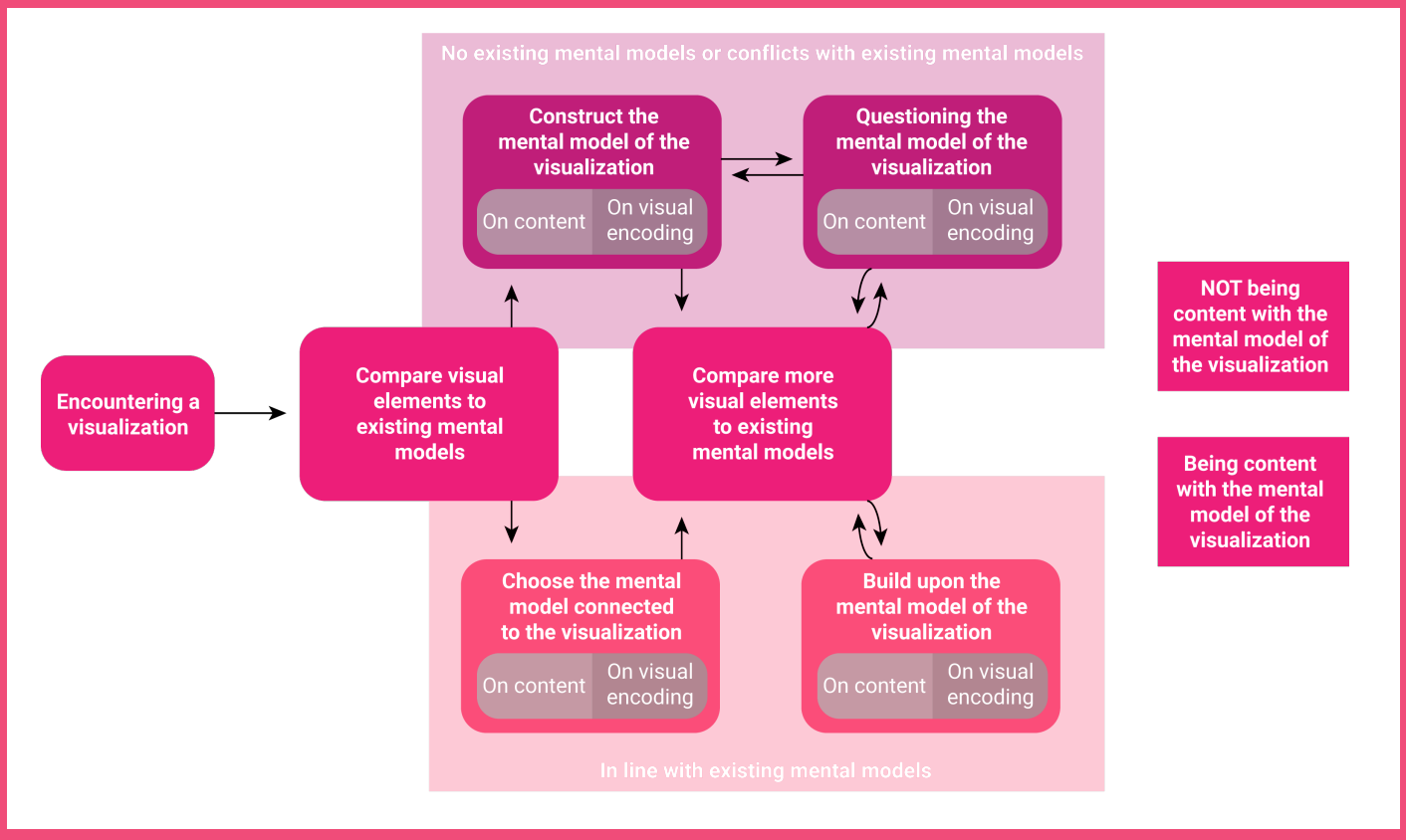
REFERENCES

REFERENCES

1. Digital Fitness & Well-being Apps - Netherlands. 2022 August 2022 [cited 2023 23-02-2023]; Available from: https://www.statista.com/outlook/dmo/digital-health/digital-fitness-well-being/digital-fitness-well-being-apps/netherlands#market-shares.
2. Altini, M. and H. Kinnunen, The Promise of Sleep: A Multi-Sensor Approach for Accurate Sleep Stage Detection Using the Oura Ring. Sensors, 2021. 21(13): p. 4302.
3. Tricás-Vidal, H.J., et al., Health Habits and Wearable Activity Tracker Devices: Analytical Cross-Sectional Study. Sensors (Basel), 2022. 22(8).
4. Ferrara, G., et al., A Focused Review of Smartphone Diet-Tracking Apps: Usability, Functionality, Coherence With Behavior Change Theory, and Comparative Validity of Nutrient Intake and Energy Estimates. JMIR Mhealth Uhealth, 2019. 7(5): p. e9232.
5. Duncan, C. and T. Nagai. Characteristics of Symptom Tracking App Data and its Potential Use for XAI. in 2022 IEEE 10th International Conference on Healthcare Informatics (ICHI). 2022.
6. Matcham, F., M. Hotopf, and J. Galloway, Mobile apps, wearables and the future of technology in rheumatic disease care. Rheumatology, 2018. 58(7): p. 1126-1127.
7. Silverman, J. and A. Barasch, You are what you track: The effect of failing to log an experience on future use of tracking apps. ACR North American Advances, 2016.
8. Jessica, S.A., et al., "You Get Reminded You're a Sick Person": Personal Data Tracking and Patients With Multiple Chronic Conditions. Journal of Medical Internet Research, 2015. 17.
9. Eschler, J., et al., Defining Menstrual Literacy With the Aim of Evaluating Mobile Menstrual Tracking Applications. CIN: Computers, Informatics, Nursing, 2019. 37: p. 1.
10. Li, I., A. Dey, and J. Forlizzi, A stage-based model of personal informatics systems, in Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. 2010. p. 557-566.
11. Adams, P., et al., Towards Personal Stress Informatics: Comparing Minimally Invasive Techniques for Measuring Daily Stress in the Wild. Proceedings - PERVASIVEHEALTH 2014: 8th International Conference on Pervasive Computing Technologies for Healthcare, 2014: p. 72-79.
12. Lutz, S. and G. Sivakumar, Leaking the secret: women's attitudes toward menstruation and menstrual-tracker mobile apps. Gender, Technology and Development, 2020. 24(3): p. 362-377.
13. Ravichandran, R., et al., Making Sense of Sleep Sensors: How Sleep Sensing Technologies Support and Undermine Sleep Health, in Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems. 2017, Association for Computing Machinery. p. 6864–6875 , numpages = 12.
14. Mehrnezhad, M. and T. Almeida, Caring for Intimate Data in Fertility Technologies, in Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems , articleno = 409 , numpages = 11. 2021, Association for Computing Machinery.
