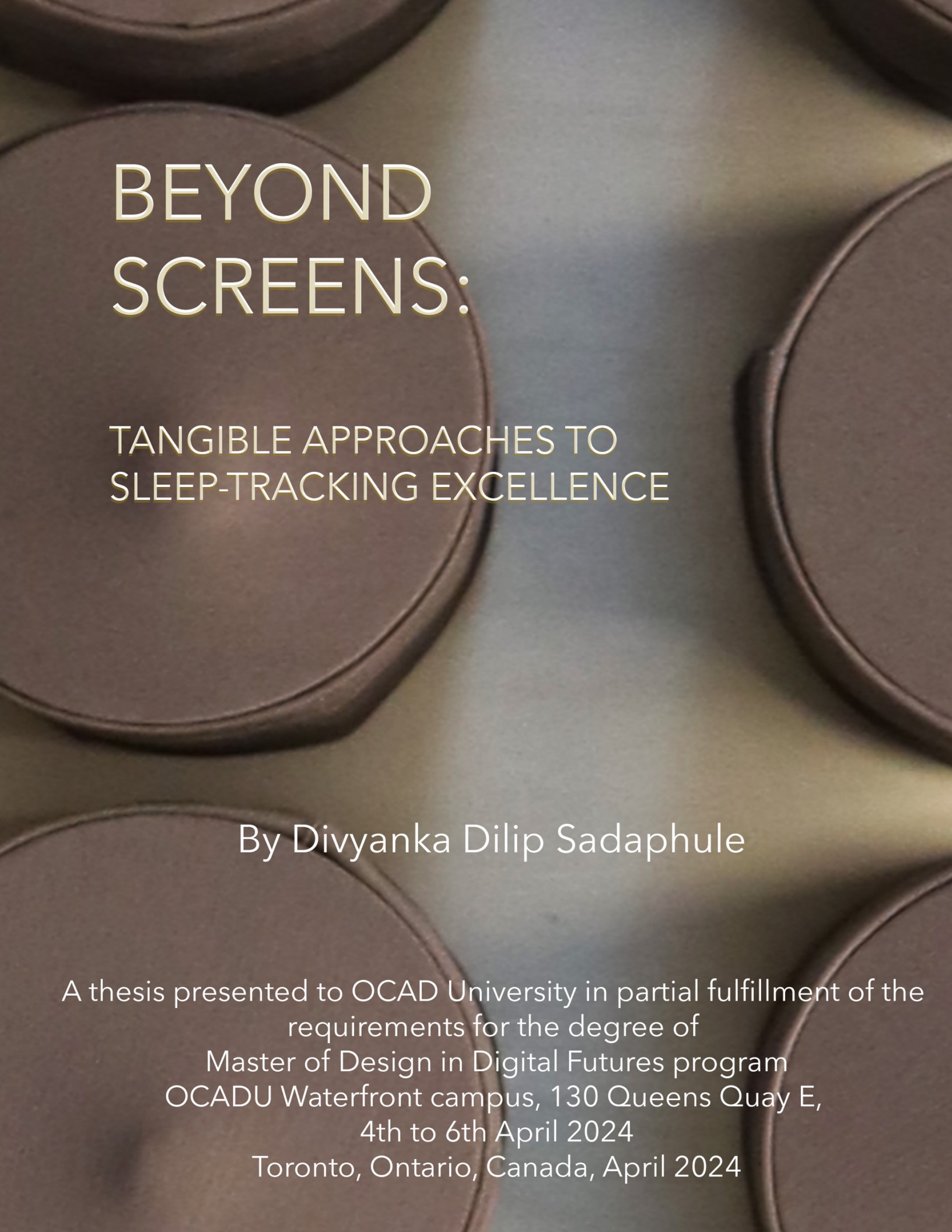

BEYOND SCREENS:

TANGIBLE APPROACHES TO SLEEP-TRACKING EXCELLENCE

By Divyanka Dilip Sadaphule

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Abstract

Sleep quality profoundly influences physical and mental well-being, yet it is frequently neglected in health discussions despite its pivotal role in these domains. This thesis utilizes Autoethnography, incorporating Mixed Method - Quantified Self-Tracking and Journaling methods to collect data and critically understand my sleep, lifestyle, and sleep environment. Sleep-tracking apps provide valuable data on our sleep, but interpreting this data can often be challenging. A sleep application utilizes mobile phone sensors and advises us to keep our phone close to the body, which may increase screen interaction and impact our quality of sleep. Sleep is complex, and many factors of our physical and mental health are interlinked. This thesis suggests tangible approaches to visualize personal data from sleep apps and journaling. Through the exploration of my own data, I experimented with different tangible representations, turning abstract information into touchable objects, aiming to foster a serene user experience by reducing reliance on screens. This research contributes to the fields of data visualization, tangible interface, and health design showcasing the potential of tangible visualization in promoting the understanding of sleep patterns.

Keywords: Tangible Representation, Sleep Environment, User Experience, Data Humanism, Data Visualization, Digital Fabrication, Quantified Self, Self-tracking

Primary Research Question – Can tangible representations enhance the understanding of data collected in sleep-tracking devices and applications, reducing nighttime screen usage, and promoting healthy sleep patterns?

Secondary Research Question - How can we improve user experience with self-tracked data to foster empathy, engagement, and meaning?

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Dedication and Gratitude

To my beloved parents, Dilip Sadaphule and Dipti Sadaphule, I express heartfelt gratitude for your unwavering support in helping me pursue my dreams. Your constant care and presence have been a source of strength throughout my journey. To my sister Dakshata Sadaphule, thank you for all things you have done for me. You are the best sister I could ever ask for. I would like to extend a special thanks to Tejas Palwankar, for the constant support, encouragement, and love.

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CHAPTER ONE: Concept

1.1 Positioning and Contextualizing My Research

My research journey is deeply rooted in personal experiences with health issues related to lifestyle problems. At the age of 16, I received a diagnosis of Polycystic Ovary Syndrome (PCOS), a condition known for its complexity and hormonal imbalances. Regrettably, there is no definitive cure for PCOS; instead, medical professionals advised self-management through a regimen of proper diet and exercise. Despite my unwavering commitment to a strict diet and exercise routine, I encountered significant challenges, particularly concerning weight management. My struggles extended beyond physical health, encompassing mental and emotional well-being, including stress, anxiety, depression, and fatigue. These issues not only affected my productivity but also strained my social and work relationships.

As I delved deeper into my exploration, I keenly observed the correlation between my dietary habits and their profound impact on my mood and productivity throughout the day. I meticulously observed how days with or without exercise influenced the trajectory of my overall well-being. In an earnest effort to address these challenges, I committed myself to a strict month-long diet regimen, anticipating improvements in my health and hoping to lose some weight. However, despite my expectations, the results remained unchanged. It was only later that I grasped the significance of a crucial factor often overlooked: sleep.

1.2 Sleep is the Antidote

In discovering more about how our daily habits impact health problems, I found something crucial: the significant role of sleep in this complex puzzle. This realization sparked my interest in understanding how our sleep patterns and daily routines affect our overall health. Sleep influences nearly everything related to our body and mind, from stress levels to our immune system, appetite, and heart health. The connection between our body's internal clock and sleep has wide-ranging effects on our well-being (Contie et al, s2013).

As health issues like PCOS, obesity, and stress become more common, it is crucial to understand where they come from. Sleep, often overlooked in discussions of health, plays a pivotal role in these conditions (*Institute of Medicine* [US], 2006). Bridging my personal journey with the broader context of sleep and lifestyle problems, I aspire to contribute to the existing body of knowledge in the domain of self-tracking.

1.3 Decision to Work with Own Data

I chose to work with my own data as it provides me with opportunities to understand myself in relation to my actions, mood, and behavior. Through the analysis of my collected data, I uncovered hidden values, beliefs, and assumptions within my lifestyle. These insights contribute to the understanding of how tangibility can benefit our well-being when it comes to sleep. If I had collected others' personal data, I would not have gained this profound understanding. I believe that self-tracking is a personal and private activity. Also, I was not comfortable subjecting another person or a group to the intense surveillance that I willingly experienced (Chatterjee, 2020). My observations and insights have guided me in discerning what works and what does not in order to enhance the design of current sleep-tracking devices.

I also recognize the value of sharing my data publicly. Visualizing and displaying my data in a public space may encourage others to think about their own sleep patterns and well-being. This approach allows me to me convey my personal experiences through tangible representation.

1.4 Scope and Limitation

The scope of this research is to use my self-tracked data to understand my sleep and reflect on how tangible representations of data can foster empathy, engagement, and meaning. The decision to track my own data gives me control over my process and helps me understand trends and insights, leading to a better understanding of the complex nature of my sleep. This research is aimed at:

1. Based on the goals of this research and the timeframe of my studies, I opted for a two-month period (28 September - 30 November) to detect trends in my sleep patterns.

2. For the final installation, 14 days of sleep score data was used because it offered a snapshot of my sleep patterns, helping identify trends and variations over different days and weeks.
3. I focused on exploring tangible representations using only two attributes: sleep score and the feeling of tiredness upon waking up. Sleep score, commonly found in sleep tracking applications, provides an overall measure of sleep quality. However, these apps often lack clarity in distinguishing between good and bad sleep, which prompted my exploration of Data Physicalizing in this research. Additionally, I used tiredness as a starting point for exploring emotions. Levels of tiredness were captured through journaling. Limiting my scope to two attributes allowed me to stay focused on tangibility (bumps, touch, and speed) to foster viewer engagement and create a sense of connection.

There are a few limitations to this project, which are listed below:

1. As the focus of this research shifted from studying light and its impact on sleep to exploring tangible representations of sleep patterns, the limited time available restricted the extent of iterative prototyping in this project.
2. Time constraints limited the depth of exploration and refinement in materialization and fabrication choices used in this research.

CHAPTER TWO: Literature Review

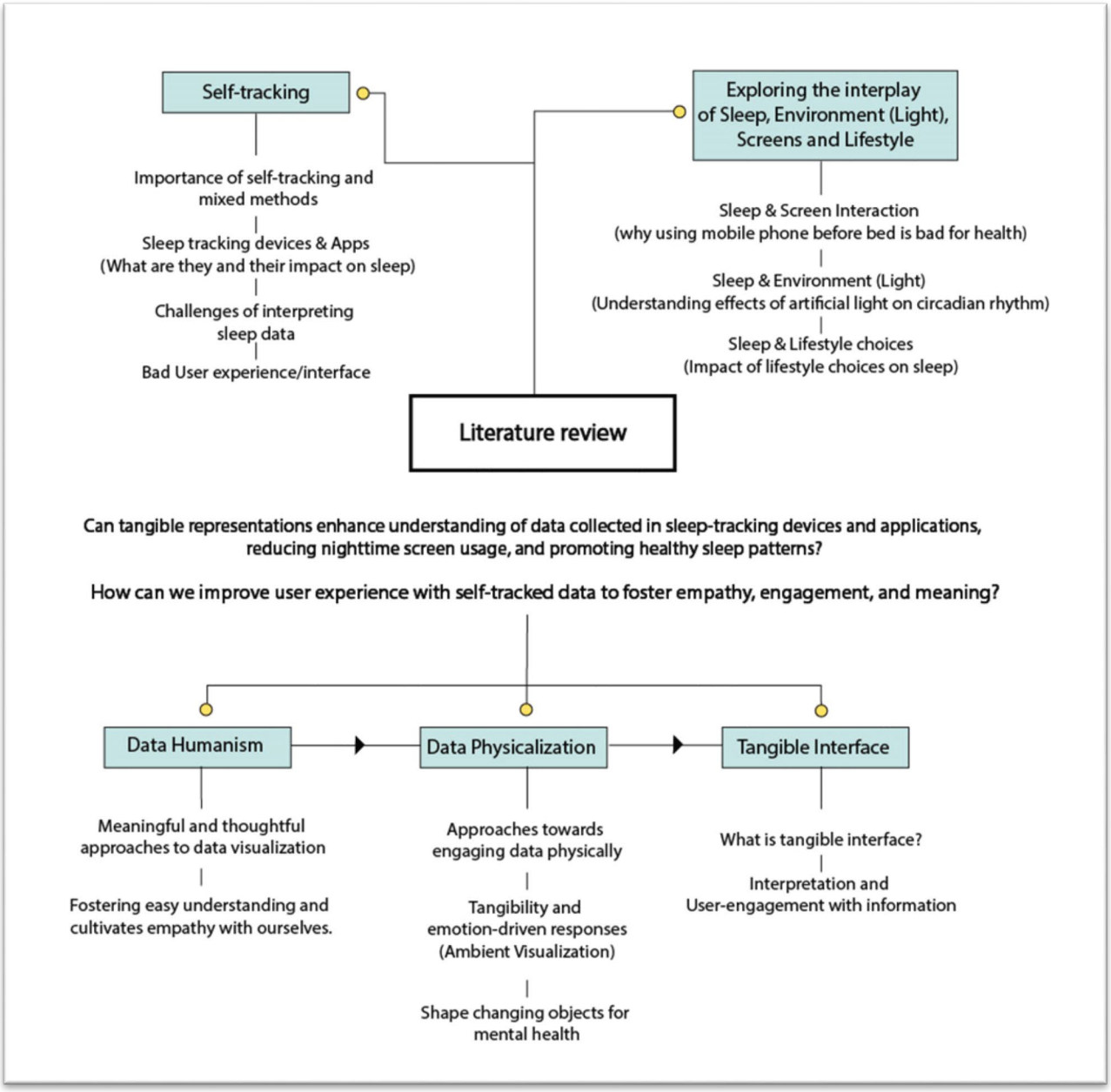


Figure 1: Brief diagram of my literature review (Author's Image)

In the early stages of my sleep research, I found myself observing my activities before and after bedtime, driven by a desire to delve deeper into the intricacies of sleep. This curiosity led me to discover nuances beyond common sense and clichés as I tracked my own data. This

chapter takes a deeper dive into the realm of sleep, aiming to gain knowledge about the interconnections among sleep, environment (light), screens, and lifestyle. I examined the importance of self-tracking and delved further into the realms of data humanism, data physicalizing, and tangible interfaces to understand the associated theories as seen in the (Fig 1).

2.1 Examining the Interplay between Sleep, Screens, Environment (Light), and Lifestyle

In our daily routines, we often adopt habits without fully grasping the potential consequences. As I started researching my sleep patterns in depth, I unraveled the answer to my questions of how things are interconnected to certain lifestyles, which impacts our physical and mental health. Beyond the commonly known principles, such as the eight-hour sleep rule and avoiding late-night snacks, I observed nuanced factors that subtly influenced and, at times, disrupted my sleep. These included activities preceding bedtime, my sleep environment, and my interaction with screens.

In this section, I aim to understand the adverse effects of nighttime screen usage, exploring the impacts of light and light exposure from electronic devices on my circadian rhythm and sleep patterns.

2.1.1 Sleep and Screen Interaction

Our contemporary lifestyle, particularly our interactions with technology, plays a crucial role in the quality of our sleep. We are tethered to our mobile phones, constantly engaged in checking emails, social media, messages, and entertainment. From the moment we wake up to the time we go to bed, our phones are a constant companion, juggling various activities. Exelmans and Van den Bulck, (2016) discuss the nighttime use of mobile phones in adults, revealing connections with sleep problems such as loss of sleep, irregular sleep patterns, poorer sleep quality, and increased daytime tiredness. Exelmans and Van den Bulck's study, involving 844 Flemish adults aged 18-94, found that half of the participants owned smartphones, with most bringing their phones to the bedroom. Engaging in text messages or calls after lights out was associated with negative sleep effects, including delays in falling asleep, reduced sleep efficiency, more disturbances, and increased daytime dysfunction. Furthermore, using a mobile phone before

bedtime was linked to waking up later, experiencing sleep difficulties, and feeling more tired. The findings suggest that bedtime mobile phone use is negatively related to sleep outcomes in adults (Exelmans and Van den Bulck, 2016).

According to Rob Newsom (2024), the screens of electronic devices such as smartphones, computers, tablets, and televisions can emit blue light that disrupts our natural sleep cycles. This research indicates that a majority of Americans use electronic devices within an hour of going to bed, which can lead to unsatisfactory sleep. Decreasing exposure to light in the evening, especially blue light, is an important way to help our body naturally prepare for sleep and get quality rest. Blue light inhibits the production of melatonin, a hormone responsible for inducing drowsiness. While beneficial for promoting wakefulness during the day, exposure to blue light at night can deceive the brain into perceiving it as daytime, disrupting circadian rhythms, and causing alertness instead of tiredness during bedtime (Rob Newsom, 2024).

In summary, I learned from the insights of Exelmans and Van den Bulck's study, which underscores the negative correlation between bedtime mobile phone use and sleep-related issues in adults. Additionally, Rob Newsom's information highlights the importance of minimizing exposure to blue light from electronic screens to foster better sleep patterns. Together, these findings emphasize the need for mindful mobile usage and limiting screen exploration at night to promote healthier sleep patterns.

2.1.2 Sleep and Environment (Light)

The quality of our sleep is influenced by our surroundings and the objects within them. While screens are one factor affecting sleep, the type of light used in our bedrooms can also disrupt our sleep.

Stone (2022) states that exposure to dim light at night can disrupt our sleep-wake cycle because the autonomic nervous system follows a strong and consistent daily pattern or rhythm. Having a dark room can help our bodies fall asleep faster (Stone, 2022). Building on this, Suni (2023) discusses light as the most critical external factor influencing sleep, playing a central role in regulating the circadian rhythm—the body’s internal clock that signals when to be alert and when to rest. With artificial light being a constant part of modern life, it dramatically affects sleep by influencing circadian rhythm, melatonin production, and sleep cycles (Suni, 2023).

Excessive or poorly timed exposure to artificial light can lead to misalignment of the circadian rhythm, affecting sleep and contributing to various health issues. Hence, Suni (2023) recommends dark rooms to reduce potential distractions and disruptions to sleep.

Therefore, understanding the type of light used in our bedroom is crucial. In my early prototyping, I explored the impact of light in bedroom spaces and gained insights. Drawing from the findings of Stone and Suni, I learned that creating a dark sleep environment is essential for promoting healthy sleep patterns and mitigating the adverse effects of artificial light on my circadian rhythm and overall well-being.

2.1.3 Sleep and Lifestyle Choices

Parallel to the influence of the sleep environment, lifestyle choices play a vital role in determining the quality of our sleep. Tamar Shochat's (2012) research delves into the intricate connections between health-related lifestyle behaviors, including weight gain, sedentary activity, and substance use, and their profound impact on sleep outcomes.

Shochat's findings suggest that implementing lifestyle changes, such as shedding excess weight, can significantly alleviate sleep issues. Even incorporating regular exercise into one's routine can positively affect sleep quality. Meanwhile, Shochat also explored interventions for high school students that despite improving various health behaviors, it did not lead to substantial changes in sleep patterns.

Understanding the intricate relationship between lifestyle and sleep is challenging, as Shochat points out. Our habits, technology usage, and health behaviors are intricately woven into our cultural and social lives. Shochat's work underscores the tight connection between our habits and the quality of our sleep, emphasizing the importance of finding effective ways to modify these habits for better sleep.

In alignment with Shochat's insights, my data collection encompasses various lifestyle factors, including mood, activities, diet, and exercise. This approach aims to provide critical insights into how these lifestyle elements influence sleep, contributing to a holistic understanding of the interplay between lifestyle choices and sleep patterns.

In summary, this exploration underscores the intricate interconnections among sleep, environment, screens, and lifestyle. The disruptive impact of technologies, such as mobile phones, and the adverse effects of artificial light on sleep and circadian rhythms have been

revealed. Considering the ideal of a screen-free and darker sleep environment, exploring tangible interfaces can be a way to address these challenges. In my making process, I experimented with different tangible representations, turning abstract information into touchable objects, aiming to foster a serene user experience by reducing reliance on screens.

2.2 Self-tracking

As I explore the intricacies of factors influencing sleep, from the negative impact of nighttime screen usage to the adverse effects of artificial light on my circadian rhythm and lifestyle choices, it is evident that fostering healthy sleep patterns requires a nuanced understanding of our activities. Recognizing the need for a mindful approach to these influences, I turned to the practice of self-tracking.

The journey of self-discovery through self-tracking provides a unique perspective. Self-tracking can help us recall our behavior with greater accuracy and see ourselves more clearly. This is because rather than relying on recollections, we have hard data in front of us that is not easy to dispute (S*elf-tracking for Self-awareness*).

Deborah Lupton (2017) studied individuals who have actively engaged in self-tracking as a core element of health promotion and healthcare. They have meticulously observed various aspects of their bodily functions, sensations, dietary choices, body weight, drug usage, and exercise routines in their pursuit of maintaining good health or effectively managing illnesses and diseases. The growing fascination with self-tracking has been fueled by extensive media coverage and the perceived potential of emerging digital technologies, especially mobile apps, to revolutionize the monitoring and measurement of human bodies, a trend prominently endorsed in medical publications (Lupton, 2017).

Lupton (2017) further discusses the cultural significance of the term 'quantified self,' denoting digital self-tracking, which has evolved since its introduction in 2007. It encompasses the use of digital tools like apps and wearables to collect intricate personal data about one's body and daily activities. Over time, this term has become deeply ingrained in discussions about the intersection of technology and personal health monitoring. It started to replace the term 'lifelogging' (traditional diary method) which has been a subject of research attention since the

advent of personal computing, especially within the field of human-computer interaction (Lupton, 2017).

The central question is whether the quantified self, primarily relying on quantitative data, can comprehensively address our inquiries. However, it is crucial to recognize the importance of qualitative data in providing valuable insights and a more holistic understanding. Quantitative data deals with numbers that you can measure, like how many hours you sleep. On the other hand, qualitative data goes further than just collecting facts. It helps us understand the trends and meanings behind things we naturally do, like our daily activities (FullStory, 2021). Both methods are valuable for understanding a complex topic, and the combination of these methods is known as mixed methods (Östlund et al.). The use of mixed methods research has become widespread in healthcare studies for various reasons, as it harnesses the strengths and perspectives of each method, acknowledging the significance of the physical, natural world and the importance of understanding reality and the influence of human experience (Östlund et al.).

Through journaling (qualitative data), I have recorded details such as my mood, activities, screen time usage, and exercise, providing valuable insights. Additionally, with quantified self (quantitative data), I have used a mobile application to monitor my sleep. These approaches allow me to collect data and critically understand various aspects of my lifestyle, sleep patterns, sleep environment, and the effectiveness of sleep tracking.

2.2.1 Sleep Tracking Devices and Applications

Sleep tracking devices monitor our sleep and give us data on how we slept. These are devices you strap around your wrist, clip onto your pillow, or even place next to your bed at night (Honeyager, 2023). Some popular sleep trackers include Apple Watch, Oura Ring, or sleep apps like Sleep Score or Sleep Watch (Honeyager, 2023). To use these devices, we need to wear them every night so that they can record our data and reveal patterns (Honeyager, 2023). These devices are safe to wear in the daytime, but are these devices safe to wear at night? Wearing these devices on the wrist can cause discomfort, especially if we sleep in a position where the arms are placed under the body or the pillow (Honeyager, 2023). Andrew Weil (2017) recommends removing the fitness tracker from your wrist during sleep, as placing your hand near your head may expose your brain to low-frequency waves.

In order for sleep tracking devices to function smoothly, they need to be connected to an application. As the wearable cannot function alone, they need to rely on a paired mobile phone for internet access (Emarketer, 2023). Some wearables offer real-time monitoring features, such as notifications for messages, calls, or fitness updates. Connecting to a mobile phone allows the wearable to receive and display these notifications (Emarketer, 2023). I understood that connecting wearables to mobile phones can enhance their functionality, but these features or reminders can also encourage users to keep their phones beside them while they sleep. As discussed in section 2.1.1, using a smartphone in bed, especially right before sleep, can have potential negative effects on sleep quality.

2.2.1.1 Sleep Application

Another popular method to track sleep is through sleep application. Although it can provide insights, it has drawbacks. Brandon Peters (2024) discusses the Sleep Cycle app, which utilizes a smartphone's accelerometer to monitor movement and instructs users to place the phone in bed. Bringing a phone into the bedroom can disrupt sleep by increasing screen time and causing disturbances from calls, texts, and alerts unless it is in airplane mode (Brandon Peters, 2024). Another issue Peters highlights is the app's high battery consumption, requiring users to keep the phone plugged in overnight, potentially posing a risk. Consequently, Peters (2024) suggests that Sleep Cycle has numerous problems with its use, limiting its utility, and he does not recommend its use for the reasons discussed.

2.2.1.2 Challenges of Interpreting Sleep Data

The challenges of interpreting sleep data from sleep applications have always been a question (Megan Thielking, 2017). A sleep application generally consists of sleep stages - awake, light (N1, N2), deep sleep (N3), and rapid eye movement (REM), and the number of hours. An average is calculated to show the overall sleep in terms of sleep score numbers. However, people often fail to understand what constitutes a good or bad sleep score or the importance of these stages. Megan Thielking (2017) discusses, that "such devices may have a role in giving us some idea about how the night’s sleep was, but I am not sure if consumers can

directly interpret the results." Thielking (2017) further points out that understanding scientific data in consumer sleep technology is challenging.

2.2.1.3 Bad User Experience/Interface

The quality of interfaces can influence how people understand and make sense of the data presented to them. This underlines the importance of user experience and interface design in ensuring effective communication of data.

The discussion in Why Most Healthcare Apps Fail, (2023) highlights that many applications fail, before they even shine, because the market needs to understand user needs and problems to create the right solution. A good User Experience/User Interface (UI/UX) relies on understanding human behavior and involves practices of iterative design and user feedback loops. Why Most Healthcare Apps Fail, (2023) states, "so the message is clear: if your healthcare app feels like a maze, don’t expect people to stick around to find the exit." It emphasizes the need to prioritize a streamlined user journey, making it more engaging, minimizing clutter, and focusing on key objectives. Failure to do so may result in creating a confusing digital experience rather than a functional healthcare solution (Why Most Healthcare Apps Fail, 2023).

Based on the above discussion, I understood that sleep tracking devices, ranging from wearables like Apple Watch to apps such as Sleep Cycle, enhance our understanding of sleep, raise concerns about safety, especially when worn during sleep. Andrew Weil advises against wearing fitness trackers at night, citing potential discomfort and exposure to low-frequency waves. Connectivity to mobile apps adds another layer, as it encourages users to keep phones aside for better sleep, addressing the adverse effects of nighttime smartphone use. Sleep applications, like Sleep Cycle, introduce challenges such as increased screen time. Interpreting sleep data, as highlighted by Megan Thielking, is challenging. Additionally, the success of these technologies depends on user-friendly interfaces, highlighting the need for clear, accessible information to ensure effective sleep tracking.

In essence, while these tools offer valuable insights, their optimal use demands a nuanced approach that considers safety, connectivity, interpretability, and user experience. Exploring tangible representations can enhance user engagement, offering a more accessible and enriching experience of their data. This approach seeks to bridge the gap between data and user comprehension, providing an alternative to traditional digital interfaces.

2.3 Data Humanism

Data is everywhere, how we perceive, understand, and interpret data is what matters the most. Data humanist Giorgia Lupi (2017) (Fig. 2) prioritizes the necessity for more meaningful and thoughtful approaches to data visualization. Lupi emphasizes personalization to connect numbers to the intricate tapestry of human experiences, behaviors, and knowledge.

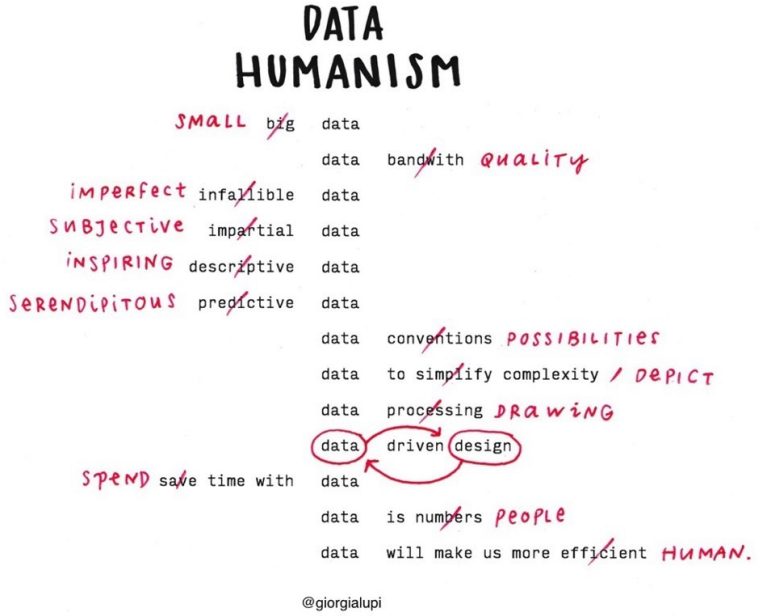


Figure 2 Giorgia Lupi's Data Humanism Manifesto (Lupi, 2017) (Received Permission, 22-02-2024).

*"*We can write rich and dense stories with data. We can educate the reader's eye to become familiar with visual languages that convey the true depth of complex stories" (Giorgia Lupi, 2017).

Lupi discusses the complexity of our world, which is filled with abundant and diverse information, requiring a thorough exploration to reveal new insights and perspectives. While complexity is inherent, the goal is to present it in a way that is still accessible and doesn't hinder understanding (Lupi, 2017).

Veda Chatterjee (2020), in her thesis "Humanizing Self-Tracking Data in a Connected World," highlights the necessity for a paradigm shift in visualizing health data. She argues that employing precise visualizations, reminiscent of those in business analytics, may unintentionally

expose our bodies to undue scrutiny and criticism. Chatterjee explores the potential outcomes of this normative approach, emphasizing the risk of establishing unrealistic health goals and contributing to heightened feelings of depression or anxiety among users. This perspective underscores the psychological impact of data visualization, advocating for a more considerate and compassionate interpretation of health metrics.

2.4 Data Physicalization

To infuse a more human touch into the presentation of data, one effective approach is to engage with it physically. Representing data in a physical form provides the chance to engage through touch, adding a sensory dimension to the otherwise abstract world of information. Hogan (2020) emphasizes the encoding of data into physical artifacts, highlighting a shift towards a more multisensory comprehension beyond conventional visual representations. Hogan (2020) suggests that the acknowledgment of potential cognitive benefits indicates that engaging with data physically could provide distinctive insights and perspectives. This aligns with the principles of data humanism, which underscores the importance of considering the human experience and inclusivity in the realm of data representation (Lupi, 2017).

I delved into the concept of Ambient Visualization, which, although not directly related to my project, aligns with the core ideas of tangibility and interactivity. Ambient Visualization involves presenting dynamic information in a way that captures attention without demanding direct focus (Vande Moere, 2007). Vande Moere's insights stress the balance needed to convey information effectively, considering subjectivity, timing, user involvement, awareness, and user-friendly design in ambient displays. This underlines how technology can not only convey information but also profoundly influence behavior and thinking.

Vande Moere further explores contemporary trends in ambient display applications, emphasizing the creation of small-scale physical artifacts at the crossroads of physical computing, product design, and electronic innovation. These designs, inspired by various fields, follow traditional ambient display heuristics. Vande Moere highlights the role of community-driven platforms like Arduino and Processing in democratizing prototyping, especially for interaction designers. In examples like James Kim's design, an egg-shaped device responds dynamically to human emotions in online chat conversations. This showcases technical

advancements and the potential for emotional and contextual engagement, pushing traditional display boundaries. In my prototyping section, I explore integrating tangibility and emotion-driven responses, aiming for richer, more immersive user experiences like ambient computing. This alignment with Vande Moere's insights enhances the potential for meaningful engagement in my project.

As I explored the concept of tangibility and emotional responses, I came across the Funktionide project by Stefan Ulrich (2009)[1], a German designer who designed a conceptual shape-changing object aimed at alleviating loneliness, incorporating artificial muscle technology, Ulrich conducted research on plastics that change shape when an electric current is applied, known as electroactive polymers, for his thesis project.

The results of Ulrich's (2009) research led to the conclusion that active materials could revolutionize our ambient products, fundamentally changing how we perceive and interact with them. By morphing their shape, these products could acquire new dimensions, essentially becoming "alive", Ulrich (2009). This realization resonated with my thoughts regarding the moments before sleep. Often, negative thoughts causing stress prompt us to seek distraction, such as scrolling on our phones, as discussed in Section 2.1. Recognizing the impact of these negative thoughts on sleep patterns and mental well-being, I can see the possibility of engaging shape-changing objects in alleviating stress and promoting better sleep.

2.5 Tangible Interfaces

In this final section, I delve into the concept of tangible representations and their potential to enhance learning in information interpretation, which is a crucial aspect to explore for this project.

A tangible interface refers to one that utilizes a physical object or token to engage with the digital realm, involving elements like data, computations, and information. This concept underscores that a user interface extends beyond screens, encompassing any tangible object that can be touched, heard, or seen (Panchal, 2022). While tangible objects are excellent tools for user-engagement, the question arises: can it enhance learning in information interpretation by touching the object?

[1]https://www.dezeen.com/2009/10/05/funktionide-by-stefan-ulrich/ Accessed March 15, 2024

Marshall (2007) emphasizes the advantages of learning through tangible interfaces. The use of physical materials suggests that if perception and cognition are closely intertwined, employing physical materials in a learning task could alter the nature of acquired knowledge compared to engaging with virtual materials alone (Marshall, 2007). For instance, three-dimensional forms might be more readily perceived and understood through the proprioceptive perception of tangible representations than through visual representation alone (Marshall, 2007).

Hiroshi Ishii (2008) discusses the mechanism of user-engagement control with tangible representations, which serve simultaneously as engaging physical controls. To simplify the engagement and enhance learning in information interpretation, Ishii (2008) suggests that designers should leverage the physical constraints of the chosen embodiment. As the physical form to some extent limits user-engagement choices, designers must craft user-engagement based on well-understood actions related to the physical object. For example, if a bottle shape is chosen, the well-understood mechanism of opening the bottle by pulling out a cork guides user engagement. This reliance on culturally common manipulation techniques helps clarify users' interpretations of how to engage with the object (Ishii, 2008).

In relation to my project, I aim to mimic the natural feedback system of our body, as discussed in more detail in my prototyping section ahead. For example, when a bump-like shape appears on the surface of our skin, it is interpreted as something concerning or negative, possibly harmful to our health. A bump informs us that there is something severe happening in our body, which is also data from which we can learn. This familiarity with common actions helps users easily interpret the information and can enhance user-engagement and learning with objects.

CHAPTER THREE: Methodology and Methods

The methodology employed in this research is autoethnography. This qualitative approach facilitates a nuanced exploration of my personal experiences with sleep, sleep environment, sleep technology, and sleep tracking. This methodology enables a comprehensive examination of inner thoughts, emotions, and experiences, providing a deeper reflection on the complexity of my sleep.

3.1 Autoethnography

Understanding the intricate connection between my mental and physical health and its relationship to sleep proves to be a complex task. With our minds bombarded by approximately 60,000 thoughts each day (Loder, 2023), it becomes challenging to disentangle the clutter and find moments for self-reflection. But self-tracking our data can be a valuable tool. Poulos, C. N. (2021), introduces autoethnography as research where individuals observe, participate, and reflect on their experiences, primarily using writing/tracking to illuminate various aspects of human social, emotional, theoretical, political, and cultural practices.

Engaging in tracking my data and documenting my thoughts on paper became instrumental in understanding my daily emotions, habits, and activities that influenced both my day and sleep. It allowed me to discern patterns, such as the impact of screen usage on my sleep, especially the disruptive effects of blue light. These insights prompted contemplation on the broader themes of sleep and sleep tracking, particularly how nighttime phone use might interfere with our sleep patterns.

Autoethnography is a unique form of scientific inquiry that entails gathering and analyzing non-numerical data to address research questions, test hypotheses, or explore phenomena (Indeed Editorial Team, 2022). Its significance lies in its ability to offer researchers a deep understanding of the intricacies of human behavior, providing insights that quantitative methods alone may not capture (Indeed Editorial Team, 2022). This allows me to use mixed methods approaches, where I combine quantitative data with qualitative data to strengthen the deep understanding of my lifestyle, sleep, sleep environment, and sleep tracking. This approach

helps address my research questions, providing a comprehensive view that goes beyond what each method can achieve individually.

3.1.1 Confessional/Self-critical Autoethnography

Confessional autoethnography is a more personal form in which the researcher critically examines their own experiences and thoughts. They may also evaluate their values, beliefs, and biases and how these potentially influenced their research. In this type, the researcher is usually more explicit about their thoughts and feelings. The goal is to understand the self and provide a space for others to do the same (Indeed Editorial Team, 2022).

This allows me to critically understand and address my research questions with my own, thoughts, biases, assumptions, and their impact on the research process. The (Fig. 3) below illustrates how I engaged in self-reflection and critically analyzed my sleep using a mixed-method approach.

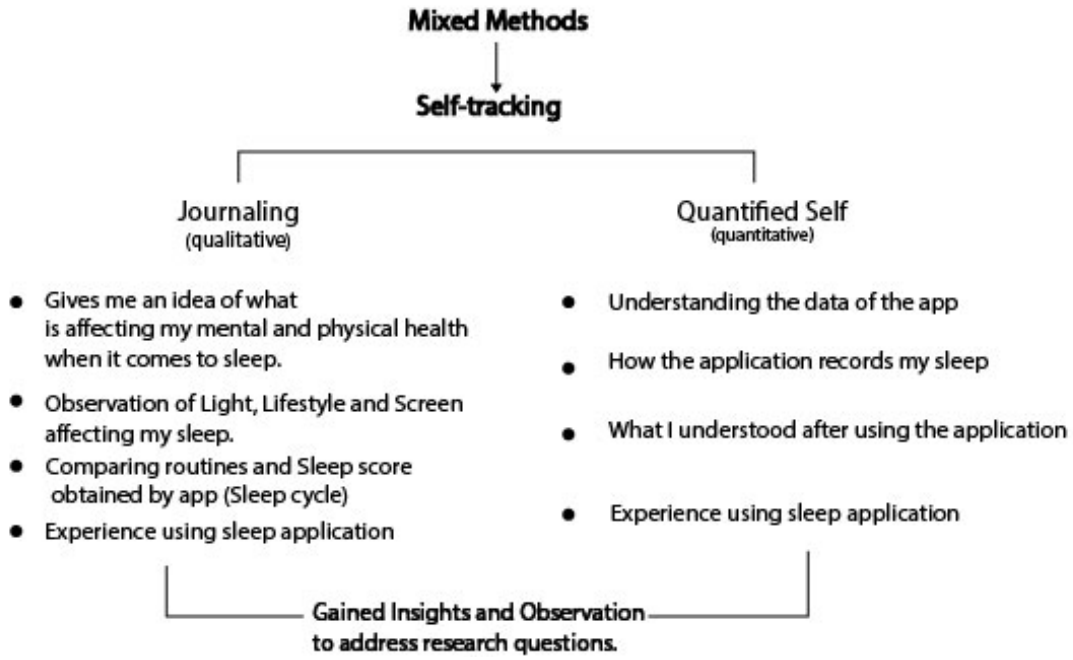


Figure 3: Mixed Methods Diagram of Journaling and Quantified Self-Observation and Insights (Author's Image)

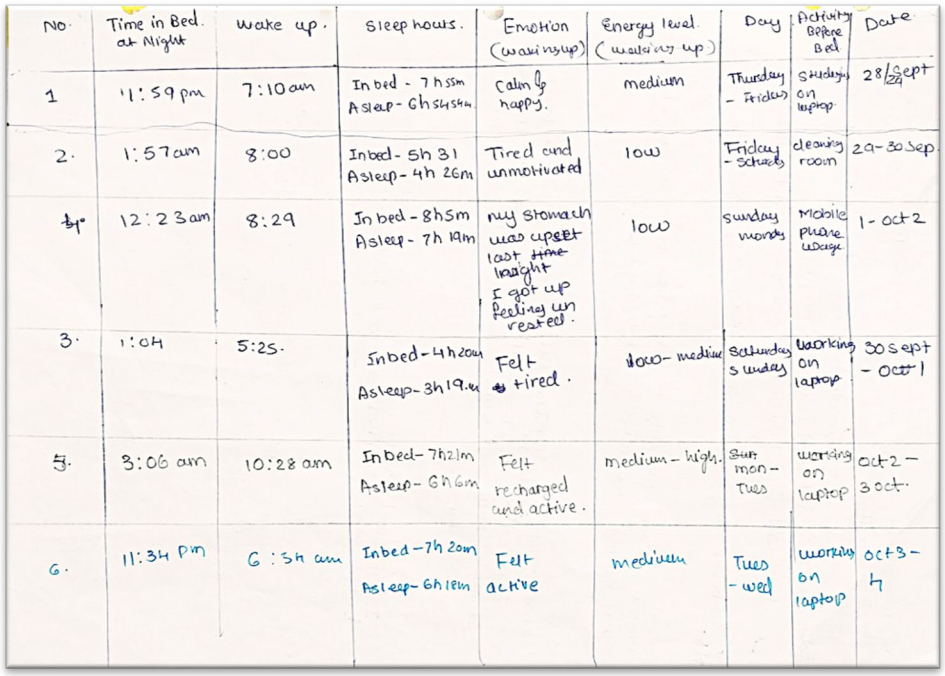
3.2 Methods

In this research, I employed four methods. Using a mixed-method approach, I combine two methods - Journaling and Quantified Self, adding depth to my knowledge and understanding of sleep. The third method I utilized is Critical Making, which allows critical thinking and provides a hands-on approach to encourage learning by doing. The final method I have employed from critical making is iterative prototyping.

3.2.1 Journaling

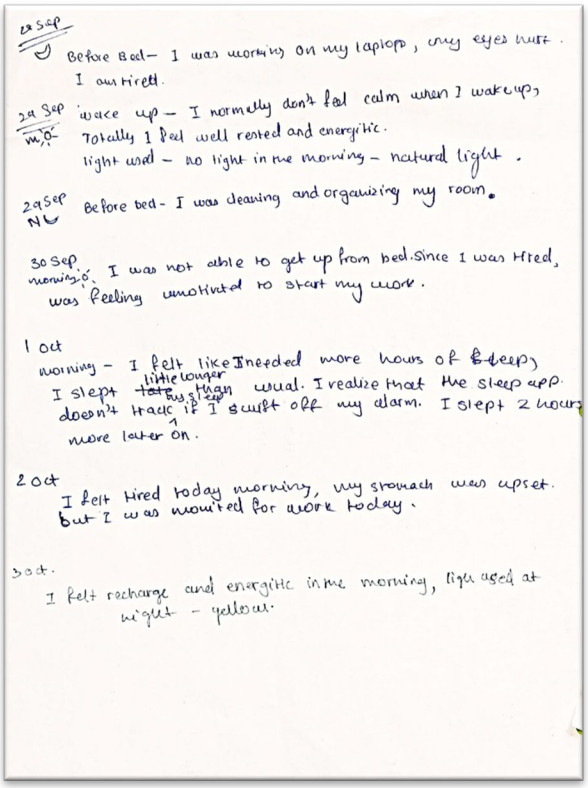
Recognizing journaling as a source of qualitative data, I utilized its subjective nature to articulate personal experiences, thoughts, and reflections on sleep, the sleep environment, and sleep tracking. This process, initiated on September 28, 2023, involves a meticulous examination of my bedroom environment, overall lifestyle, and mood (Fig. 4). In comparison to self-tracking apps, traditional journaling methods offer unique advantages, particularly within the realms of qualitative and self-reflective research.

As I transitioned to the tactile experience of pen and paper, the act of documenting the events of the day opened a space for a more profound connection with myself. This analog approach not only captured the quantitative aspects of sleep, such as duration and patterns, but, more importantly, delved into the qualitative realm — emotions, environmental influences, mood, and other subtle nuances (Fig. 4 and Fig. 5). As I compared self-tracking with quantified self-tracking, journaling emerged as a valuable tool, offering a perspective to understand the intricate connection between sleep and the body in a more enriched way.