15. Choe, E.K., et al., Understanding quantified-selfers' practices in collecting and exploring personal data, in Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. 2014. p. 1143-1152.
16. Rowley, J., The wisdom hierarchy: representations of the DIKW hierarchy. Journal of Information Science, 2007. 33(2): p. 163-180.
17. Lupton, D., Feeling your data: Touch and making sense of personal digital data. New Media & Society, 2017. 19(10): p. 1599-1614.
18. Ajani, K., et al., Declutter and Focus: Empirically Evaluating Design Guidelines for Effective Data Communication. IEEE Trans Vis Comput Graph, 2022. 28(10): p. 3351-3364.
19. Helen, K. and H. Rosemary Lucy, The Feeling of Numbers: Emotions in Everyday Engagements with Data and Their Visualisation. Sociology, 2018. 52(4): p. 830-848.
20. Hollis, V., et al., On Being Told How We Feel: How Algorithmic Sensor Feedback Influences Emotion Perception. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol., 2018. 2(3).
21. Murnane, E.L., et al., Personal Informatics in Interpersonal Contexts: Towards the Design of Technology That Supports the Social Ecologies of Long-Term Mental Health Management. Proc. ACM Hum.-Comput. Interact., 2018. 2(CSCW).
22. Rooksby, J., et al., Personal Tracking as Lived Informatics, in Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. 2014, Association for Computing Machinery. p. 1163–1172 , numpages = 10.
23. Steven, L.F., et al., The Science of Visual Data Communication: What Works. Psychological Science in the Public Interest, 2021. 22(3): p. 110-161.
24. Baker, J., D. Jones, and J. Burkman, Using Visual Representations of Data to Enhance Sensemaking in Data Exploration Tasks. J. Ais, 2009. 10.
25. Xiong, C., L. Van Weelden, and S. Franconeri, The Curse of Knowledge in Visual Data Communication. IEEE Trans Vis Comput Graph, 2020. 26(10): p. 3051-3062.
26. Pichon, A., et al., The messiness of the menstruator: assessing personas and functionalities of menstrual tracking apps. J Am Med Inform Assoc, 2022. 29(2): p. 385-399.
27. Stanford, J.B., et al., Fecundability in relation to use of mobile computing apps to track the menstrual cycle. Hum Reprod, 2020. 35(10): p. 2245-2252.
28. Epstein, D.A., et al., Examining Menstrual Tracking to Inform the Design of Personal Informatics Tools, in Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems. 2017. p. 6876-6888.
29. Fox, S.E., et al., Multiples Over Models: Interrogating the Past and Collectively Reimagining the Future of Menstrual Sensemaking. ACM Trans. Comput.-Hum. Interact., 2020. 27(4).
30. Worsfold, L., et al., Period tracker applications: What menstrual cycle information are they giving women? Womens Health (Lond), 2021. 17: p. 17455065211049905.
31. Hohmann-Marriott, B., Periods as powerful data: User understandings of menstrual app data and information. New Media & Society, 2021: p. 146144482110402.
32. Cuttone, A., M. Petersen, and J. Larsen, Four Data Visualization Heuristics to Facilitate Reflection in Personal Informatics. 2014. p. 541-552.