No.	Time in Bed at Night	Wake up.	Sleep hours.	Emotion (waking up)	Energy level (waking up)	Day	Activity Before Bed	Date
1	11:59 pm	7:10 am	In bed - 7h 55m Asleep - 6h 54m	Calm & happy.	medium	Thursday - Friday	studying on laptop	28/29 Sept
2.	1:57 am	8:00	In bed - 5h 31 Asleep - 4h 26m	Tired and unmotivated	low	Friday - Saturday	cleaning room	29-30 Sep.
3.	12:23 am	8:29	In bed - 8h 5m Asleep - 7h 19m	my stomach was upset last ~~time~~ night I got up feeling un rested.	low	sunday monday	Mobile phone usage	1 - oct 2
4.	1:04	5:25.	In bed - 4h 20m Asleep - 3h 19m	Felt ~~as~~ tired.	low - medium	Saturday sunday	working on laptop	30 sept - oct 1
5.	3:06 am	10:28 am	In bed - 7h 21m Asleep - 6h 6m	Felt recharged and active.	medium - high.	Sun mon - Tues	working on laptop	oct 2 - 3 oct.
6.	11:34 pm	6:54 am	In bed - 7h 20m Asleep - 6h 18m	Felt active	medium	Tues - wed	working on laptop	oct 3 - 4

Figure 4: Journaling record of my data (Time, Emotions, Energy Level, Activity Before Bed) (Author's Image)



28 Sep
Before Bed- I was working on my laptop, my eyes hurt. I am tired.

29 Sep
Wake up - I normally don't feel calm when I wake up, Totally I feel well rested and energitic.
light used - no light in the morning - natural light.

29 Sep
Before bed - I was cleaning and organising my room.

30 Sep
morning - I was not able to get up from bed. Since I was tired, was feeling unmotivated to start my work.

1 Oct
morning - I felt like I needed more hours of ~~sleep~~ sleep, I slept ~~late~~ little longer than usual. I realize that the sleep app doesn't track if I snuff off my alarm. I slept 2 hours more later on.

2 Oct
I felt tired today morning, my stomach was upset. but I was monited for work today.

3 Oct.
I felt recharge and energitic in the morning, light used at night - yellow.

Figure 5: Writings about my daily routines, activities, and moods (Author's Image)

While self-tracking apps are constrained by predefined metrics, journaling provides the flexibility to explore diverse aspects of sleep. It helps uncover the "why" behind certain sleep patterns, offering a deeper layer of understanding as discussed further in section 4.2.1.

3.2.2 Quantified Self

As discussed in section 2.2, the term "Quantified Self" involves utilizing technology to systematically collect numerical data for the analysis of patterns and trends. In my research, I employ the Quantified Self method through the use of the Sleep Cycle application[2]. This app tracks various parameters, including my movement, wake-up time, sleep duration, and recorded sounds, such as snoring, coughing, and talking. The application provides comprehensive insights into my sleep patterns, presenting data on total nights, total time in bed, average time in bed, and regularity as you can see in (Fig. 6). Additionally, it calculates an average based on the quality of sleep, considering factors like heart rate, time spent awake or restless, and sleep stages, ultimately assigning a sleep score ranging from 0 to 100. Contrary to journaling, which involves subjective descriptions, listening to my sleep sounds and examining the statistical sleep-tracked data offers an objective and measurable means to assess the quality of sleep.

As both methods provide a more comprehensive and nuanced approach to understanding sleep, I aim to use-them to observe and gain insight about my sleep.

[2] Sleep Cycle AB (publ), Sleep-tracking application. https://www.sleepcycle.com/

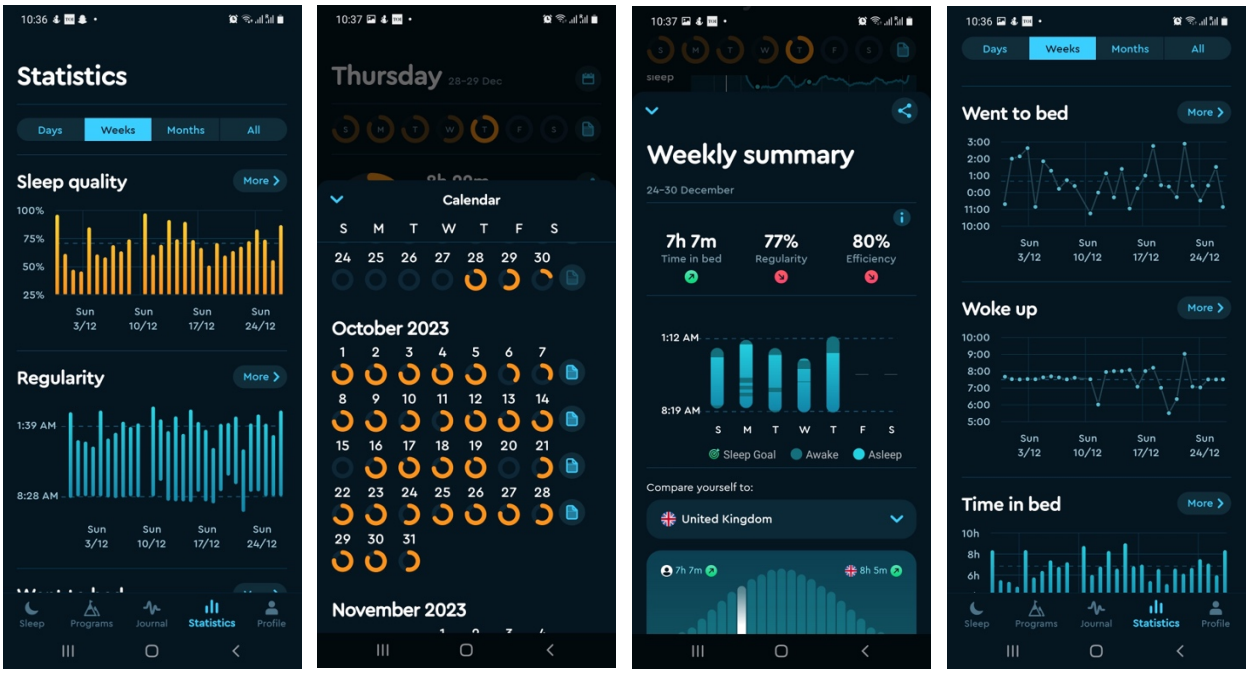


Figure 6: Sleep summary from my sleep cycle application Sleep Cycle AB (publ). Statistics of weekly sleep quality and regularity (Left Image) (Author's Image). September 28-October 31 sleep score (Middle Left Image). Weekly summary of 24-30 December sleep data (Middle Right) (Author's Image). Statistics of regular bedtime and wake up timings (Right Image) (Author's Image).

3.2.3 Critical Making

Given that my thesis involves hands-on experimentation with physical prototypes, critical thinking, and the use of materials and technology to enhance the design of existing sleep-tracking devices and applications, the critical-making method fits perfectly with my research approach. By using this method, I aim to unite critical making and hands on experiments to encourage learning by doing.

Shannon Butts (2019) explains critical making represents a dynamic fusion of abstract thinking and tangible creation, bridging the realms of critical analysis and material production. Traditionally, critical thinking involves abstract, linguistic analysis, while making entails tangible, goal-driven creation. However, critical making recognizes the symbiotic relationship between these seemingly disparate processes. Designers, while creating physical prototypes, engage critically with ideas, and thinkers, through material experimentation, to explore and

refine concepts. This approach acknowledges an intertwined process where object-making is interconnected with academic scholarship and theory-driven practices. Originally rooted in pedagogy, critical making has evolved into a robust research program and method, influencing and shaping emerging research practices (Butts, 2019).

This relates to my research practice as I examine the theories around sleep and collected my personal data to foster empathy, engagement, and meaning.

3.2.3.1 Iterative Prototyping in Critical Making

I choose to use this final method to address my research question as whole. This method facilitates experimentation with different materials and technologies to visualize and embody aspects of sleep tracking. Through successive iterations, the prototypes evolve, contributing not only to the development of tangible outputs but also deepening the theoretical understanding of the relationships between self-tracking data, materiality, and human experiences.

In this thesis, I first investigated light visualization to understand its impact on sleep. Through this exploration, I gained insights that led me to start iterating with tangible representations. I have created the first version of a tangible prototype that can undergo numerous further cycles of development until it reaches its full potential in future. This iterative approach has been crucial in my learning process, allowing me to build upon insights from previous prototypes. It has also been beneficial for refining my design decisions, design thinking, and making process, as further explored in section 4.3.

CHAPTER FOUR: Project Development and Prototyping

I commenced this research journey by immersing myself in various resources related to my lifestyle. The screenshot (Fig. 7) from my Miro board (online visual workspace) encapsulates the visual representation of these connections, fostering an understanding of the problem space. This mapping exercise was crucial to gain knowledge about my sleep and lifestyle before proceeding further. As I began researching, I understood that light plays a crucial role in sleep and signals our body clock when to be alert and when to rest, as discussed in the literature review section 2.1.2. Different lights have different impacts on us (Romocean, 2017). With this concept, I was eager to explore light in my initial prototype.

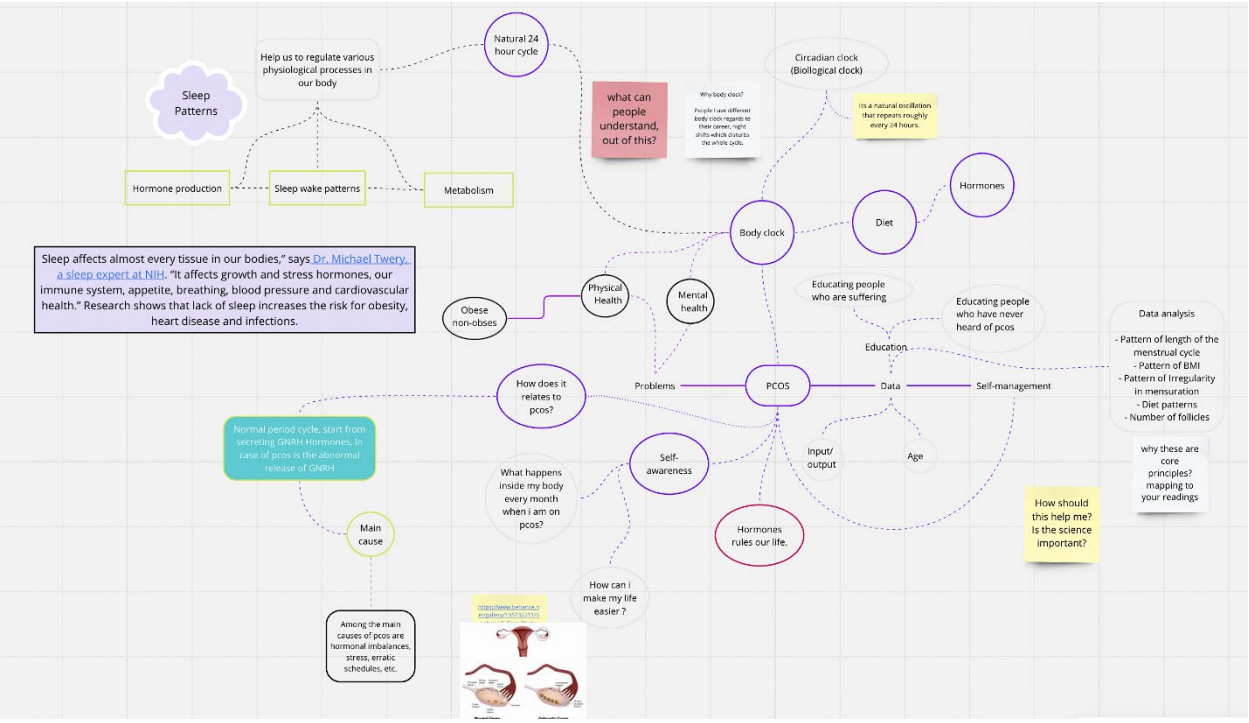


Figure 7: Mind mapping of the problem space (screenshot of my Miro board) (Author's Image)

4.1 Light Research Prototype

Having gathered knowledge from the Romocean (2017) article, I understood that white light can enhance productivity and alertness, while yellow light aids in better sleep by promoting

the release of melatonin. I became acutely aware of my own light usage habits, in my new apartment, equipped with only an Ikea lamp offering three color options — allowing a shift from white to yellow temperatures — I embarked on a personal experiment. Without formal tracking, I observed the effects of each light setting. Yellow light induced a sense of calmness and alertness without causing undue stress to my body. On the other hand, white light heightened alertness and productivity and posed challenges in falling asleep quickly. These revelations prompted me to delve deeper into the interplay between light, mood, and emotion during a course, "Thinking Through Making," where I seized the opportunity to explore the question: How does light affect our mood and emotion?

Figure 8: Thinking Through Making assignment, depicting three lighting scenarios. Daylight white (Left), Sunset yellow (Middle), Blue light (Right) (Author's Image)

The space served as a communicative platform for participants to engage in discussions about their bedroom lighting choices. It functioned as an experiment where participants immersed themselves in various lighting scenarios, each simulating specific natural conditions (e.g., Daylight, Sunset, Blue Light) using Ikea lights (Fig. 8). Through this experience, participants shared feedback on how each lighting condition influenced their feelings of alertness, relaxation, and overall mood. With 10 persons' feedback, I received unambiguous response and understood that light preferences vary from person to person (No REB permission was taken).

In the initial phases of planning, I envisioned using light as a medium to visualize data. To kickstart this exploration, I turned to publicly available sleep data recorded over a year by an

individual (Riinu Anslan)[3], which was uploaded on Kaggle (Fig. 9). Opting to begin with a month's worth of data, I faced the challenge of deciphering the data set (Fig. 10) given my lack of experience with tracking devices. However, as I grasped the nuances of sleep scores—comprising individual scores for sleep duration, quality, and restoration, with a total score up to 100—I tailored my visualizations accordingly.

A	B	C	D	E	F	G	H	I
APRIL	DATE	SLEEP SCORI	HOURS OF SI	REM SLEEP	DEEP SLEEP	HEART RATE I	SLEEP TIME	
Friday	04/01/2022	90	7:22:00	18.00%	21.00%	98.00%	9:49pm - 6:01am	
Saturday	04/02/2022	89	8:40:00	21.00%	21.00%	73.00%	9:50pm - 7:26am	
Sunday	04/03/2022	81	8:52:00	21.00%	17.00%	26.00%	11:29pm - 9:54am	
Monday	04/04/2022	83	6:50:00	17.00%	19.00%	99.00%	10:12pm - 5:49am	
Tuesday	04/05/2022	84	6:57:00	18.00%	21.00%	97.00%	9:45pm - 5:43am	
Wednesday	04/06/2022	83	7:27:00	17.00%	19.00%	77.00%	9:22pm - 6:14am	
Thursday	04/07/2022	87	7:57:00	22.00%	14.00%	68.00%	10:05pm - 6:55am	
Friday	04/08/2022	83	7:27:00	19.00%	18.00%	71.00%	9:42pm - 6:36am	
Saturday	04/09/2022	87	8:12:00	19.00%	15.00%	71.00%	11:27pm - 8:36am	
Sunday	04/10/2022	83	6:57:00	15.00%	18.00%	96.00%	12:53am - 8:39am	
Monday	04/11/2022	88	7:39:00	17.00%	19.00%	98.00%	9:35pm - 6:02am	
Tuesday	04/12/2022	86	8:00:00	20.00%	19.00%	73.00%	9:52pm - 7:10am	
Wednesday	04/13/2022	82	7:48:00	11.00%	13.00%	73.00%	10:51pm - 8:02am	
Thursday	04/14/2022	83	7:19:00	19.00%	23.00%	77.00%	9:35pm - 5:58am	
Friday	04/15/2022	82	8:04:00	17.00%	19.00%	57.00%	11:37pm - 8:52am	
Saturday	04/16/2022	90	9:39:00	21.00%	17.00%	96.00%	9:43pm - 8:35am	
Sunday	04/17/2022	91	7:32:00	24.00%	14.00%	99.00%	10:50pm - 7:21am	
Monday	04/18/2022	89	7:59:00	17.00%	18.00%	95.00%	10:14pm - 7:04am	
Tuesday	04/19/2022	82	7:59:00	15.00%	17.00%	45.00%	10:04pm - 7:08am	
Wednesday	04/20/2022	75	6:54:00	20.00%	15.00%	9.00%	12:37am - 8:42am	
Thursday	04/21/2022	93	7:59:00	22.00%	24.00%	99.00%	10:36pm - 7:37am	
Friday	04/22/2022	87	7:44:00	19.00%	8.00%	88.00%	9:00pm - 5:54am	
Saturday	04/23/2022	79	7:55:00	8.00%	12.00%	57.00%	10:10pm - 7:22am	
Sunday	04/24/2022	81	8:17:00	13.00%	15.00%	64.00%	12:10am - 9:46am	
Monday	04/25/2022	84	7:39:00	16.00%	20.00%	70.00%	9:52pm - 6:55am	
Tuesday	04/26/2022	85	7:18:00	22.00%	14.00%	100.00%	9:32pm - 6:00am	
Wednesday	04/27/2022	90	7:34:00	24.00%	19.00%	98.00%	9:19pm - 5:49am	
Thursday	04/28/2022	87	6:54:00	21.00%	22.00%	90.00%	10:02pm - 5:46am	
Friday	04/29/2022	86	7:45:00	19.00%	17.00%	95.00%	10:15pm - 7:24am	
Saturday	04/30/2022	89	7:11:00	22.00%	18.00%	75.00%	11:08pm - 7:04am	

Figure 9: Public data set of Riinu Anslan uploaded on Kaggle (2022, April). April sleep data - Sheet1.csv, version 1. Accessed May 2023

To initiate the visualization process, I crafted a mood board with a focus on fostering a serene ambiance in the sleep environment, I translated these inspirations into sketches in my notebook. During this phase, the data was approached subjectively as I aimed to experiment with the potential impact of this visualization within our bedrooms. This led me to delve into Touch Designer[4], where I engaged with noise elements that influenced the visual representation. In (Fig. 10), the colors undergo a morphing transformation, where the pink hue signifies the range between 85-90% of the sleep score, green corresponds to 80-85%, and 75-80% is represented by

[3] https://www.kaggle.com/datasets/riinuanslan/sleep-data-from-fitbit-tracker

[4] https://derivative.ca/ Touch Designer is a node-based visual programming language for real-time interactive multimedia content, developed by the Toronto-based company Derivative.

warmer red. The degrees were not precisely defined; rather, the primary objective was to comprehend the influence of these aesthetics in a given space.

Figure 10: Experimented visuals using noise node in Touch designer (Derivative Inc), (Left, Middle, Right) (Author's Image).

Subsequently, I used a projector in my bedroom to gauge the scale and impact of the visualization while preparing for sleep. My observations yielded specific feedback:

1. The vibe of the aesthetics was calming and soothing but the impact of light on my eyes were stressful.
2. While experimenting with various colors in my sleep environment, I observed that vivid colors, when used individually, had a soothing effect on my eyes. However, I also noticed that the impact of each color differed, leading me to the conclusion that using multiple colors in a bedroom setting might not be universally suitable. Based on the insights from Thinking through Making prototype I understood that it is important to note that individual responses to colors vary, and what works for one person may not work for another. My decision to move away from multiple colors in my exploration was based on my personal experience and insight gained from my initial installation. There is a need for a sleep environment that promotes relaxation and comfort to achieve a good sleep.
3. Although there was potential to explore with table lamps or any small visualization, the decision to shift away from light-based exploration in bedroom spaces was grounded in the profound impact of light on sleep as discussed in section 2.1.2. It disrupts the natural transitions between sleep cycles, leading to a reduction in the overall quality of sleep. Excessive light has been linked to repeated awakenings, interrupting the sleep cycle and

diminishing the duration spent in deeper, more rejuvenating sleep stages. Recognizing the significance of a screen-free sleep environment, I chose to explore alternative avenues that would contribute to maintaining healthier sleep patterns and a more conducive sleep environment.

In conclusion, while my exploration of light visualization initially aimed to enhance our understanding of sleep patterns, I understood the impact of artificial light on sleep, based on my exploration and literature review. Hues, saturation, and brightness of artificial color might impact our emotions and moods and have other effects on the body (Romocean, 2017). When it comes to sleep, having a darker environment with no light and screens helps our body fall asleep quickly as discussed in section 2.1.2. Recognizing the superiority of natural lighting over artificial light, these observations prompt a shift in my exploration towards less stressful alternatives that promote healthier sleep patterns and embrace a screen-free environment, acknowledging the diverse responses individuals may have to light interventions in the bedroom.

4.2 Collecting and Visualizing my Sleep Data

4.2.1 Data Collection

4.2.1.1 Journaling

Maintaining daily records of my habits proved incredibly beneficial. This practice enabled me to articulate my thoughts and feelings, fostering a clearer understanding of my daily experiences. It allowed me to discern which habits left me feeling fatigued and which ones contributed to my well-being.

I categorized my day into various aspects, including time spent in bed, waking up routine, sleep hours, morning emotions, energy levels, activities before bedtime, and weekdays. Additionally, I delved into detailed descriptions of my mornings and daily emotions, capturing a nuanced understanding of my well-being. These categories provided insights distinct from those obtained through app-based self-tracking.

To document my dietary habits, I introduced separate categories such as caffeine consumption, alcohol intake, and dinner quantity before bedtime. For tracking screen usage,

activities before bedtime and daytime napping, I created a separate column to assess their impact on my sleep. Based on this, I observed patterns after one month of tracking data, particularly on these certain days, which are relevant to the data collection period from September 28, 2023, to November 30, 2023.