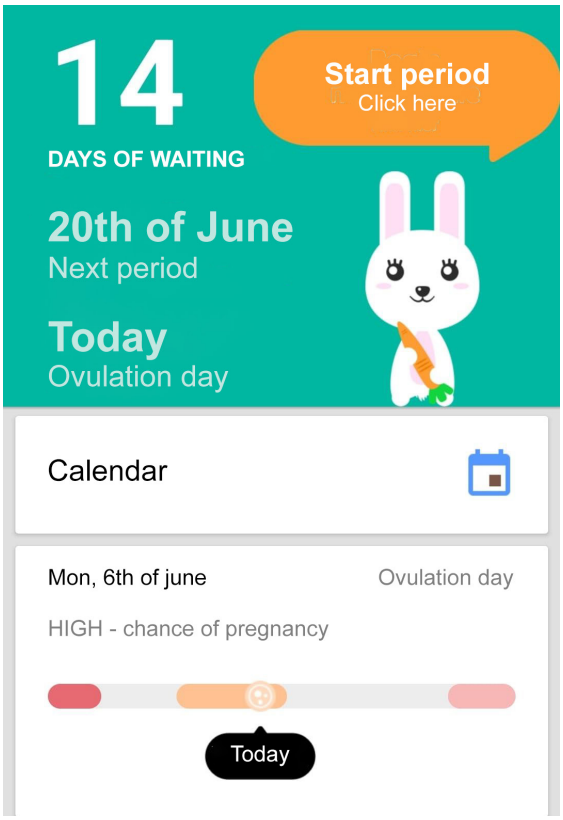
33. Lee, S., et al., How do People Make Sense of Unfamiliar Visualizations?: A Grounded Model of Novice's Information Visualization Sensemaking. IEEE Transactions on Visualization and Computer Graphics, 2016. 22(1): p. 499-508.
34. Choe, E.K., et al., Understanding Self-Reflection: How People Reflect on Personal Data Through Visual Data Exploration. 2017.
35. Klein, G., B. Moon, and R. Hoffman, Making Sense of Sensemaking 2: A Macrocognitive Model. Intelligent Systems, IEEE, 2006. 21: p. 88-92.
36. Klein, G., et al., A data-frame theory of sensemaking. Expertise out of Context: Proceedings of the Sixth International Conference on Naturalistic Decision Making, 2007: p. 113-155.
37. Liu, Z. and J. Stasko, Mental Models, Visual Reasoning and Interaction in Information Visualization: A Top-down Perspective. IEEE Transactions on Visualization and Computer Graphics, 2010. 16(6): p. 999-1008.
38. Dictionary, O.E., "metaphor, n.". Oxford University Press.
39. Epstein, D.A., et al., A lived informatics model of personal informatics, in Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing - UbiComp '15. 2015. p. 731-742.
40. Whooley, M., B. Ploderer, and K. Gray, On the Integration of Self-tracking Data amongst Quantified Self Members. 2014. p. 151-160.
41. Ellis, G. and A. Dix, A Taxonomy of Clutter Reduction for Information Visualisation. IEEE Transactions on Visualization and Computer Graphics, 2007. 13(6): p. 1216-1223.
42. Borkin, M.A., et al., What Makes a Visualization Memorable? IEEE Transactions on Visualization and Computer Graphics, 2013. 19(12): p. 2306-2315.
43. Bigelow, A., et al., Reflections on How Designers Design with Data, in Proceedings of the 2014 International Working Conference on Advanced Visual Interfaces. 2014, Association for Computing Machinery. p. 17–24 , numpages = 8.
44. Pantazos, K. and S. Lauesen, Constructing Visualizations with InfoVis Tools – An Evaluation from a User Perspective. 2012.
45. Méndez, G.G., U. Hinrichs, and M.A. Nacenta. Bottom-up vs. Top-down: Trade-offs in efficiency, understanding, freedom and creativity with infovis tools. in Conference on Human Factors in Computing Systems - Proceedings. 2017.