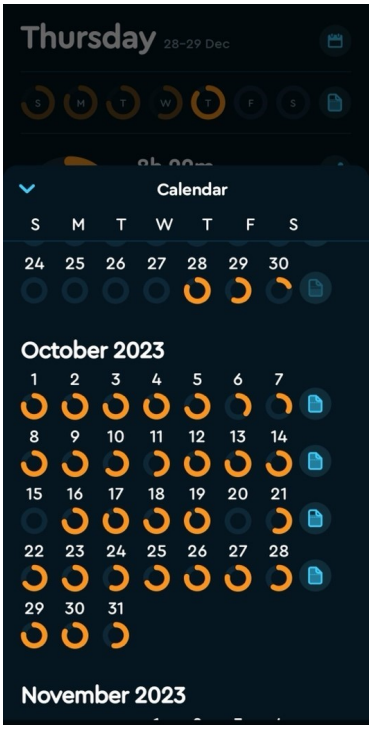
General observation taken from journal:

Date	Observation
21-10-2023	Despite sleeping fewer hours, I felt active because in the preceding days, I had well-rested nights of 7-8 hours. On this day, my sleep duration was 5 hours, during which I consumed coffee, had healthy food, avoided screen time, and minimized other negative factors influencing my sleep.
25-10-2023	I realized that oversleeping has its own effects, akin to insufficient sleep. Days of oversleeping were not flagged by the application, and I experienced mood swings and low energy levels, leading to lethargy.
7-11-2023	I observed that daytime sleeping can cause tiredness. Sleeping during the day, both on the day before and the observed day, resulted in less productivity.
15-11-2023	After installing a white light bulb in my room for 8 days, I noticed that its brightness kept my brain alert, making it unsuitable for nighttime. I experienced a delay of about 2 hours in falling asleep.
16-11-2023	Taking a bath before bedtime and achieving a good 8-hour-sleep made me calmer and more energetic the next day.

4.2.1.2 Sleep Cycle (Mobile Application)

The Sleep Cycle[5] is a sleep tracking application that has been instrumental in monitoring both the quality and duration of sleep. Beyond simple data collection, the app employs a range of techniques to provide a comprehensive analysis of sleep patterns affecting my sleep quality. The data used from the application are as follows: date, time, hours, and days, The data collected includes detailed information about each sleep session, including the date, time of sleep onset, duration of sleep, and the specific day of the week.

Sleep score[6] - The application generated a sleep score for each night, offering an overview of my sleep quality based on factors like duration and restfulness. This data provided me an idea of the duration and the sleep score provided an average of my overall quality of sleep. However, the numbers in the sleep score were confusing, and it was difficult to interpret what each percentage stands for.



[5] Sleep Cycle AB (publ), Sleep-tracking application. https://www.sleepcycle.com/

[6] Sleep Cycle assesses sleep quality based on the total time spent in bed, time spent in deep sleep, frequency and intensity of movement, and the number of times you are fully awake during sleep. The combination of these factors produces personal sleep quality score.

Figure 11: Sleep summary from my sleep cycle application Sleep Cycle AB (publ). Sleep data of 28-29 December 2023, which gives insights into sleep quality of that particular night (Left Image), September 28-31 October sleep score (Right Image) (Author's Image)

Another challenge I encountered was the difficulty in interpreting the displayed information. In (Fig. 11) above, the sleep quality is indicated as 88%. However, without prior knowledge of sleep stages, it was challenging to ascertain whether 88% was indicative of good or poor sleep. As discussed in section 2.2.1.3, there is a need to interpret data easily and make it more engaging and meaningful for users to comprehend and derive a clear message.

In addition, I observed a behavioral pattern related to my phone usage. While configuring my alarm for the sleep app, I consistently engaged with my phone. On certain days, I would set the alarm an hour before bedtime. However, in busier moments or unconsciously, notifications on my phone became distractions, leading to instances where I forgot to initiate the sleep tracker application. This underscores how external factors can impact the consistency of self-tracking practices. Despite the clear delineation of different sleep stages in the line graph, it felt akin to an electrocardiogram (ECG) recording my sleep. The importance of these stages eluded me until I sought information online. On days when motivation waned, I found myself easily distracted by various activities on my mobile phone. This suggests a potential link between motivation levels and engagement with self-tracking tools.

Building upon the data collected from both mediums and the challenges encountered during this phase, I would like to establish a clear definition before proceeding to the next prototype. Drawing from my personal experiences, initial light prototyping, data reflection, and critical insights, I aim to define the requirements for an improved presentation of the collected data:

1. Need for no screen environment
2. Making the data more humane to help people interpret information easily
3. Considering engagement and tangibility to boost motivation in learning

4.2.2 Visualization of my Sleep Data

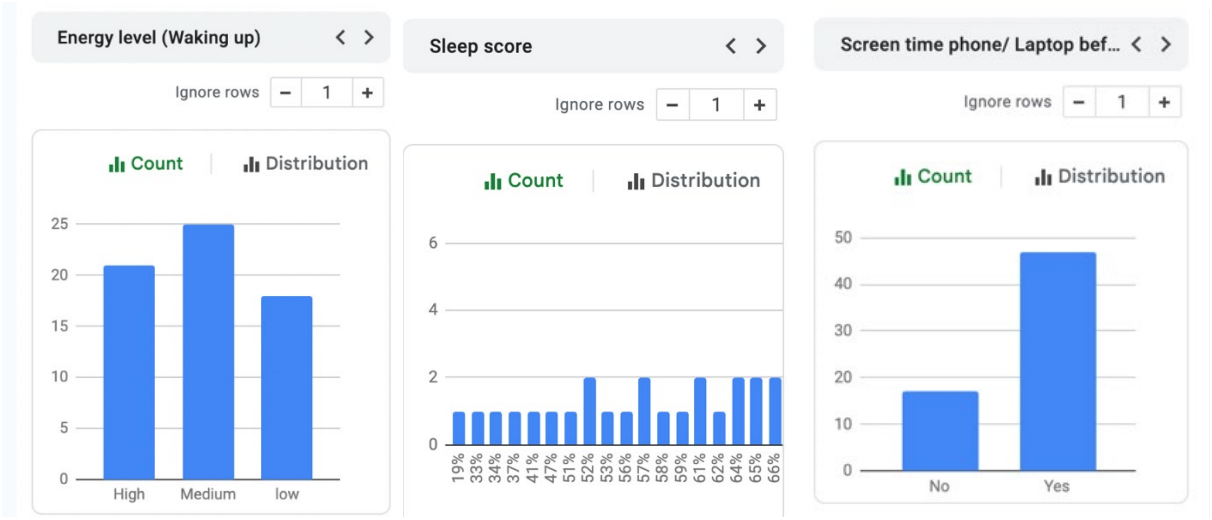


Figure 12: Screenshot from Microsoft excel sheet depicting graphs of my energy levels (Left Image), sleep score (Middle Image), screen time (Right Image) of 28 September-31 November, 2023 (Author's Image)

After data collection, I prepared the data in the spreadsheet and used excel to review all the trends and patterns within the collected data. Post combining both data from journaling and sleep cycle application, I converted it to the excel sheet to visualize it using graphs. This was helpful to understand the interconnections of sleep, lifestyle, environment (light), and screen, which I compared to my sleep score see (Fig. 12). To understand the visualization better, I opted to visualize the information to discern trends and patterns before delving into the exploration of tangible representations. The visualization (Fig. 14) captures the data spanning from September 28, 2023, to October 31, 2023. The inspiration behind this visualization was drawn from transplant Hydrangeas, which is a type of flower commonly seen during the Fall season. With this inspiration in (Fig. 13), I sketched out and planned for the visualization, which can capture the emotional atmosphere of each day, categorizing emotions into high, medium, and low degrees.

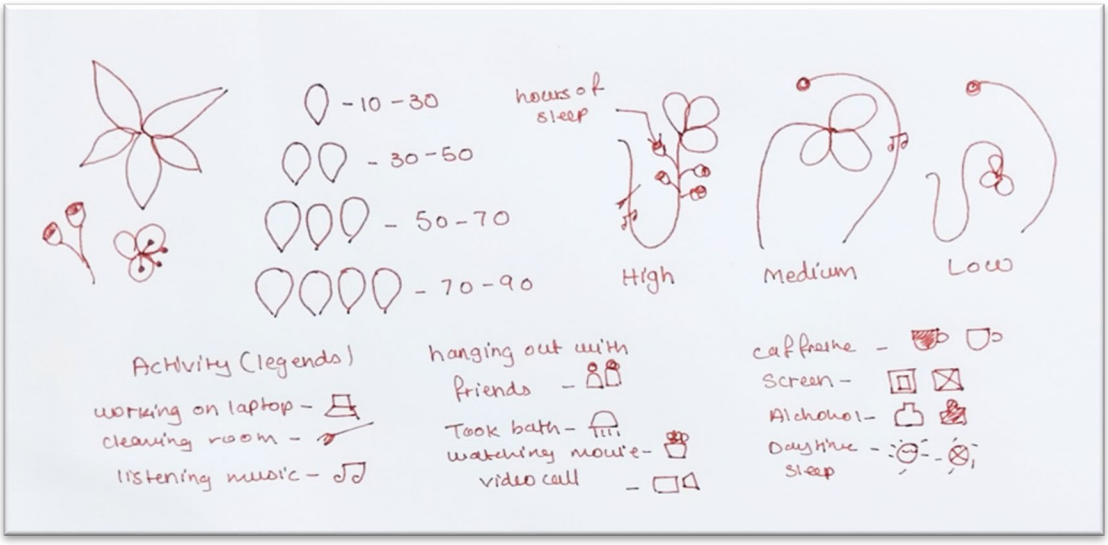


Figure 13: Data sketch exploration for visualizing my sleep data (Author's Image)

The visualization encapsulates details for each day, including energy levels, sleep score, emotions, food, and activities before bed. In summary, this visualization helped me understand how I felt each day, the activities I performed, and how it affected my sleep score.

While two-dimensional visualizations provide valuable information, I recognize the potential to convey my emotions and sleep score in physical forms to promote empathy, engagement, and meaning. As discussed in section 2.5, I learned that physical representations of data, especially in three dimensions, offer a more intuitive understanding than flat visuals. This understanding suggests that integrating tangible representations could improve comprehension and user-engagement with the data. Building on this insight, I will further explore tangible representations in upcoming prototypes.

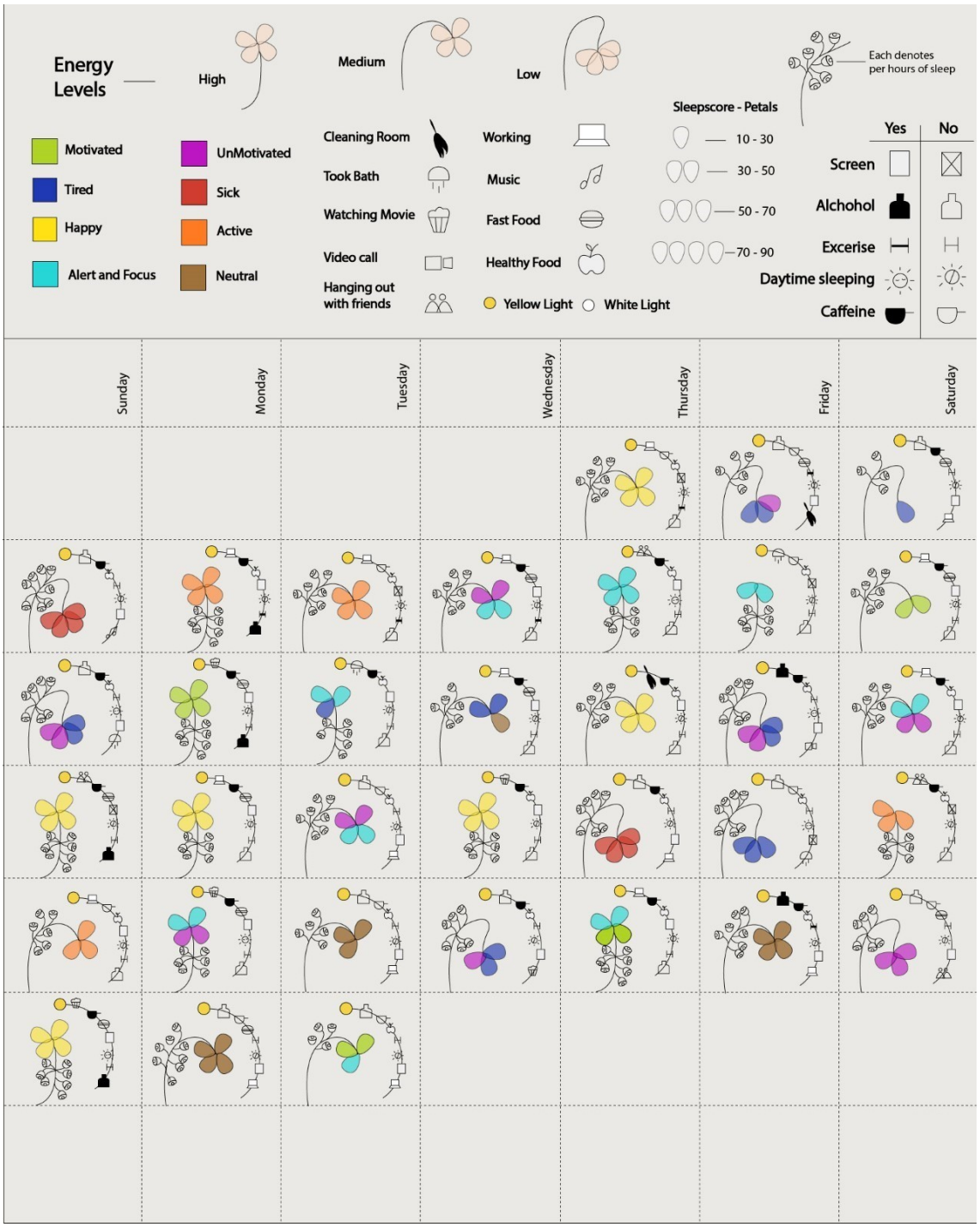


Figure 14: Data visualization of my sleep data both (journaling and sleep tracking application) from 28 September 2023 to 31 October 2023 (Author's Image)

4.3 Exploration of Tangibility

The motivation driving this prototype lies in understanding and empathizing with ourselves. As we explore its main objectives, the goal is to understand the connection between our body and data.

4.3.1 Motivation - Our Body and Data

Understanding and nurturing our bodies necessitates a compassionate and attentive perspective. Our bodies, akin to natural visual storytellers, communicate potential concerns through a diverse language of colors, textures, touch, and feelings. For instance, unusual discolorations may signify internal issues like bleeding. Changes in skin texture serve as vital indicators, offering a tangible glimpse into our well-being. The sense of touch becomes a medium of communication, whether detecting bumps during pregnancy or discerning irregularities, it conveys essential information. Emotions, expressed through sensations, further enrich this dialogue, allowing us to gauge the intensity of various bodily experiences. Embracing and comprehending these innate signals is foundational for fostering self-awareness, enabling us to respond appropriately to our body's intricate messages.

In essence, our bodies embody a nuanced visual language that informs us about the state of our internal health. This natural feedback system, entailing colors, textures, touch, and feelings, serves as a guidebook to our well-being. Recognizing the significance of each element in this bodily communication allows us to build a profound connection with ourselves and respond empathetically to the needs and signals our bodies convey. I aim to mimic the natural feedback system of our bodies to develop a more empathetic and user-friendly experience with data, enhancing engagement and meaning.

In the winter of 2023, I enrolled in a course called Data to Perception. One of the assignments focused on incidental visualization, prompting me to delve into a variety of environmental visualizations. The exploration encompassed observing patterns of dust on a window to discern the subtle traces on an old building. This exploration expanded my perspective, leading me to contemplate the scars on our bodies as a rich source of data. Delving into the realms of empathy, meaning, and engagement. It became evident that the act of touching

and feeling something alive imparts a profound emotional depth and connection, resonating with the very essence of being alive.

4.3.2 Prototype 1

In section 2.5, I learned that when designing tangible objects, it is important to ensure they function in ways that people are familiar with, making them easier to understand and use. Accordingly, I mimicked the body's natural feedback system by using the analogy of "bumps" to represent sleep scores, thus providing a concrete representation of the abstract concept of sleep quality.

Figure 15: Exploration of first tangible prototypes. The first circular object gives sleep score of 43% (Left), the second circular object depicts sleep score of 80% (Middle), the third circular object shows the emotion of tiredness where T-shaped stick component was attached inside with the servo handle (Right) (Author's Image)

Using these bumps as a visual indicator for sleep score can enhance understanding of personal data to foster empathy, engagement, and meaning.

For this prototype, I explored three circular objects (Fig. 15). The first two objects represent sleep scores of 43% and 80%, indicating bad and good sleep, respectively. The motivation behind exploring the difference between good and bad sleep stemmed from the lack of clarity in the sleep app I used, as identified in the observation stage (Section 4.2.1.2). The app's distinction between good and bad sleep was unclear. In response, my prototype explores a tactile representation—a scale of bumps—to convey this information in a meaningful way.

Figure 16: Legends of tangible visualization depicting different ranges of sleep scores in the form of bumps (Author's Image)

Legends:

1. Scores ranging from 20% to 40% manifest as higher bumps, indicating poor sleep score
2. Between 40% and 60%, the bumps are less pronounced, denoting average sleep score
3. A range of 60% to 80% corresponds to raised areas representing a good sleep score
4. While scores from 80% to 100% result in lower raised areas symbolizing excellent sleep score

Mechanism: Servo motors, an Arduino microcontroller, and a breadboard were employed to facilitate the object's movement. The primary motivation for integrating these electronics was to imbue the object with a sense of being alive. By animating the object in this way, the goal was to evoke a feeling of connection and empathy when users engaged with the surface of tangible objects. Furthermore, for the first two circular objects in Fig. (15), the servo speed was set to medium. As the servo moved, the bumps rose on the surface area, indicating the respective legends.

The third circular object (the smaller circle) in (Fig.15) symbolizes the feeling of tiredness. I wanted to explore how this emotion could be understood through touch, fostering empathy and meaning. By using servo motors at a low speed, the object gives a sense of slowing down when touched, capturing the feeling of tiredness. Inside the circle, I attached a T-shaped stick to the

servo handle. Since this was one of my initial explorations, I used tape and cardboard to support the movement.

I tested this prototype with two of my classmates during my meeting with thesis instructors. When they encountered the prototype on the table, their initial reaction was curiosity about what it was. One of them found the sensation peculiar, likening it to the feeling of tracing the palm during a flirtatious handshake gesture. Another classmate described feeling a sense of tiredness, noting that as the servo moved, it caused slight vibrations, and the slow movement evoked a feeling of fatigue. There were no question asked for this prototype as I wanted to understand their reaction rather than interrogate them.

Similarly, I developed another prototype to explore the sensation of tiredness. This prototype consisted of two sticks and two pearl balls attached to the servo handles, as shown in (Fig. 17) below. As the servos moved in slow motion, the tactile experience conveyed a sense of fatigue through the deliberate movement. While this may not be apparent in the picture, the focus is on the experiential aspect of touch and feel.

Figure 17: Second exploration of tiredness emotion (this prototype consists of two sticks and two pearl balls attached to the servo handles) (Left, Right) (Author's Image)

While comparing both explorations in (Fig. 15) and (Fig. 17), I found the T-shaped stick component and slow speed of the servo in (Fig. 17) reflecting more towards feeling tired. I

understood that the shape, texture, and size of the component inside the physical objects matters the most when it comes to tangible experience. This tangible approach helps visualize my personal data, transforming it into something one can touch and understand better. It provides users with a tangible way to engage with and comprehend the information.

4.3.3 Prototype 2

In this prototype, I explored the fabrication process to achieve firmness for these moving objects. I utilized a laser cutting machine to precisely cut two circles, and a fabric was stitched in between them to prevent excessive movement and enable stretching when the servo motors go up.

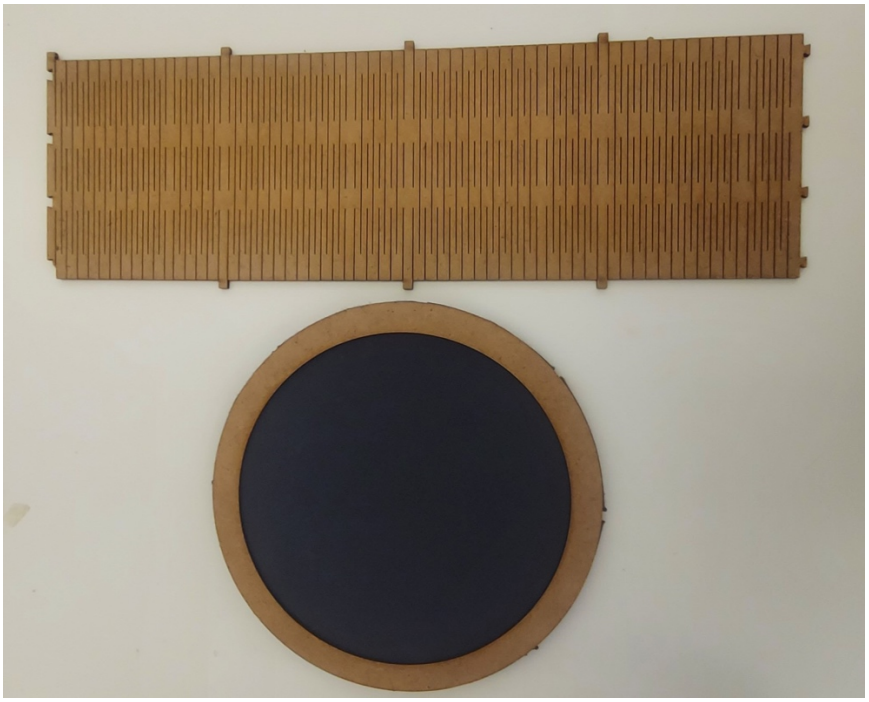


Figure 18: Fabrication exploration of Prototype 2 (Author's Image)

To provide flexibility for wrapping around the circle, I laser-cut the side panel, designed for interlocking with the remaining pieces. While the side panel offered flexibility, it lacked reliability in terms of firmness, with interlocked pieces occasionally separating when a servo moved upwards. Despite this, the fabrication process achieved a cleaner look, as depicted in (Fig. 18 and Fig. 19)

Figure 19: Left Image shows the attached side panels and whole circular object. Right Image shows the early exploration of linear servo actuators (Author's Image)

In Prototype 1, I used simple thin wooden sticks taped around the servo fan to enable the ball's upward movement. To replicate this structure, I 3D-printed some linear servo motor actuators and secured them with M3 machine screws. While this approach was smoother and provided insights into the mechanism's behavior, it required bottom support to handle the servo weight and its movement. This highlights the importance of precise measurements and structural integrity for ensuring the functionality of this prototype.

In summary, I learned several things from both prototypes 1 and 2, which I would like to explore in the final prototype.

1. When interacting with the palm, the size of the object's surface, or lid, is crucial. Making it smaller can improve its effectiveness.
2. These prototyping needs stability, support, and base, which allows the servo motors to move.
3. Instead of two panels to attach the servo, one strong whole object is needed.
4. Based on the reactions of two classmates and thesis instructors, I wanted to explore the final prototype based on feelings of curiosity and reactions of people.