46. Levy, J. and N. Romo-Avilés, "A good little tool to get to know yourself a bit better": a qualitative study on users' experiences of app-supported menstrual tracking in Europe. BMC Public Health, 2019. 19(1): p. 1213.
47. Karlsson, A., A Room of One's Own? Nordicom Review, 2019. 40: p. 111-123.
48. Lupton, D., The digitally engaged patient: Self-monitoring and self-care in the digital health era. Social Theory & Health, 2013. 11(3): p. 256-270.
49. Costa Figueiredo, M., et al., Engaging with Health Data: The Interplay Between Self-Tracking Activities and Emotions in Fertility Struggles. Proc. ACM Hum.-Comput. Interact., 2018. 2(CSCW).
50. Bretschneider, R.A. A goal-and context-driven approach in mobile period tracking applications. in Universal Access in Human-Computer Interaction. Access to Learning, Health and Well-Being: 9th International Conference, UAHCI 2015, Held as Part of HCI International 2015, Los Angeles, CA, USA, August 2-7, 2015, Proceedings, Part III 9. 2015. Springer.
51. Patel, R.A., Design for use and acceptance of tracking tools in healthcare. 2014.
52. Starič, K.D., et al., Smart phone applications for self-monitoring of the menstrual cycle: a review and content analysis. CEOG, 2019. 46(5): p. 731-735.
53. Mantri, P., et al., How Do Viewers Synthesize Conflicting Information from Data Visualizations? IEEE Transactions on Visualization & Computer Graphics, 2023. 29(01): p. 1005-1015.
54. Attfield, S., S. Hara, and B.L. Wong, Sensemaking in Visual Analytics: Processes and Challenges. 2010.
55. Cho, J., D.J. Park, and H. Lee, Cognitive Factors of Using Health Apps: Systematic Analysis of Relationships Among Health Consciousness, Health Information Orientation, eHealth Literacy, and Health App Use Efficacy. Journal of medical Internet research, 2014. 16: p. e125.
56. Norman, C.D. and H.A. Skinner, eHEALS: The eHealth Literacy Scale. J Med Internet Res, 2006. 8(4): p. e27.
57. de Boer, P.S., A.J.A.M.v. Deursen, and T.J.L. van Rompay, Health on the move—can we keep up? Activity tracker performance test to measure data and strategic skills. International Journal of Human–Computer Interaction, 2022: p. 1-11.
58. Neter, E., E. Brainin, and O. Baron-Epel, Group differences in health literacy are ameliorated in ehealth literacy. Health Psychol Behav Med, 2021. 9(1): p. 480-497.