4.4 Final Prototype and Discussion

My research foundation relies on the literature review, where I explore science and theories around sleep to gain knowledge. This research involves a critical understanding of my lifestyle, activities, routines, and their connections to sleep. By exploring these theories, they serve as a backbone, emphasizing the importance of tangibility. Through exploration, trial, failure, and learning, I gained insights into what worked and what did not, understanding the importance of physical objects. Given the complex nature of sleep, exploring different domains enriched my learning and allowed me to recognize patterns through personal experience.

4.4.1 Final Installation

In this section, I will discuss the final thesis installation. After learning from Section 4.3, my goal is to create a two-week data visualization from September 28, 2023, to October 11, 2023, using tangible objects. I chose to focus on sleep score as it provides a number based on overall sleep quality, allowing for targeted visualization rather than presenting all the data at once. I decided to visualize a two-week period after understanding that 5-10 nights were required for monthly estimates (TeYang Lau et al., 2022). This allows for a calendar-like comparison between weeks. To achieve this, I utilized 14 servo motors, 14 linear actuators, 14 thermcol balls, 1 PCA9685, and 1 Arduino Uno for the movement of the bumps inside the tangible objects.

Fabrication was a crucial aspect of the final prototype, as it is needed to provide stability and support to maintain the movement of the servos, as discussed in Section 4.3. This installation represents one of the explorations of translating visual data into tangible form.

4.4.1.1 Fabrication

As I understood in the prototype 2, precise measurement is needed for prototype functionality. Based on this observation, I have created the fabrication for linear servo actuators, the main body of the cylindrical object, and constructed a whole box for the final installation.

1. *Linear servo actuators*: After realizing that the previous linear servo actuator needed support and stability to bear the weight of the servo motor and its movements, I designed a base for the linear servo actuator to balance it using a 3D design software called Tinker

CAD (a web app for 3D design, electronics, and coding) and 3D printed it. With the base and screws fixed in a box, it can have support and stability.

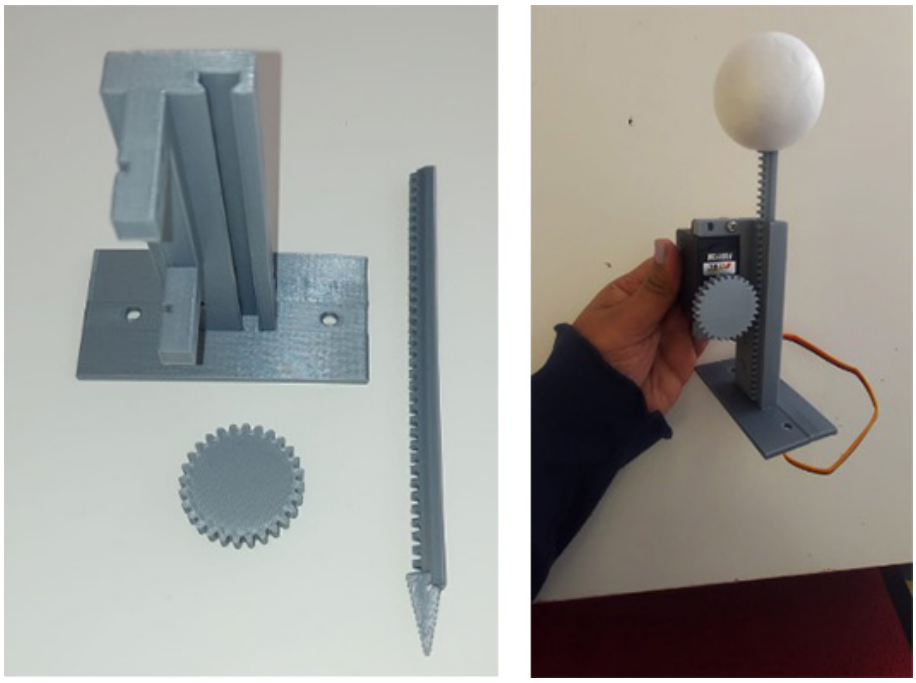


Figure 20: Final outcome of linear servo actuators (Left, Right) (Author's Image)

As you can see in (Fig. 20), instead of a stick, I developed a pointed pusher so the thermocol balls can get a grip. With the help of these components, I mounted this on the servos and used it inside the cylindrical objects. The filament for 3D print was a PLA (Polylactic acid), it took 17 hours to print 3 main body of the actuator, and along with the gear and pusher, in total, 15 linear servo actuators were developed.

2. *Main body of the cylindrical object*: In the process of developing the prototype, various challenges and considerations emerged. One notable challenge involved ensuring the stability and durability of the cylindrical object. Previous iterations, particularly Prototype 2, revealed issues with side panels breaking apart due to the movement of servo motors. While 3D printing initially seemed like a viable solution, the resulting objects were flimsy and time-consuming to produce. However, the discovery of heavy-duty carpet tubes provided a promising alternative (Appendix C). These tubes, known for their robustness, offered the necessary structural integrity for the prototype. Additionally, feedback from instructors highlighted the importance of optimizing the size of the

cylindrical object for palm placement, prompting adjustments to the diameter. Furthermore, the method of attaching fabric to the cylindrical surface was refined to ensure a seamless tactile experience for users. Hence, these challenges were addressed in the final prototype.

3. *Fabric*: Drawing on my background in knitwear design, I opted to work with two different fabrics for the prototype. Initially, I experimented with double jersey fleece fabric, known for its flexibility and comfort, commonly used in leggings. However, for the final installation, I chose a single jersey fabric with a blend of viscose, polyester, and cotton. This fabric offers a soft, smooth finish, prioritizing comfort and stress relief during sleep.
4. *Box Frame*: A box frame was developed, for the base of the final prototype. As I learned from prototype 2, there is a need for stability and support to allow the servo motors to move freely (appendix C).

4.4.1.2 Technical Aspects

I used Arduino uno, PCA9685, and 14 servo motors to build the entire project. The Arduino Uno served as the main microcontroller, providing the necessary processing power and interface capabilities to control the PCA9685 servo motor controller. The PCA9685 allowed for precise control of up to 16 servo motors simultaneously, making it an ideal choice for managing the multiple servo motors utilized in the project. By leveraging these components in conjunction with 14 servo motors, I was able to create the main base of responsive system that effectively translated data into tangible experience.

4.5 Final Exhibit

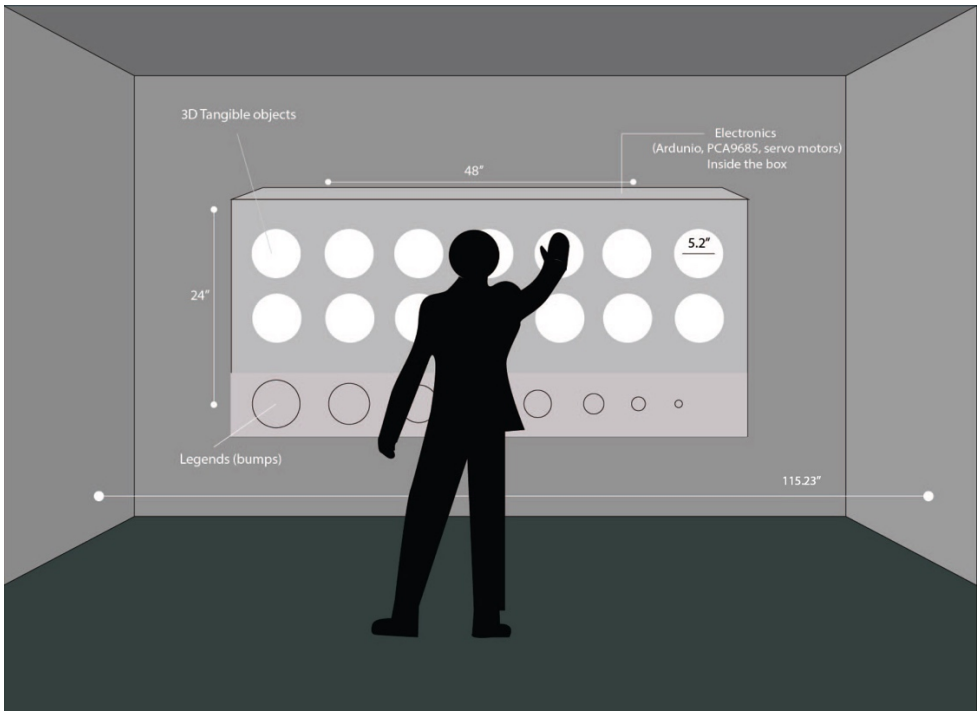


Figure 21: Illustration of my final prototype for the exhibit (Author's Image)

For the final exhibit, I envisioned my project within a space where people can engage with my data through touch. Presenting my data in a public space can encourage people to reflect on their own sleep patterns and wellbeing. This can also allow me to communicate my personal experiences and story through visual and tangible means.

The final prototype also addresses a common issue in sleep tracking app interfaces, which is distinguishing between good and bad sleep scores. Using the scale of bumps on the surface of tangible objects, I aim to tackle this problem by allowing visitors to touch the bumps and feel the difference. My goal is to foster a sense of connection when individuals engage with the tangible objects in a public space. Unlike traditional visualizations on app interfaces, tangible representations offer the possibility to reduce screen time, interpret data easily, and make the user experience engaging, meaningful, and empathetic.

During the exhibit, I had the opportunity to observe visitors engaging with the installation in addition to conversations about their personal experiences. By shaping my exhibit in this

manner, I anticipate that visitors will have the opportunity to explore the visualizations more deeply, gaining additional insights.

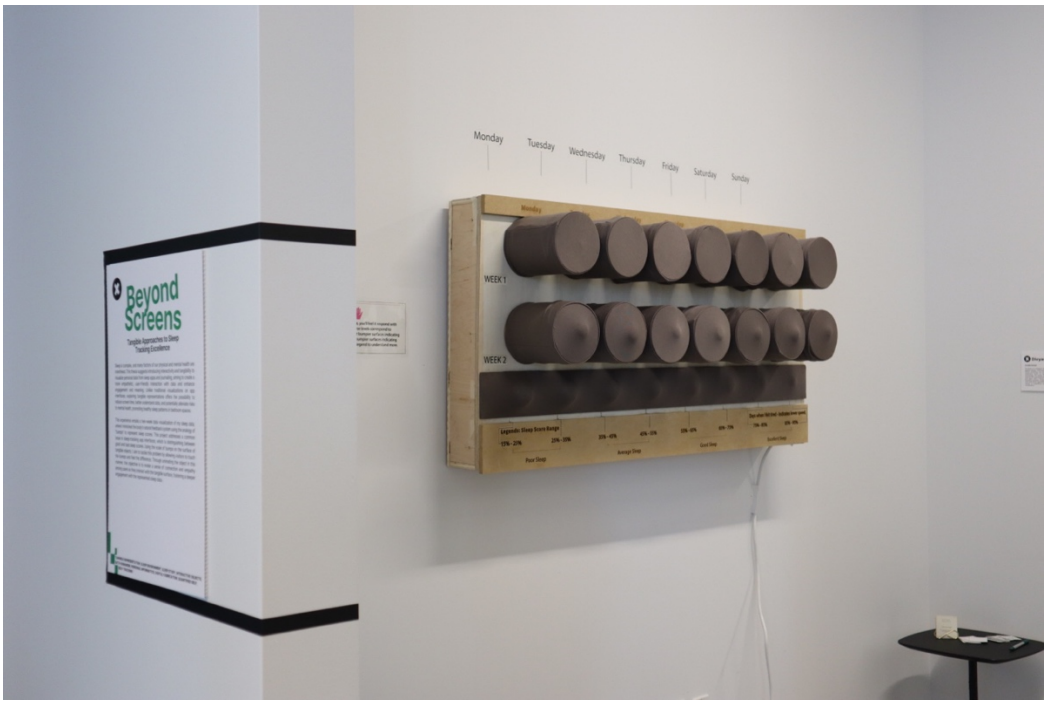


Figure 22: Side view of the final exhibition installation (Author's Image)

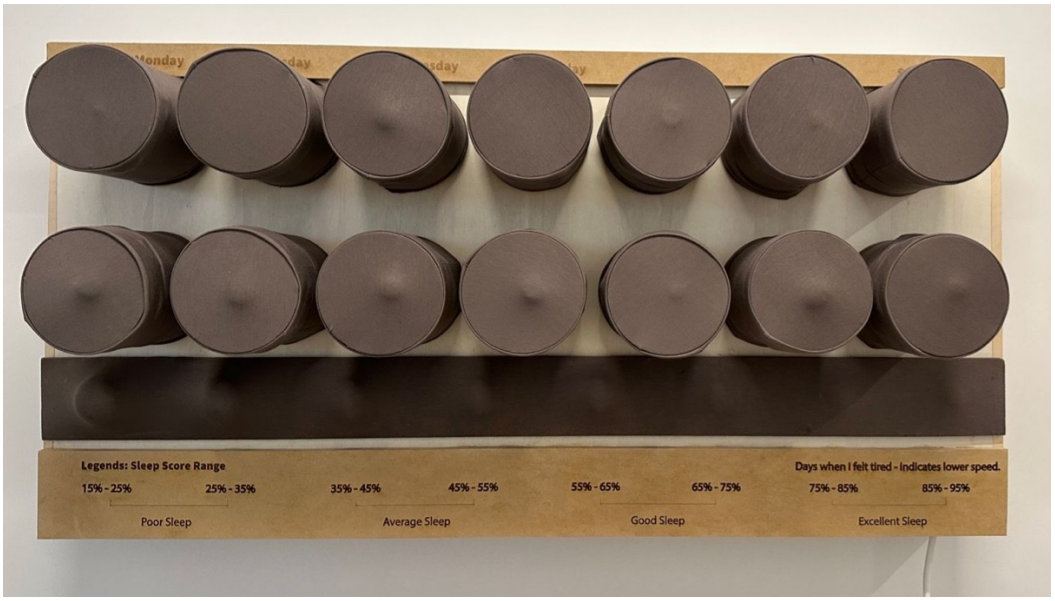


Figure 23: Front view of the final Prototype (Author's Image)

Figure 24: Left Image: two people engaging with the piece (received consent). Right Image: a person feeling the bumps (received consent) (Author's Image)

4.5.1 Reflection of the Exhibition

In the final exhibit, after installing the piece on the wall, I noticed that people were curious about the bumps and eager to experience it. Conversations with visitors revealed a notable difference between simply observing the piece from a distance and physically touching it. I understood that when people touched the surface and felt the movement of the bumps in various positions, the experience was more impactful, and they felt a stronger connection to the piece. This experience allowed them to distinguish between good and bad sleep days without the need of a legend. What I appreciated most was the sense of familiarity people experienced. As discussed in Section 2.5, that familiarity with common actions helps users easily interpret the information, I achieved this by explaining my inspiration behind bumps, of how our bodies provide clues, people were able to relate to the metaphor and found it more engaging. Beyond the expected perspectives, I also made some new discoveries through the exhibit, and I understood people's thoughts with reflection notes, which can be found in (Appendix E).

Sound: The sound of the piece was unintentional, as operating 14 servo motors generated a squealing noise. I adjusted the pulse rate of the standard servo motors to a moderate speed, representing neutral days, to reduce the sound out of concern that it might disturb the experience. However, conversations with viewers revealed that they enjoyed the sound, associating it with sleep-related experiences such as white noise, bed creaking, and restlessness during sleepless nights. The overall sound had a calming effect, enhancing the experience and making it more engaging with the bump's movement.

Fabric: The fabric used in the piece made the experience feel more human as people touched the surface (Appendix E). They associated the softness of the fabric with bedsheets and blankets. One individual remarked that the choice of textile harmonized with the theme of sleep, which was an intriguing insight I gained (Appendix E).

The piece also encouraged visitors to reflect on their own sleep patterns. When discussing the days I had poor sleep, they compared these experiences with their own lifestyles, schedules, and sleeping habits, leading to intriguing conversations around the common grounds of sleep. I also noticed that when people were simply observing the piece, a conversation arose between two individuals about how fewer hours of sleep can impact the next working day, causing a sense of haziness and a less active, unproductive mind. This is something which I can relate to my journey of tracking sleep through journaling. For instance, on September 30, 2023, my sleep score was 19%, and I had only 4 hours and 20 minutes of sleep, which impacted both that day and the next with low energy and tiredness (Appendix C).

Apart from that, people also began sharing their experiences with the same sleep-tracking application I used (Sleep Cycle), discussing similar frustrations such as having to keep the phone in bed, loud noises when the battery was low, and the temptation to engage with social media platforms. These observations and conversations during the exhibition offered fresh perspectives and enhanced the value of my research on tangible representations.

4.5.1.1 Physical Computing and Making

To execute this experience, careful fabrication played a crucial role in this project, as discussed in Section 4.3. Representing my two-week sleep data visualization and fostering a sense of engagement when people touched the surface required precise positioning and functioning of the 14 servos. Working with Arduino Uno and other physical computing components presented challenges due to their unpredictability and glitches. At one point, I even experienced a short circuit. However, the ongoing process of building, adjusting, and learning from these experiences allowed me to see the imperfections to refine the project and work efficiently on the final piece. Additionally, working with wood was a new experience for me, involving drilling, cutting, screwing, and understanding the material as a whole. I used maple wood for the final installation, which offered high quality and stability, effectively supporting all 14 servos and components.

CHAPTER FIVE: Conclusion and Next steps

5.1 Conclusions and Critical Reflection

This thesis reflects upon the effects of screen time, usage of mobile phones, and challenges using sleep-tracking applications, and represents initial exploration to visualize personal data in tangible modalities. The literature review gains knowledge about connections between sleep, lifestyle, screens, and the impact of light on circadian rhythms, which highlights an exploration of self-tracking, sleep devices, and applications. Concepts like Data Humanism, Data Physicalization, and Tangible Interfaces were explored to further understand and address sleep-related issues.

I employed Autoethnography as a primary methodology to provide a platform to explore, observe, and learn from personal data. Utilizing mixed methods such as Journaling and Quantified Self; alongside Critical Making, I facilitated visualization of data and exploration of tangibility, user-engagement and technology. Gathering data for 64 days revealed insights into sleep-related challenges, highlighting the importance to consider data interpretation, mental, and physical health in interface design.

Developing prototypes broadened my understanding of tangible representations and user experience design. Exploring areas like 3D printing, Arduino, and servos during this process helped me expand my knowledge in electronics, learning CAD (Computer-Aided Design) software and fabrication process, with iterative prototyping guiding design decisions. Building physical prototypes helped me understand how the tangible representations may bridge the gap between raw data and meaningful experiences.

The final outcome of this project was a multi-model exhibit installation, where it involves public engagement with the piece. With the help of reflection notes (Appendix E), I understood that by incorporating different modes such as sound, tangibility, visualization of data and movement within the piece offered better understanding of my sleep patterns. With time and careful planning, testing, and troubleshooting, I learned what works and what does not work when managing multiple components.

This research suggests that developing tangible interfaces specifically for representation of sleep data could offer significant benefits. In addressing my primary research question—

whether tangible representations can enhance the understanding of data collected in sleep-tracking devices and applications, reduce nighttime screen usage, and promote healthy sleep patterns—it remains a challenge to provide a definitive answer. However, based on my personal experiences, knowledge gained from the literature review, and reflection notes from the exhibit, I can affirm that incorporating tangibility in representation of sleep patterns has potential positive effects.

In addressing my secondary research question, visitors notes at the exhibition contributed to a richer understanding of the research outcomes. The bumps not only helped visitors connect with the experience by evoking a sense of familiarity with how our bodies communicate (Appendix E), but also provided meaning by depicting a range of sleep scores from poor to excellent. This depiction, coupled with the speed of each component, which represented the difference between feeling tired (slow speed) and neutral days (normal speed), made it easier for people to understand the data and added meaning to each data attribute. The inclusion of multiple sensory elements in the final outcome further enhanced engagement with the piece.

5.1.1 Research Contributions

This research helped identify problems with using screens at night, the impact of different lights in bedroom spaces, and sleep tracking applications, and opened new possibilities for data visualization that can cater to diverse user preferences and learning styles. Having bodily engagement with our data can help promote a mindful approach to our mental and physical well-being, particularly in relation to sleep (section 2.4). This research suggests considering this perspective when designing sleep-tracking devices that present sleep data.

5.2 Next Steps

For the next steps of this project, these are potential future directions that I will take:

1. For future development, I plan to create additional iterative prototypes, incorporating vibration and pressure sensors to improve the experience with tangible components.
2. I will conduct user testing on my prototype, allowing me to gather findings and insights from user feedback.
3. I will experiment with different materials and methods of digital fabrication in order to explore and refine tangible forms for the future projects.
4. I aim to gather sleep tracking data from individuals to uncover insights, unique patterns, and observations for future research.
5. I also aim to collaborate with sleep specialists and healthcare professionals to enhance the quality and relevance of my research.

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APPENDICES

Appendix A

Combined data of Journaling Data and Sleep Application data

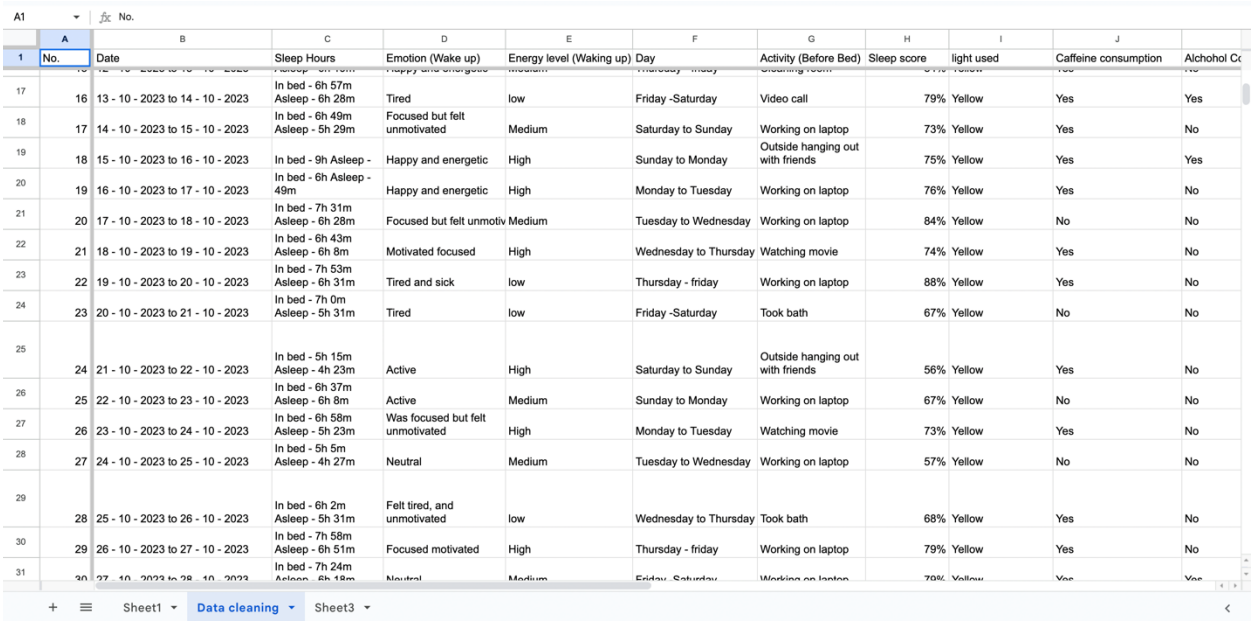
Since I used mixed methods, I combined my written data and data from sleep cycle on the Microsoft excel sheet.

1. Sleep data (28-09-2023 to 13-10-2023)

No.	Date	Sleep Hours	Emotion (Wake up)	Energy level (Waking up)	Day	Activity (Before Bed)	Sleep score	light used	Caffeine consumption	Alchohol Co
1	28-09-2023 to 29-09-2023	In bed - 7h 55m Asleep - 6h 54m	Happy and energetic	Medium	Thursday - friday	Working on laptop	82%	Yellow	No	No
2	29-09-2023 to 30-09-2023	in bed - 5h 31m Asleep - 4h 26m	Tired and unmotivated	low	Friday -Saturday	cleaning room	57%	Yellow	No	No
3	30 - 09 - 2023 to 1 - 10 - 2023	In bed - 4h 20m Asleep -3h 19m	Tired and unmotivated	low	Saturday to Sunday	Working on laptop	19%	Yellow	Yes	No
4	1 - 10 - 2023 to 2 - 10 - 2023	In bed - 8h 5m Asleep -7h 19m	Sick	low	Sunday to Monday	Listening music	80%	Yellow	Yes	No
5	2 - 10 - 2023 to 3 - 10 - 2023	In bed - 7h 21m Asleep - 6h 6m	Active	High	Monday to Tuesday	Working on laptop	81%	Yellow	Yes	Yes
6	3 - 10 - 2023 to 4 -10 -2023	In bed - 7h 20m Asleep - 6h 18 m	Active	Medium	Tuesday to Wednesday	Working on laptop	78%	Yellow	No	No
7	4 - 10 -2023 to 5 - 10 -2023	In bed - 7h 27m Asleep - 6h 20 m	Alert and unmotivated	Medium	Wednesday to Thursday	Working on laptop	84%	Yellow	Yes	No
8	5 - 10 - 2023 to 6 - 10 - 2023	In bed - 6h 21m Asleep - 4h 59m	Alert and focused	High	Thursday - friday	Outside hanging out with friends	71%	Yellow	Yes	No
9	6 - 10 - 2023 to 7 - 10 - 2023	In bed - 5h 36m Asleep - 4h 14m	Alert and focused	High	Friday -Saturday	Took bath	37%	Yellow	No	No
10	7 - 10 - 2023 to 8 - 10 - 2023	In bed - 7h 34m Asleep - 6h 30 m	Motivated	Medium	Saturday to Sunday	Working on laptop	33%	Yellow	Yes	No
11	8 - 10 - 2023 to 9 - 10 - 2023	In bed - 7h 3m Asleep - 5h 28m	Tired and unmotivated	low	Sunday to Monday	Took bath	74%	Yellow	Yes	No
12	9 - 10 - 2023 to 10 - 10 - 2023	In bed - 7h 3m Asleep - 6h 17m	Motivated	High	Monday to Tuesday	Watching movie	73%	Yellow	Yes	Yes
13	10 - 10 - 2023 to 11 - 10 - 2023	In bed - 8 h Asleep - 5h 39m	Tired and focus	High	Tuesday to Wednesday	Took bath	64%	Yellow	Yes	No
14	11 - 10 - 2023 to 12 - 10 - 2023	In bed - 6h 14m Asleep - 4h 57 m	Neutral and tired	Medium	Wednesday to Thursday	Working on laptop	51%	Yellow	Yes	No
15	12 - 10 - 2023 to 13 - 10 - 2023	In bed - 7h 56m Asleep - 6h 19m	Happy and energetic	Medium	Thursday - friday	Cleaning room	84%	Yellow	Yes	No
16	13 - 10 - 2023 to 14 - 10 - 2023	In bed - 6h 57m Asleep - 6h 28m	Tired	low	Friday -Saturday	Video call	79%	Yellow	Yes	Yes

Figure 25: Sleep data (28-09-2023 to 13-10-2023)

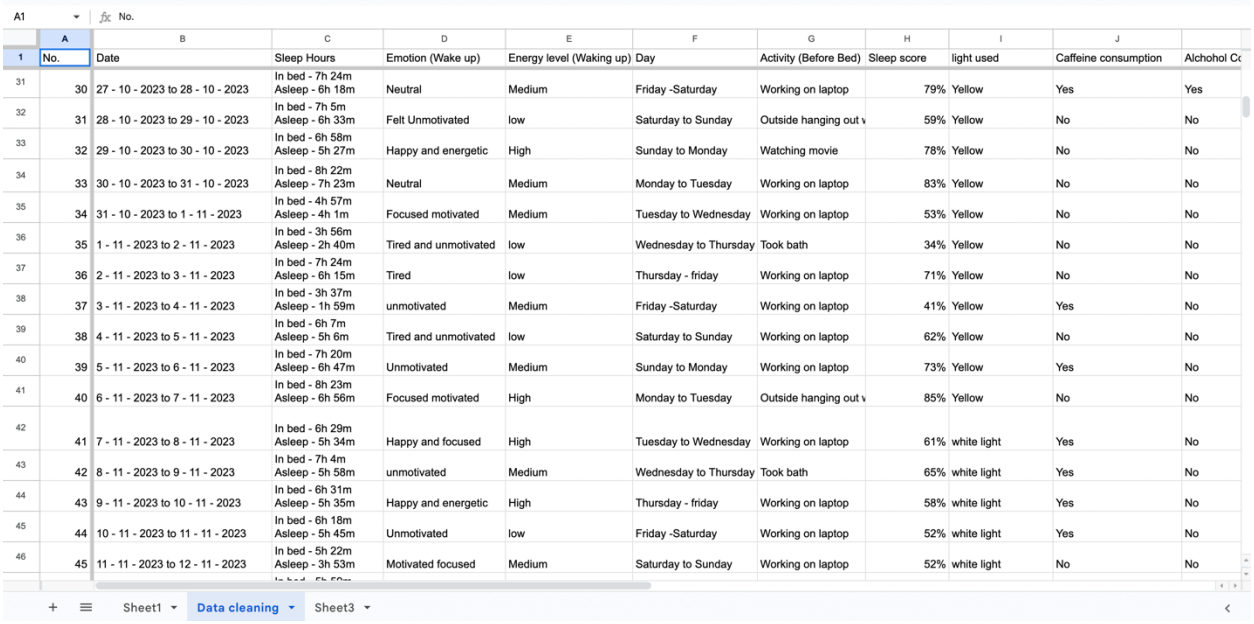
2. Sleep data (14-10-2023 to 26-10-2023)



No.	Date	Sleep Hours	Emotion (Wake up)	Energy level (Waking up)	Day	Activity (Before Bed)	Sleep score	light used	Caffeine consumption	Alchohol Co
16	13 - 10 - 2023 to 14 - 10 - 2023	In bed - 6h 57m Asleep - 6h 28m	Tired	low	Friday -Saturday	Video call	79%	Yellow	Yes	Yes
17	14 - 10 - 2023 to 15 - 10 - 2023	In bed - 6h 49m Asleep - 5h 29m	Focused but felt unmotivated	Medium	Saturday to Sunday	Working on laptop	73%	Yellow	Yes	No
18	15 - 10 - 2023 to 16 - 10 - 2023	In bed - 9h Asleep -	Happy and energetic	High	Sunday to Monday	Outside hanging out with friends	75%	Yellow	Yes	Yes
19	16 - 10 - 2023 to 17 - 10 - 2023	In bed - 6h Asleep - 49m	Happy and energetic	High	Monday to Tuesday	Working on laptop	76%	Yellow	Yes	No
20	17 - 10 - 2023 to 18 - 10 - 2023	In bed - 7h 31m Asleep - 6h 28m	Focused but felt unmotiv	Medium	Tuesday to Wednesday	Working on laptop	84%	Yellow	No	No
21	18 - 10 - 2023 to 19 - 10 - 2023	In bed - 6h 43m Asleep - 6h 8m	Motivated focused	High	Wednesday to Thursday	Watching movie	74%	Yellow	Yes	No
22	19 - 10 - 2023 to 20 - 10 - 2023	In bed - 7h 53m Asleep - 6h 31m	Tired and sick	low	Thursday - friday	Working on laptop	88%	Yellow	Yes	No
23	20 - 10 - 2023 to 21 - 10 - 2023	In bed - 7h 0m Asleep - 5h 31m	Tired	low	Friday -Saturday	Took bath	67%	Yellow	No	No
24	21 - 10 - 2023 to 22 - 10 - 2023	In bed - 5h 15m Asleep - 4h 23m	Active	High	Saturday to Sunday	Outside hanging out with friends	56%	Yellow	Yes	No
25	22 - 10 - 2023 to 23 - 10 - 2023	In bed - 6h 37m Asleep - 6h 8m	Active	Medium	Sunday to Monday	Working on laptop	67%	Yellow	No	No
26	23 - 10 - 2023 to 24 - 10 - 2023	In bed - 6h 58m Asleep - 5h 23m	Was focused but felt unmotivated	High	Monday to Tuesday	Watching movie	73%	Yellow	Yes	No
27	24 - 10 - 2023 to 25 - 10 - 2023	In bed - 5h 5m Asleep - 4h 27m	Neutral	Medium	Tuesday to Wednesday	Working on laptop	57%	Yellow	No	No
28	25 - 10 - 2023 to 26 - 10 - 2023	In bed - 6h 2m Asleep - 5h 31m	Felt tired, and unmotivated	low	Wednesday to Thursday	Took bath	68%	Yellow	Yes	No
29	26 - 10 - 2023 to 27 - 10 - 2023	In bed - 7h 58m Asleep - 6h 51m	Focused motivated	High	Thursday - friday	Working on laptop	79%	Yellow	Yes	No
30		In bed - 7h 24m								

Figure 26: Sleep data (14-10-2023 to 26-10-2023)

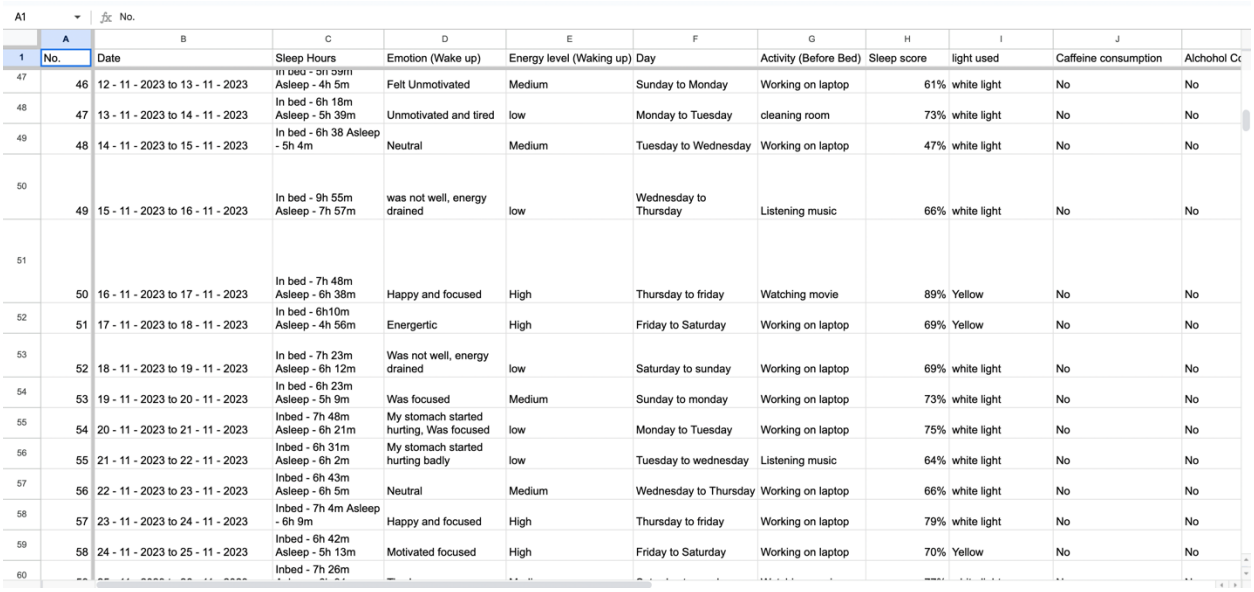
3. Sleep data (27-10-2023 to 11-11-2023)



No.	Date	Sleep Hours	Emotion (Wake up)	Energy level (Waking up)	Day	Activity (Before Bed)	Sleep score	light used	Caffeine consumption	Alchohol Co
30	27 - 10 - 2023 to 28 - 10 - 2023	In bed - 7h 24m Asleep - 6h 18m	Neutral	Medium	Friday -Saturday	Working on laptop	79%	Yellow	Yes	Yes
31	28 - 10 - 2023 to 29 - 10 - 2023	In bed - 7h 5m Asleep - 6h 33m	Felt Unmotivated	low	Saturday to Sunday	Outside hanging out v	59%	Yellow	No	No
32	29 - 10 - 2023 to 30 - 10 - 2023	In bed - 6h 58m Asleep - 5h 27m	Happy and energetic	High	Sunday to Monday	Watching movie	78%	Yellow	No	No
33	30 - 10 - 2023 to 31 - 10 - 2023	In bed - 8h 22m Asleep - 7h 23m	Neutral	Medium	Monday to Tuesday	Working on laptop	83%	Yellow	No	No
34	31 - 10 - 2023 to 1 - 11 - 2023	In bed - 4h 57m Asleep - 4h 1m	Focused motivated	Medium	Tuesday to Wednesday	Working on laptop	53%	Yellow	No	No
35	1 - 11 - 2023 to 2 - 11 - 2023	In bed - 3h 56m Asleep - 2h 40m	Tired and unmotivated	low	Wednesday to Thursday	Took bath	34%	Yellow	No	No
36	2 - 11 - 2023 to 3 - 11 - 2023	In bed - 7h 24m Asleep - 6h 15m	Tired	low	Thursday - friday	Working on laptop	71%	Yellow	No	No
37	3 - 11 - 2023 to 4 - 11 - 2023	In bed - 3h 37m Asleep - 1h 59m	unmotivated	Medium	Friday -Saturday	Working on laptop	41%	Yellow	Yes	No
38	4 - 11 - 2023 to 5 - 11 - 2023	In bed - 6h 7m Asleep - 5h 6m	Tired and unmotivated	low	Saturday to Sunday	Working on laptop	62%	Yellow	No	No
39	5 - 11 - 2023 to 6 - 11 - 2023	In bed - 7h 20m Asleep - 6h 47m	Unmotivated	Medium	Sunday to Monday	Working on laptop	73%	Yellow	Yes	No
40	6 - 11 - 2023 to 7 - 11 - 2023	In bed - 8h 23m Asleep - 6h 56m	Focused motivated	High	Monday to Tuesday	Outside hanging out v	85%	Yellow	No	No
41	7 - 11 - 2023 to 8 - 11 - 2023	In bed - 6h 29m Asleep - 5h 34m	Happy and focused	High	Tuesday to Wednesday	Working on laptop	61%	white light	Yes	No
42	8 - 11 - 2023 to 9 - 11 - 2023	In bed - 7h 4m Asleep - 5h 58m	unmotivated	Medium	Wednesday to Thursday	Took bath	65%	white light	Yes	No
43	9 - 11 - 2023 to 10 - 11 - 2023	In bed - 6h 31m Asleep - 5h 35m	Happy and energetic	High	Thursday - friday	Working on laptop	58%	white light	Yes	No
44	10 - 11 - 2023 to 11 - 11 - 2023	In bed - 6h 18m Asleep - 5h 45m	Unmotivated	low	Friday -Saturday	Working on laptop	52%	white light	Yes	No
45	11 - 11 - 2023 to 12 - 11 - 2023	In bed - 5h 22m Asleep - 3h 53m	Motivated focused	Medium	Saturday to Sunday	Working on laptop	52%	white light	No	No
46		In bed - 5h 59m								

Figure 27: Sleep data (27-10-2023 to 11-11-2023)

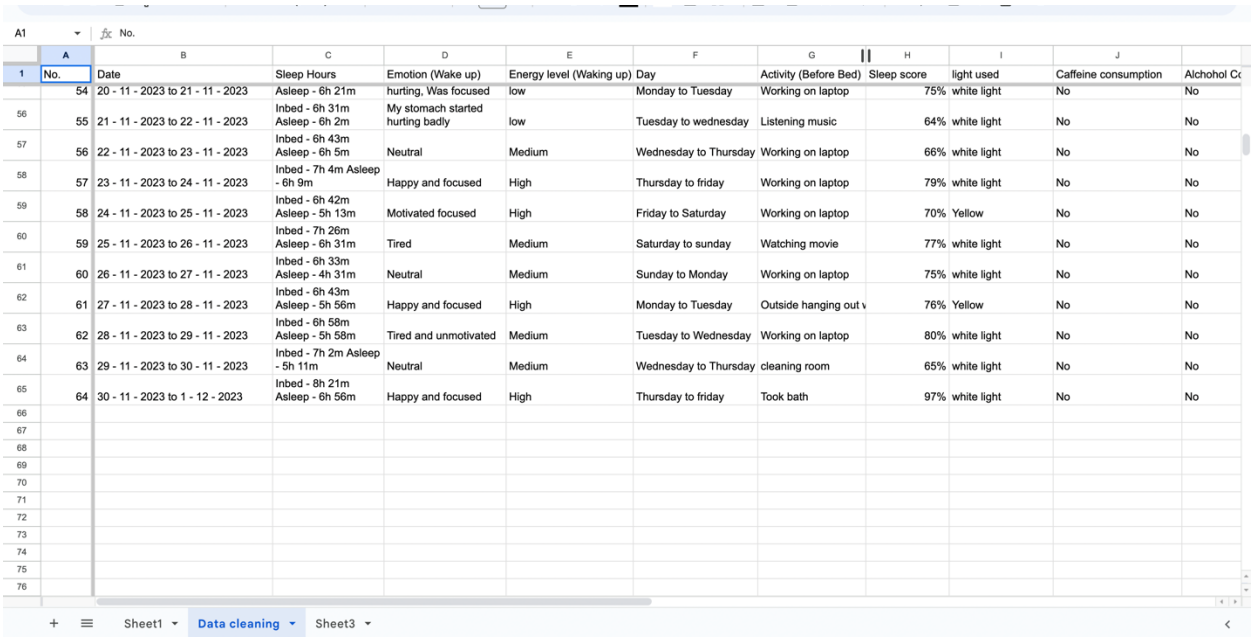
4. Sleep data (12-11-2023 to 24-11-2023)



No.	Date	Sleep Hours	Emotion (Wake up)	Energy level (Waking up)	Day	Activity (Before Bed)	Sleep score	light used	Caffeine consumption	Alchohol Co
46	12 - 11 - 2023 to 13 - 11 - 2023	In bed - 5h 59m Asleep - 4h 5m	Felt Unmotivated	Medium	Sunday to Monday	Working on laptop	61%	white light	No	No
47	13 - 11 - 2023 to 14 - 11 - 2023	In bed - 6h 18m Asleep - 5h 39m	Unmotivated and tired	low	Monday to Tuesday	cleaning room	73%	white light	No	No
48	14 - 11 - 2023 to 15 - 11 - 2023	In bed - 6h 38 Asleep - 5h 4m	Neutral	Medium	Tuesday to Wednesday	Working on laptop	47%	white light	No	No
49	15 - 11 - 2023 to 16 - 11 - 2023	In bed - 9h 55m Asleep - 7h 57m	was not well, energy drained	low	Wednesday to Thursday	Listening music	66%	white light	No	No
50	16 - 11 - 2023 to 17 - 11 - 2023	In bed - 7h 48m Asleep - 6h 38m	Happy and focused	High	Thursday to friday	Watching movie	89%	Yellow	No	No
51	17 - 11 - 2023 to 18 - 11 - 2023	In bed - 6h10m Asleep - 4h 56m	Energertic	High	Friday to Saturday	Working on laptop	69%	Yellow	No	No
52	18 - 11 - 2023 to 19 - 11 - 2023	In bed - 7h 23m Asleep - 6h 12m	Was not well, energy drained	low	Saturday to sunday	Working on laptop	69%	white light	No	No
53	19 - 11 - 2023 to 20 - 11 - 2023	In bed - 6h 23m Asleep - 5h 9m	Was focused	Medium	Sunday to monday	Working on laptop	73%	white light	No	No
54	20 - 11 - 2023 to 21 - 11 - 2023	Inbed - 7h 48m Asleep - 6h 21m	My stomach started hurting, Was focused	low	Monday to Tuesday	Working on laptop	75%	white light	No	No
55	21 - 11 - 2023 to 22 - 11 - 2023	Inbed - 6h 31m Asleep - 6h 2m	My stomach started hurting badly	low	Tuesday to wednesday	Listening music	64%	white light	No	No
56	22 - 11 - 2023 to 23 - 11 - 2023	Inbed - 6h 43m Asleep - 6h 5m	Neutral	Medium	Wednesday to Thursday	Working on laptop	66%	white light	No	No
57	23 - 11 - 2023 to 24 - 11 - 2023	Inbed - 7h 4m Asleep - 6h 9m	Happy and focused	High	Thursday to friday	Working on laptop	79%	white light	No	No
58	24 - 11 - 2023 to 25 - 11 - 2023	Inbed - 6h 42m Asleep - 5h 13m	Motivated focused	High	Friday to Saturday	Working on laptop	70%	Yellow	No	No
59		Inbed - 7h 26m								