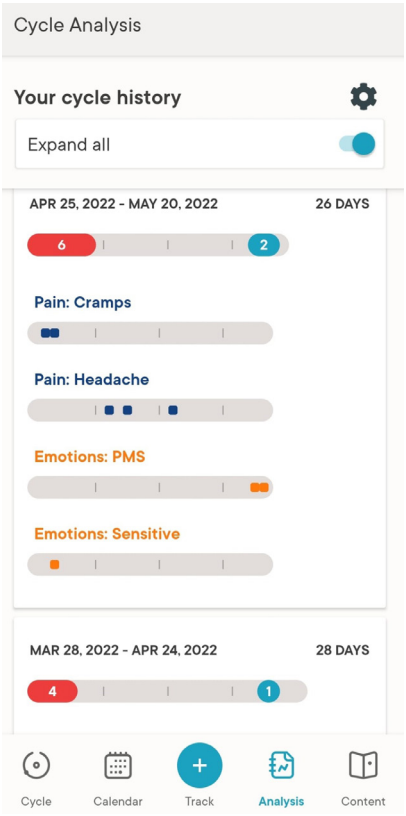
Appendix

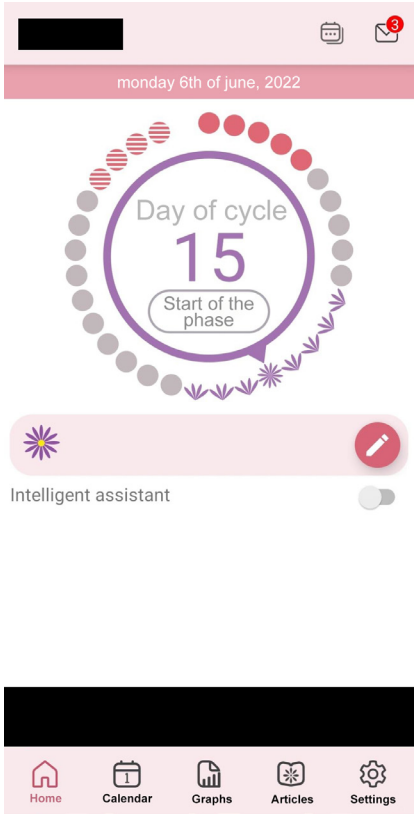


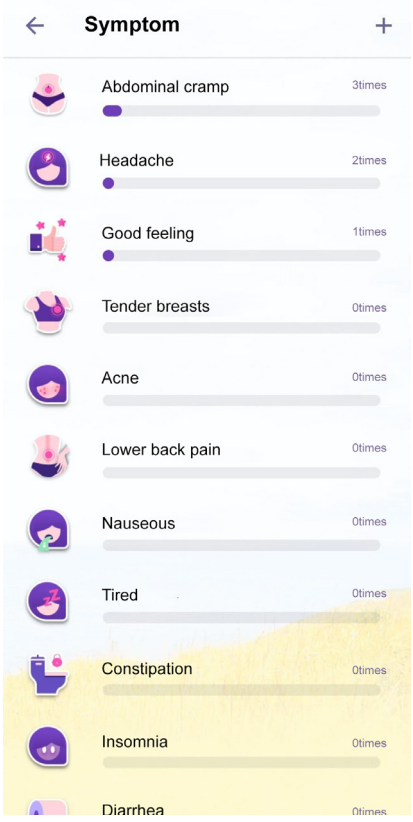
Content:

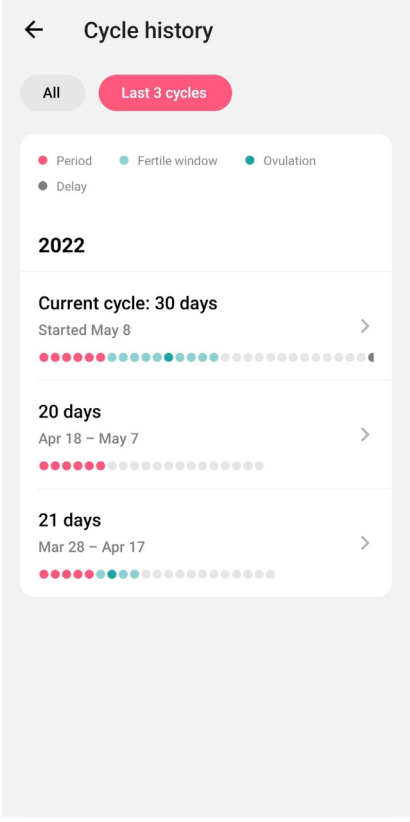
Appendix A - Nine Data Visualizations used in Interviews

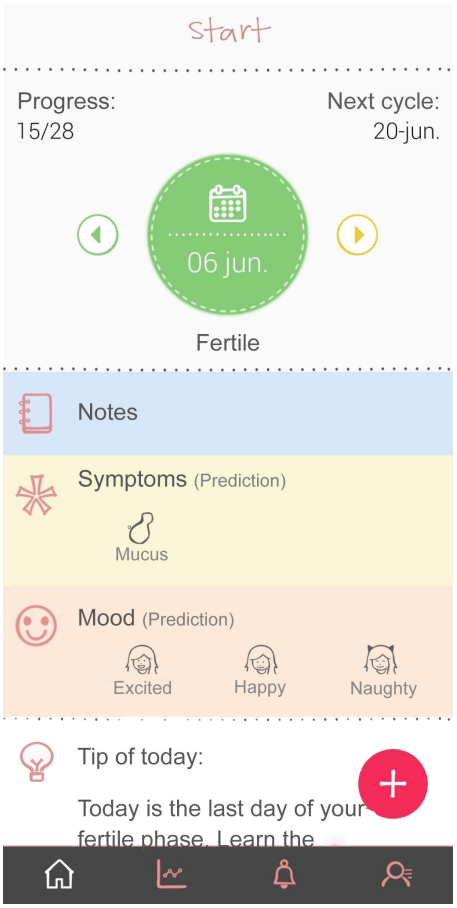


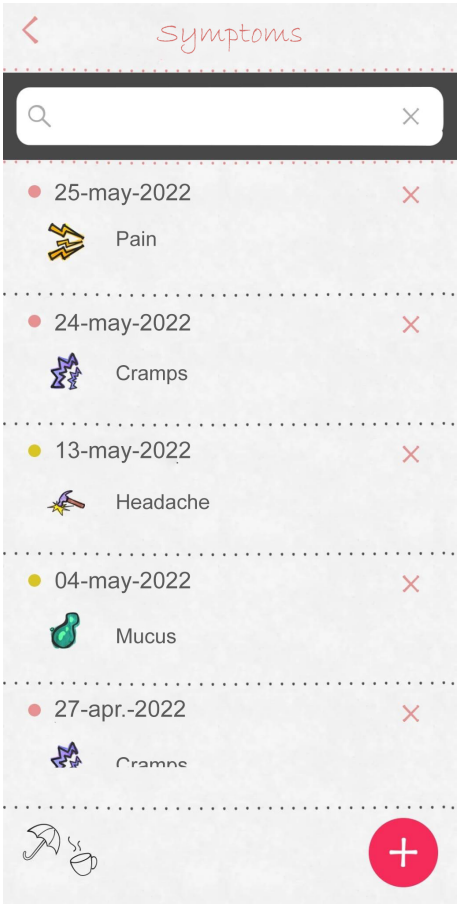


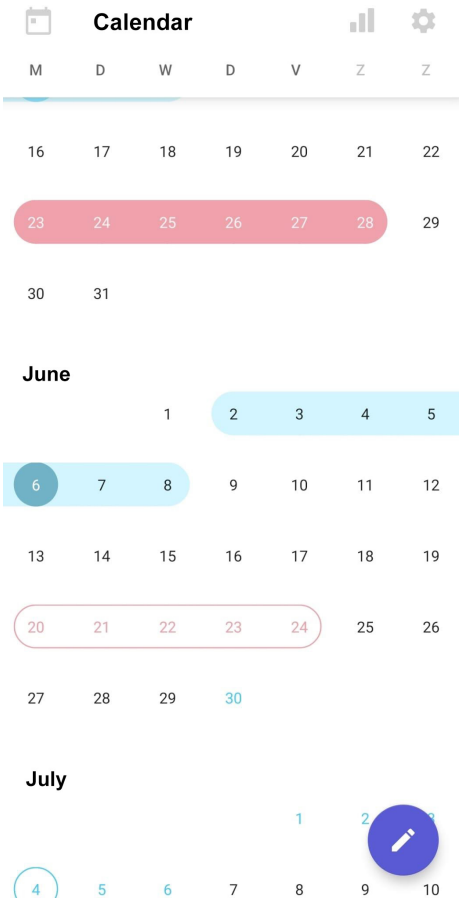


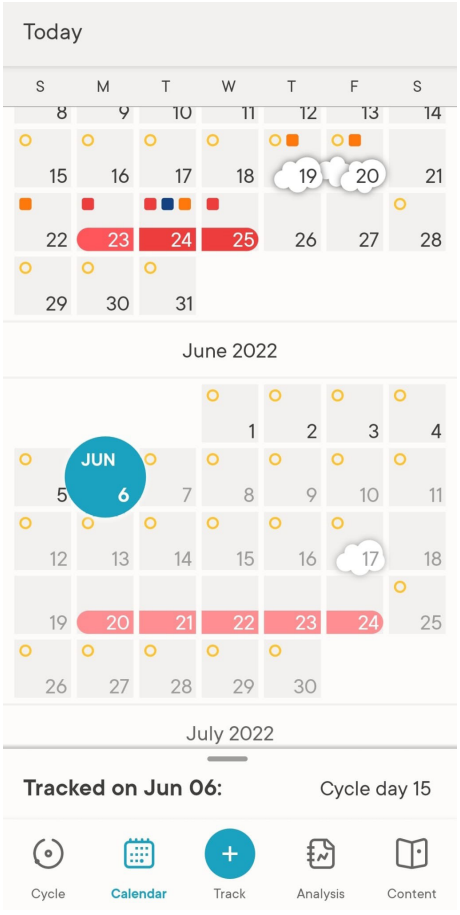





Start
Progress:
15/28
Next cycle:
20-jun.
06 jun.
Fertile
Notes
Symptoms (Prediction)
Mucus
Mood (Prediction)
Excited
Happy
Naughty
Tip of today:
Today is the last day of your


Symptoms
25-may-2022
Pain
24-may-2022
Cramps
13-may-2022
Headache
04-may-2022
Mucus
27-apr.-2022


Calendar
M D W D V Z Z
June
July


Today
S M T W T F S
June 2022
JUN
July 2022
Tracked on Jun 06:
Cycle day 15
Cycle
Calendar
Track
Analysis
Content

Appendix B - First Version Data Visualization Sensemaking Framework