Figure 28: Sleep data (12-11-2023 to 24-11-2023)

5. Sleep data (25-11-2023 to 30-11-2023)



No.	Date	Sleep Hours	Emotion (Wake up)	Energy level (Waking up)	Day	Activity (Before Bed)	Sleep score	light used	Caffeine consumption	Alchohol Co
54	20 - 11 - 2023 to 21 - 11 - 2023	Asleep - 6h 21m	hurting, Was focused	low	Monday to Tuesday	Working on laptop	75%	white light	No	No
55	21 - 11 - 2023 to 22 - 11 - 2023	Inbed - 6h 31m Asleep - 6h 2m	My stomach started hurting badly	low	Tuesday to wednesday	Listening music	64%	white light	No	No
56	22 - 11 - 2023 to 23 - 11 - 2023	Inbed - 6h 43m Asleep - 6h 5m	Neutral	Medium	Wednesday to Thursday	Working on laptop	66%	white light	No	No
57	23 - 11 - 2023 to 24 - 11 - 2023	Inbed - 7h 4m Asleep - 6h 9m	Happy and focused	High	Thursday to friday	Working on laptop	79%	white light	No	No
58	24 - 11 - 2023 to 25 - 11 - 2023	Inbed - 6h 42m Asleep - 5h 13m	Motivated focused	High	Friday to Saturday	Working on laptop	70%	Yellow	No	No
59	25 - 11 - 2023 to 26 - 11 - 2023	Inbed - 7h 26m Asleep - 6h 31m	Tired	Medium	Saturday to sunday	Watching movie	77%	white light	No	No
60	26 - 11 - 2023 to 27 - 11 - 2023	Inbed - 6h 33m Asleep - 4h 31m	Neutral	Medium	Sunday to Monday	Working on laptop	75%	white light	No	No
61	27 - 11 - 2023 to 28 - 11 - 2023	Inbed - 6h 43m Asleep - 5h 56m	Happy and focused	High	Monday to Tuesday	Outside hanging out v	76%	Yellow	No	No
62	28 - 11 - 2023 to 29 - 11 - 2023	Inbed - 6h 58m Asleep - 5h 58m	Tired and unmotivated	Medium	Tuesday to Wednesday	Working on laptop	80%	white light	No	No
63	29 - 11 - 2023 to 30 - 11 - 2023	Inbed - 7h 2m Asleep - 5h 11m	Neutral	Medium	Wednesday to Thursday	cleaning room	65%	white light	No	No
64	30 - 11 - 2023 to 1 - 12 - 2023	Inbed - 8h 21m Asleep - 6h 56m	Happy and focused	High	Thursday to friday	Took bath	97%	white light	No	No

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Figure 29: Sleep data (25-11-2023 to 30-11-2023)

6. Sleep data (caffeine consumption, alcohol consumption, dinner before bed, screen time, daytime sleeping, exercise, and observations) (28-09-2023 to 13-10-2023)

No.	Date	Caffeine consumption	Alchohol Consumption	Dinner before bed	Screen time phone/ Laptop before bed.	Day time sleeping	Excercise	Observation Till date
1	28-09-2023 to 29-09-2023	No	No	dal rice	No			
2	29-09-2023 to 30-09-2023	No	No	Burger and fries	Yes	No	Yes	
3	30 - 09 - 2023 to 1 - 10 - 2023	Yes	No	Food from outside	Yes	No	No	
4	1 - 10 - 2023 to 2 - 10 - 2023	Yes	No	Dal rice	Yes	No	No	
5	2 - 10 - 2023 to 3 - 10 - 2023	Yes	Yes	Chicken and Pasta	Yes	No	Yes	
6	3 - 10 - 2023 to 4 -10 -2023	No	No	Pasta	Yes	No	Yes	
7	4 - 10 -2023 to 5 - 10 -2023	Yes	No	Burger and fries	Yes	No	Yes	
8	5 - 10 - 2023 to 6 - 10 - 2023	Yes	No	Bhaji Chapati	Yes	Yes	No	
9	6 - 10 - 2023 to 7 - 10 - 2023	No	No	Bhaji Chapati	No	No	No	
10	7 - 10 - 2023 to 8 - 10 - 2023	Yes	No	Order food from outside	Yes	No	No	
11	8 - 10 - 2023 to 9 - 10 - 2023	Yes	No	Fried Rice Home made	Yes	Yes	No	
12	9 - 10 - 2023 to 10 - 10 - 2023	Yes	Yes	Order food from outside	Yes	No	No	
13	10 - 10 - 2023 to 11 - 10 - 2023	Yes	No	Egg and Bread	Yes	No	No	
14	11 - 10 - 2023 to 12 - 10 - 2023	Yes	No	Pasta	Yes	No	No	
15	12 - 10 - 2023 to 13 - 10 - 2023	Yes	No	Fried Rice	Yes	No	No	
16	13 - 10 - 2023 to 14 - 10 - 2023	Yes	Yes	Fried Rice	Yes	Yes	No	

Figure 30: Sleep data (caffeine consumption, alcohol consumption, dinner before bed, screen time, daytime sleeping, exercise, and observations) (28-09-2023 to 13-10-2023)

7. Sleep data (caffeine consumption, alcohol consumption, dinner before bed, screen time, daytime sleeping, exercise, and observations) (14-10-2023 to 28-10-2023)

No.	Date	Caffeine consumption	Alchohol Consumption	Dinner before bed	Screen time phone/ Laptop before bed.	Day time sleeping	Excercise	Observation Till date
17	14 - 10 - 2023 to 15 - 10 - 2023	Yes	No	Bhaji Chapati	Yes	No	No	
18	15 - 10 - 2023 to 16 - 10 - 2023	Yes	Yes	Order food from outs	No	No	No	
19	16 - 10 - 2023 to 17 - 10 - 2023	Yes	No	Dal Rice	Yes	No	No	
20	17 - 10 - 2023 to 18 - 10 - 2023	No	No	Bread and eggs	Yes	No	No	
21	18 - 10 - 2023 to 19 - 10 - 2023	Yes	No	Salad and fruits	Yes	No	No	
22	19 - 10 - 2023 to 20 - 10 - 2023	Yes	No	Chicken and salad	Yes	No	No	
23	20 - 10 - 2023 to 21 - 10 - 2023	No	No	Rice and egg	No	Yes	No	
24	21 - 10 - 2023 to 22 - 10 - 2023	Yes	No	Bhaji Chapati	No	No	No	Although i slept for less hours i felt active today, Rested well last 3 to 4 days.
25	22 - 10 - 2023 to 23 - 10 - 2023	No	No	Egg and Bread	Yes	No	No	
26	23 - 10 - 2023 to 24 - 10 - 2023	Yes	No	Ordered food from outside	Yes	Yes	No	
27	24 - 10 - 2023 to 25 - 10 - 2023	No	No	Dal Rice	Yes	No	No	
28	25 - 10 - 2023 to 26 - 10 - 2023	Yes	No	Bhel	Yes	No	No	I observe oversleeping can be harmful for our health too.
29	26 - 10 - 2023 to 27 - 10 - 2023	Yes	No	Pasta	Yes	No	No	
30	27 - 10 - 2023 to 28 - 10 - 2023	Yes	Yes	Salad and fruits	Yes	No	Yes	
31	28 - 10 - 2023 to 29 - 10 - 2023	No	No	Food from outside	No	No	No	

Figure 31: Sleep data (caffeine consumption, alcohol consumption, dinner before bed, screen time, daytime sleeping, exercise, and observations) (14-10-2023 to 28-10-2023)

8. Sleep data (caffeine consumption, alcohol consumption, dinner before bed, screen time, daytime sleeping, exercise, and observations) (29-10-2023 to 13-11-2023)

No.	Date	Caffeine consumption	Alchohol Consumption	Dinner before bed	Screen time phone/ Laptop before bed.	Day time sleeping	Excercise	Observation Till date
32	29 - 10 - 2023 to 30 - 10 - 2023	No	No	Dal rice	Yes	Yes	No	
33	30 - 10 - 2023 to 31 - 10 - 2023	No	No	NOODLES	Yes	No	No	
34	31 - 10 - 2023 to 1 - 11 - 2023	No	No	Veggies and chicker	Yes	No	No	
35	1 - 11 - 2023 to 2 - 11 - 2023	No	No	Burger and fries	Yes	No	No	
36	2 - 11 - 2023 to 3 - 11 - 2023	No	No	Soup	Yes	No	No	
37	3 - 11 - 2023 to 4 - 11 - 2023	Yes	No	Bhaji Chapati	No	No	No	
38	4 - 11 - 2023 to 5 - 11 - 2023	No	No	Salad	Yes	No	No	
39	5 - 11 - 2023 to 6 - 11 - 2023	Yes	No	Mushroom rice	No	No	No	
40	6 - 11 - 2023 to 7 - 11 - 2023	No	No	Dal Rice	No	Yes	Yes	
41	7 - 11 - 2023 to 8 - 11 - 2023	Yes	No	Noodles	No	Yes	Yes	Day time sleeping and also cause tiredness in our body.
42	8 - 11 - 2023 to 9 - 11 - 2023	Yes	No	Rice and egg	No	No	Yes	
43	9 - 11 - 2023 to 10 - 11 - 2023	Yes	No	Pasta	Yes	No	No	
44	10 - 11 - 2023 to 11 - 11 - 2023	Yes	No	Salad	Yes	No	No	
45	11 - 11 - 2023 to 12 - 11 - 2023	No	No	Rice and chicken	Yes	No	No	
46	12 - 11 - 2023 to 13 - 11 - 2023	No	No	Fish and chapati	Yes	No	No	
47	13 - 11 - 2023 to 14 - 11 - 2023	No	No	Soup	No	No	No	

Figure 32: Sleep data (caffeine consumption, alcohol consumption, dinner before bed, screen time, daytime sleeping, exercise, and observations) (29-10-2023 to 13-11-2023)

9. Sleep data (caffeine consumption, alcohol consumption, dinner before bed, screen time, daytime sleeping, exercise, and observations) (14-11-2023 to 26-11-2023)

No.	Date	Caffeine consumption	Alchohol Consumption	Dinner before bed	Screen time phone/ Laptop before bed.	Day time sleeping	Excercise	Observation Till date
48	14 - 11 - 2023 to 15 - 11 - 2023	No	No	Soup	No	No	No	
49	15 - 11 - 2023 to 16 - 11 - 2023	No	No	Curd rice.	Yes	Yes	No	White light was helping me to stay alert but it was hard for me to sleep at night
50	16 - 11 - 2023 to 17 - 11 - 2023	No	No	Bhel	Yes	No	Yes	I realize that was more focused in the morning, taking bath relaxes me as well as sleeping for 8hrs did not make me lousy
51	17 - 11 - 2023 to 18 - 11 - 2023	No	No	Egg and Rice	Yes	No	Yes	
52	18 - 11 - 2023 to 19 - 11 - 2023	No	No	Fried rice	Yes	No	Yes	I stoped consuming Coffee, My heart started beating fast
53	19 - 11 - 2023 to 20 - 11 - 2023	No	No	Pasta	Yes	No	No	with White its hard to fall asleep
54	20 - 11 - 2023 to 21 - 11 - 2023	No	No	Ordered food from outside	Yes	Yes	No	
55	21 - 11 - 2023 to 22 - 11 - 2023	No	No	veg bhaji and chapati	No	No	No	
56	22 - 11 - 2023 to 23 - 11 - 2023	No	No	egg and chapati	Yes	No	No	
57	23 - 11 - 2023 to 24 - 11 - 2023	No	No	Fried rice	Yes	No	No	
58	24 - 11 - 2023 to 25 - 11 - 2023	No	No	Salad	Yes	No	Yes	
59	25 - 11 - 2023 to 26 - 11 - 2023	No	No	Dal and Rice	Yes	No	No	
60	26 - 11 - 2023 to 27 - 11 - 2023	No	No	Rice and egg	Yes	No	No	

Figure 33: Sleep data (caffeine consumption, alcohol consumption, dinner before bed, screen time, daytime sleeping, exercise, and observations) (14-11-2023 to 26-11-2023)

10. Sleep data (caffeine consumption, alcohol consumption, dinner before bed, screen time, daytime sleeping, exercise, and observations) (27-11-2023 to 30-11-2023)

No.	Date	Caffeine consumption	Alchohol Consumption	Dinner before bed	Screen time phone/ Laptop before bed.	Day time sleeping	Excercise	Observation Till date
61	27 - 11 - 2023 to 28 - 11 - 2023	No	No	Noodles	No	No	No	
62	28 - 11 - 2023 to 29 - 11 - 2023	No	No	Chicken and rice	Yes	No	No	
63	29 - 11 - 2023 to 30 - 11 - 2023	No	No	Salad and fruits	No	No	No	
64	30 - 11 - 2023 to 1 - 12 - 2023	No	No	Soup	No	No	No	

Figure 34: Sleep data (caffeine consumption, alcohol consumption, dinner before bed, screen time, daytime sleeping, exercise, and observations) (27-11-2023 to 30-11-2023)

Appendix B

Sleep Tracking Application (Sleep Cycle) Data

Start	End	Sleep Quality	Regularity	Mood	Steps	Air Pressure (Pa	City	Movements per hour	Time in bed (seconds)	Window start
2023-09-28 21:57:03	2023-09-28 23:14:57	13%	—		0			1	4674.397	23-09-29 07:03:14
2023-09-28 23:15:51	2023-09-29 7:10:56	81%	—		0			20.706255	28504.946	23-09-29 07:04:07
2023-09-30 1:57:41	2023-09-30 7:28:54	57%	75%		0			0	19873.269	23-09-30 07:05:08
2023-10-01 1:04:51	2023-10-01 5:25:42	19%	75%		0			67.449326	15650.625	23-10-01 05:05:00
2023-10-02 0:23:01	2023-10-02 8:29:01	79%	73%		0			33.33492	29159.826	23-10-02 08:07:41
2023-10-03 3:06:12	2023-10-03 10:28:01	80%	70%		0			11.540318	26508.722	23-10-03 10:06:15
2023-10-03 23:34:35	2023-10-04 6:54:52	77%	50%		0			17.866985	26417.389	23-10-04 06:34:09
2023-10-05 0:01:53	2023-10-05 7:29:21	84%	64%		0			5.0792537	26847.889	23-10-05 07:04:24
2023-10-06 0:10:46	2023-10-06 6:31:48	71%	74%		0			4.2420406	22861.228	23-10-06 07:06:38
2023-10-07 0:22:18	2023-10-07 5:58:31	37%	91%		0			80.334465	20172.178	23-10-07 05:36:09
2023-10-07 23:20:32	2023-10-08 6:54:33	32%	88%		0			185.44466	27240.686	23-10-08 06:37:21
2023-10-09 2:35:50	2023-10-09 9:39:15	74%	75%		0			30.521532	25404.67	23-10-09 09:35:47
2023-10-10 0:12:05	2023-10-10 7:16:02	73%	64%		0			37.75276	25436.185	23-10-10 07:17:56
2023-10-10 23:56:40	2023-10-11 6:09:33	63%	66%		0			40.665363	22373.151	23-10-11 06:03:08
2023-10-12 0:56:04	2023-10-12 7:10:35	50%	70%		0			125.02668	22471.22	23-10-12 07:05:51
2023-10-12 22:49:13	2023-10-13 6:45:48	84%	81%		0			33.855206	28594.416	23-10-13 06:37:42
2023-10-14 0:00:58	2023-10-14 6:58:56	78%	83%		0			5.2356086	25077.746	23-10-14 06:35:06
2023-10-15 0:54:16	2023-10-15 7:43:19	72%	84%		0			28.322433	24543.769	23-10-15 07:35:05
2023-10-16 23:07:47	2023-10-17 5:57:27	75%	70%		0			11.878059	24579.778	23-10-17 05:36:05
2023-10-17 22:59:20	2023-10-18 6:30:58	84%	94%		0			5.6075654	27098.593	23-10-18 06:05:02
2023-10-19 0:17:52	2023-10-19 7:01:51	74%	89%		0			10.959648	24239.281	23-10-19 07:03:42
2023-10-19 23:34:24	2023-10-20 7:27:38	87%	89%		0			6.7395587	28394.466	23-10-20 07:04:15
2023-10-22 0:48:11	2023-10-22 6:03:19	56%	84%		0			21.463955	18907.753	23-10-22 06:05:42
2023-10-23 0:49:50	2023-10-23 7:27:01	67%	83%		0			41.594364	23831.513	23-10-23 07:07:01
2023-10-24 0:06:54	2023-10-24 7:05:22	72%	85%		0			31.753674	25108.58	23-10-24 07:06:36
2023-10-25 1:23:35	2023-10-25 6:28:57	56%	87%		0			7.121993	18322.371	23-10-25 06:07:52
2023-10-26 1:28:07	2023-10-26 7:30:58	68%	88%		0			0.37763384	21771.28	23-10-26 07:07:30
2023-10-26 23:29:49	2023-10-27 7:28:45	78%	87%		0			46.51583	28736.019	23-10-27 07:03:26
2023-10-28 0:26:52	2023-10-28 7:51:49	78%	87%		0			22.684835	26697.129	23-10-28 07:35:31
2023-10-29 0:07:13	2023-10-29 7:12:20	59%	87%		0			96.33436	25506.547	23-10-29 07:07:35
2023-10-30 0:06:07	2023-10-30 7:04:35	77%	93%		0			6.436068	25108.925	23-10-30 07:04:29
2023-10-30 22:56:21	2023-10-31 7:18:56	82%	93%		0			47.311996	30155.421	23-10-31 07:03:05
2023-11-01 0:23:06	2023-11-01 5:20:15	53%	86%		0			22.00358	17828.641	23-11-01 07:06:26
2023-11-02 2:01:50	2023-11-02 5:58:02	34%	80%		0			90.2361	14171.998	23-11-02 05:33:29
2023-11-02 23:52:38	2023-11-03 7:17:34	71%	74%		0			57.60579	26696.551	23-11-03 07:18:26
2023-11-04 2:49:56	2023-11-04 6:27:46	41%	72%		0			2.6263058	13069.7	23-11-04 06:03:42
2023-11-05 1:26:55	2023-11-05 6:34:13	62%	72%		0			41.60976	22038.166	23-11-05 06:00:00
2023-11-05 23:09:56	2023-11-06 6:30:52	73%	78%		0			45.568417	26456.013	23-11-06 06:00:00
2023-11-06 22:07:15	2023-11-07 6:30:46	84%	90%		0			43.345726	30210.915	23-11-07 06:00:00
2023-11-08 0:08:20	2023-11-08 6:38:18	61%	87%		0			64.02092	23398.536	23-11-08 06:00:00
2023-11-08 23:25:32	2023-11-09 6:30:23	65%	88%		0			70.95654	25490.327	23-11-09 06:00:00
2023-11-10 1:29:07	2023-11-10 8:00:15	58%	84%		0			81.14506	23467.973	23-11-10 07:30:00
2023-11-11 1:43:00	2023-11-11 8:01:15	52%	85%		0			103.09277	22695.612	23-11-11 07:30:00
2023-11-12 0:41:13	2023-11-12 6:03:50	51%	81%		0			62.10031	19356.594	23-11-12 05:30:00
2023-11-13 0:04:17	2023-11-13 6:04:03	60%	84%		0			46.291653	21585.798	23-11-13 05:30:00
2023-11-14 0:44:09	2023-11-14 7:02:32	73%	85%		0			1.7283478	22703.491	23-11-14 06:30:00
2023-11-15 0:26:37	2023-11-15 7:04:54	47%	92%		0			138.93852	23897.294	23-11-15 06:30:00
2023-11-16 0:09:30	2023-11-16 6:04:52	65%	90%		0			15.959937	21322.028	23-11-16 05:30:00

Figure 35: Sleep data from sleep cycle application

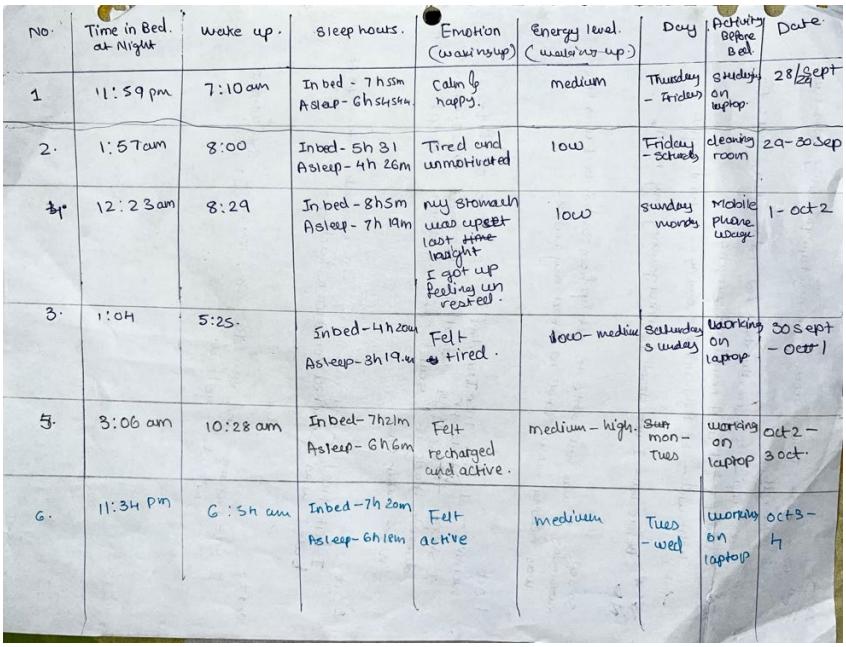
Window stop	Did snore	Snore time	Weather tempera	Weather type	Notes
23-09-29 07:30:00	FALSE	0			
23-09-29 07:30:00	TRUE	5015			
23-09-30 07:30:00	FALSE	0			
23-10-01 05:30:00	TRUE	97			
23-10-02 08:30:00	TRUE	1004			
23-10-03 10:30:00	TRUE	153			
23-10-04 07:00:00	TRUE	87			
23-10-05 07:30:00	TRUE	73			
23-10-06 07:30:00	TRUE	49			
23-10-07 06:00:00	TRUE	616			
23-10-08 07:00:00	TRUE	914			
23-10-09 10:00:00	TRUE	2133			
23-10-10 07:40:00	TRUE	1480			
23-10-11 06:30:00	TRUE	2722			
23-10-12 07:30:00	TRUE	1991			
23-10-13 07:00:00	TRUE	5281			
23-10-14 07:00:00	FALSE	0			
23-10-15 08:00:00	TRUE	25			
23-10-17 06:00:00	TRUE	618			
23-10-18 06:30:00	FALSE	0			
23-10-19 07:30:00	TRUE	12			
23-10-20 07:30:00	FALSE	0			
23-10-22 06:30:00	TRUE	26			
23-10-23 07:30:00	TRUE	1820			
23-10-24 07:30:00	FALSE	0			
23-10-25 06:30:00	TRUE	2349			
23-10-26 07:30:00	FALSE	0			
23-10-27 07:30:00	TRUE	77			
23-10-28 08:00:00	TRUE	326			
23-10-29 07:30:00	TRUE	32			
23-10-30 07:30:00	TRUE	158			
23-10-31 07:30:00	TRUE	2232			
23-11-01 07:30:00	TRUE	207			
23-11-02 06:00:00	TRUE	1011			
23-11-03 07:45:00	TRUE	3252			
23-11-04 06:30:00	TRUE	15			
23-11-05 06:30:00	TRUE	2594			
23-11-06 06:30:00	TRUE	426			
23-11-07 06:30:00	TRUE	1848			
23-11-08 06:30:00	TRUE	1089			
23-11-09 06:30:00	TRUE	9			
23-11-10 08:00:00	TRUE	1775			
23-11-11 08:00:00	TRUE	2124			
23-11-12 06:00:00	TRUE	280			
23-11-13 06:00:00	TRUE	1696			
23-11-14 07:00:00	TRUE	1282			
23-11-15 07:00:00	TRUE	97			
23-11-16 06:00:00	TRUE	546			

Figure 36: Sleep data from sleep cycle application

Appendix C

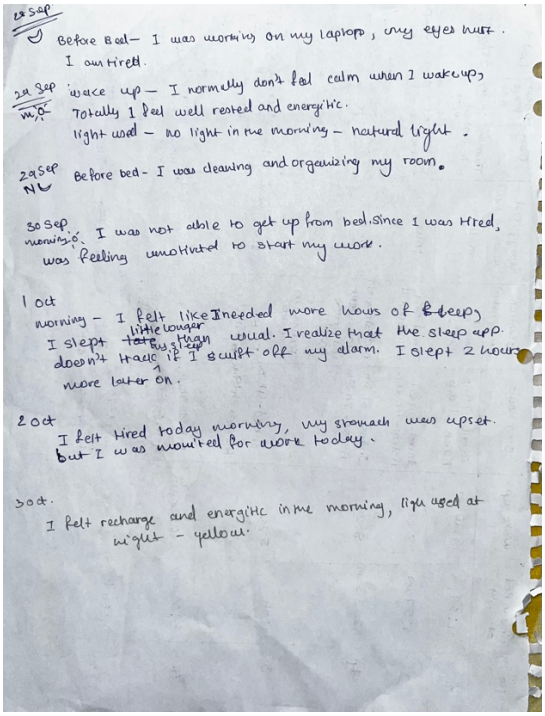
Journaling

The journaling was done from 28-09-2023 to 15-10-2023, and it was recorded and combined in Microsoft excel sheet (Appendix A)



No.	Time in Bed. at Night	Wake up.	Sleep hours.	Emotion (waking up)	Energy level. (waking up)	Day	Activity Before Bed	Date.
1	11:59 pm	7:10 am	In bed - 7h 5m Asleep - 6h 54m	Calm & happy.	medium	Thursday - Friday	studying on laptop	28/29 sept
2.	1:57 am	8:00	In bed - 5h 31 Asleep - 4h 26m	Tired and unmotivated	low	Friday - school	cleaning room	29-30 Sep
3.	12:23 am	8:29	In bed - 8h 5m Asleep - 7h 19m	my stomach was upset last ~~time~~ night I got up feeling un rested.	low	sunday monday	Mobile phone usage	1 - oct 2
3.	1:04	5:25.	In bed - 4h 20m Asleep - 3h 19m	Felt tired.	low - medium	Saturday s unday	working on laptop	30 sept - oct 1
5.	3:06 am	10:28 am	In bed - 7h 21m Asleep - 6h 6m	Felt recharged and active.	medium - high.	Sun mon - Tues	working on laptop	oct 2 - 3 oct.
6.	11:34 pm	6:54 am	In bed - 7h 20m Asleep - 6h 18m	Felt active	medium	Tues - wed	working on laptop	oct 3 - 4

Figure 37: Written records (28-09-2023 to 3-10-2023)



28 Sep
Before Bed - I was working on my laptop, my eyes hurt. I am tired.

29 Sep
Wake up - I normally don't feel calm when I wake up, Totally I feel well rested and energitic.
light used - no light in the morning - natural light.

29 Sep
Before bed - I was cleaning and organizing my room.

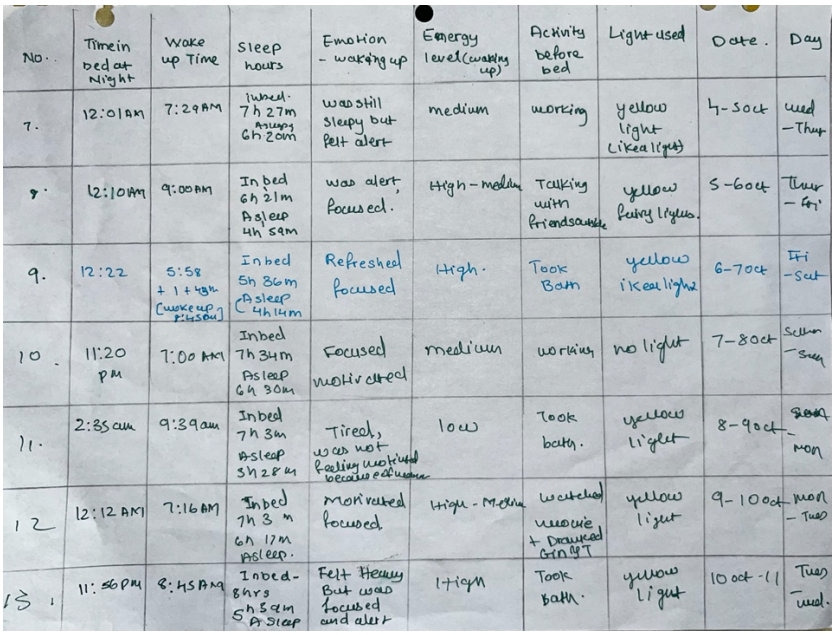
30 Sep
morning - I was not able to get up from bed. since I was tired, was feeling unmotivated to start my work.

1 oct
morning - I felt like I needed more hours of ~~sleep~~, I slept ~~little~~ longer ~~than~~ usual. I realize that the sleep app ~~does~~ doesn't track if I switch off my alarm. I slept 2 hours more later on.

2 oct
I felt tired today morning, my stomach was upset. but I was motivated for work today.

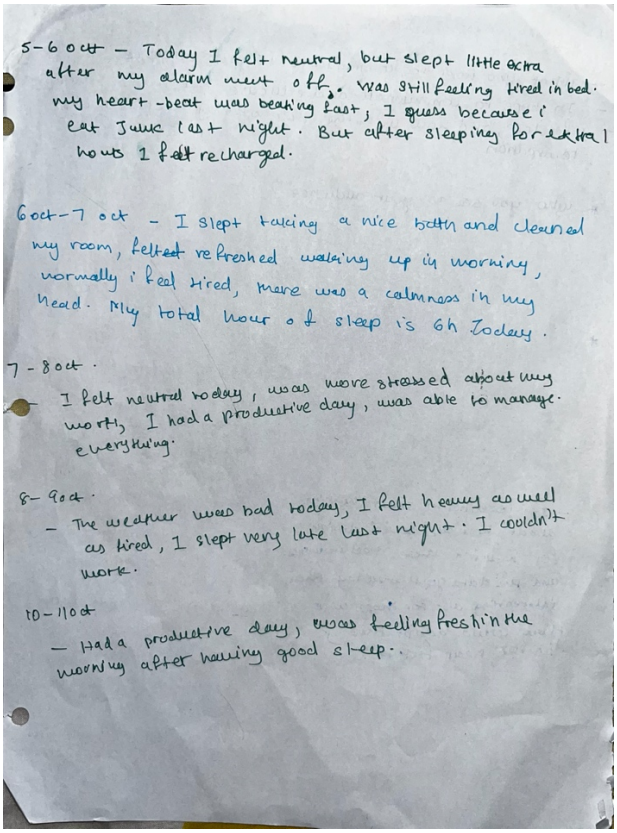
3 oct.
I felt recharge and energitic in the morning, light used at night - yellow.

Figure 38: Written notes (28-09-2023 to 3-10-2023)



No.	Time in bed at Night	Wake up Time	Sleep hours	Emotion - waking up	Energy level (waking up)	Activity before bed	Light used	Date.	Day
7.	12:01AM	7:29AM	Inbed. 7h 27m Asleep 6h 20m	was Still Sleepy but felt alert	medium	working	yellow light (like a light)	4-5oct	wed - Thur
8.	12:10AM	9:00AM	In bed 6h 21m Asleep 4h 59m	was alert, focused.	High - medium	Talking with friends	yellow feeling lights.	5-6oct	Thur - Fri
9.	12:22	5:58 + 1 + 43m [Woke up 5:43am]	In bed 5h 36m Asleep 4h 14m	Refreshed focused	High.	Took Bath	yellow like a light	6-7oct	Fri - Sat
10.	11:20 PM	7:00 AM	Inbed 7h 34m Asleep 6h 30m	Focused motivated	medium	working	no light	7-8oct	Satur - Sun
11.	2:35am	9:39am	Inbed 7h 3m Asleep 5h 28m	Tired, was not feeling motivated because of lack	low	Took bath.	yellow light	8-9oct	Sun - Mon
12	12:12 AM	7:16AM	Inbed 7h 3 m 6h 17m asleep.	Motivated focused	High - Medium	watched movie + Drawked GIN gT	yellow light	9-10oct	Mon - Tues
13.	11:56PM	8:45AM	Inbed - 8hrs 5h 54m Asleep	Felt Heavy But was focused and alert	High	Took bath.	yellow Light	10oct - 11	Tues - wed.

Figure 39: Written records (4-10-2023 to 10-10-2023)



5-6 oct – Today I felt neutral, but slept little extra after my alarm went off. Was still feeling tired in bed. my heart-beat was beating fast, I guess because i eat Junk last night. But after sleeping for extra 1 hours I felt recharged.

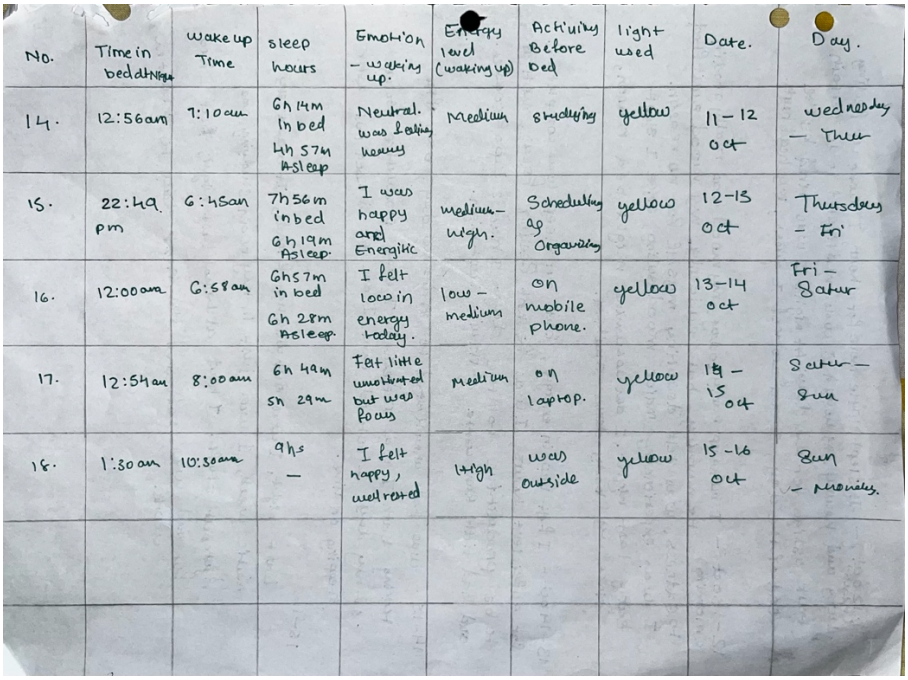
6oct-7 oct – I slept taking a nice bath and cleaned my room, felt refreshed waking up in morning, normally i feel tired, there was a calmness in my head. My total hour of sleep is 6h Today.

7-8oct.
– I felt neutral today, was more stressed about my work, I had a productive day, was able to manage everything.

8-9oct.
– The weather was bad today, I felt heavy as well as tired, I slept very late last night. I couldn't work.

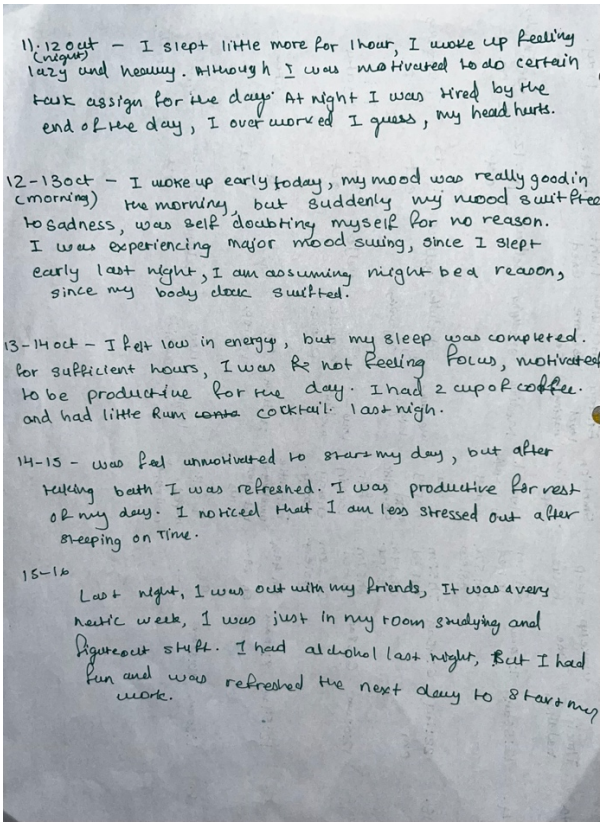
10-11oct
– Had a productive day, was feeling fresh in the morning after having good sleep.

Figure 40: Written notes (5-10-2023 to 10-10-2023)



No.	Time in bed (Night)	Wake up Time	sleep hours	Emotion - waking up.	Energy level (waking up)	Activity Before bed	light used	Date.	Day.
14.	12:56am	7:10am	6h 14m in bed 4h 57m Asleep	Neutral. was Lazy, heavy	Medium	studying	yellow	11-12 Oct	wednesday - Thur
15.	22:49 pm	6:45am	7h 56m in bed 6h 19m Asleep.	I was happy and Energitic	medium-high.	Scheduling ag Organizing	yellow	12-13 Oct	Thursday - Fri
16.	12:00am	6:58am	6h 57m in bed 6h 28m Asleep.	I felt loco in energy today.	low - medium	on mobile phone.	yellow	13-14 oct	Fri - Satur
17.	12:54am	8:00am	6h 49m 5h 29m	Fat little unmotivated but was focus	Medium	on laptop.	yellow	14 - 15 Oct	Satur - Sun
18.	1:30am	10:30am	9h= -	I felt happy, well rested	High	was outside	yellow	15-16 Oct	Sun - Monday.

Figure 41: Written records (11-10-2023 to 15-10-2023)



11-12 Oct - I slept little more for 1hour, I woke up feeling (night) lazy and heavy. Although I was motivated to do certain task assign for the days. At night I was tired by the end of the day, I over worked I guess, my head hurts.

12-13 Oct - I woke up early today, my mood was really good in (morning) the morning, but suddenly my mood suit-free to sadness, was self doubting myself for no reason. I was experiencing major mood swing, since I slept early last night, I am assuming night bed reason, since my body clock suitted.

13-14 oct - I felt low in energy, but my sleep was completed. for sufficient hours, I was Re not feeling focus, motivated to be productive for the day. I had 2 cup of coffee. and had little Rum contra cocktail last nigh.

14-15 - was feel unmotivated to start my day, but after feeling bath I was refreshed. I was productive for rest of my day. I noticed that I am less stressed out after sleeping on time.

15-16
Last night, I was out with my friends, It was a very hectic week, I was just in my room studying and figure out stuff. I had alcohol last night, But I had fun and was refreshed the next day to start my work.

Figure 42: Written notes (11-10-2023 to 15-10-2023)

Appendix D

Fabrication and Materials used for Prototypes

Figure 43: Carboard Tube (used for fabrication)

Figure 44: Heavy-duty carboard cuts for final prototype fabrication

Figure 45: First exploration for circular fabrication using 3D printing

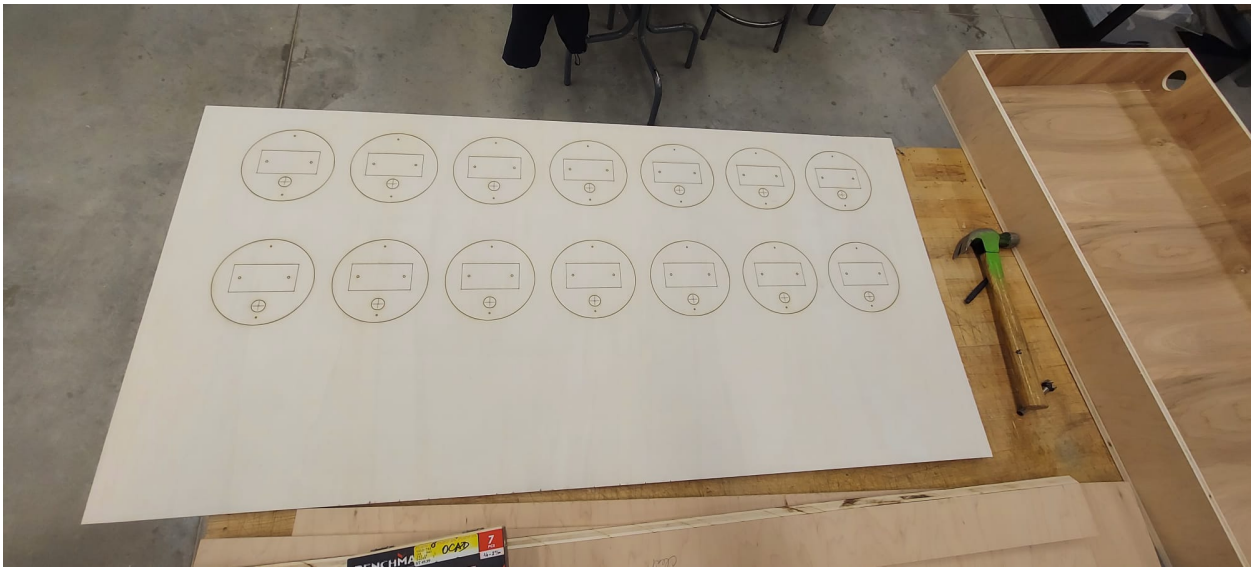


Figure 46: Final prototype lid for the box with engraving for measurement and position purpose

Figure 47: Final prototype fabrication (box)

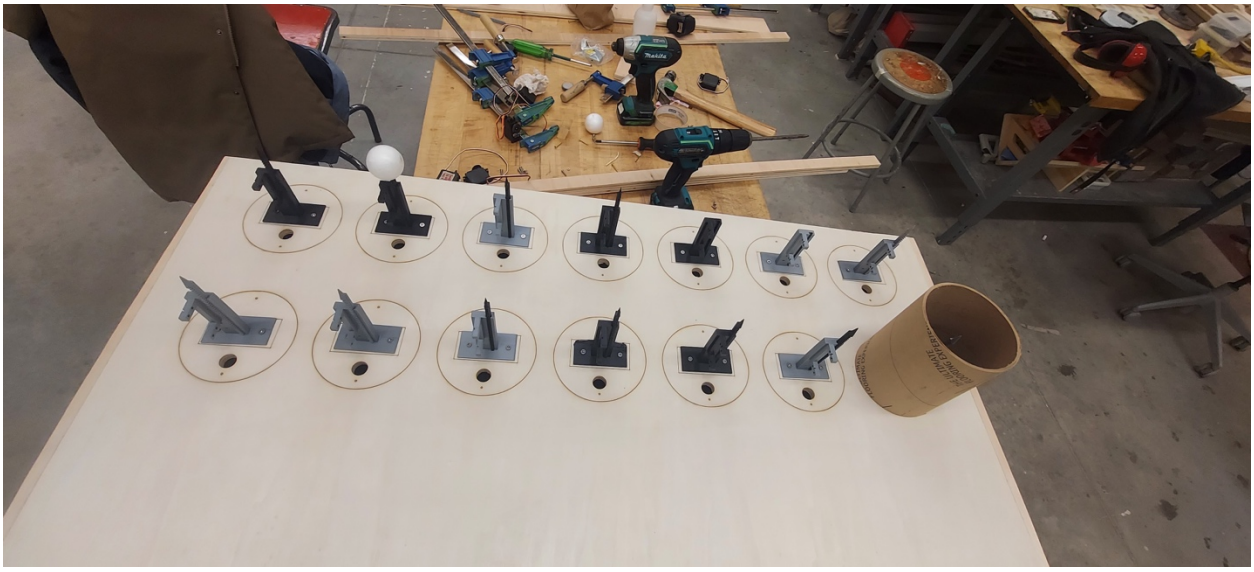


Figure 48: Linear servo actuator attached to the box

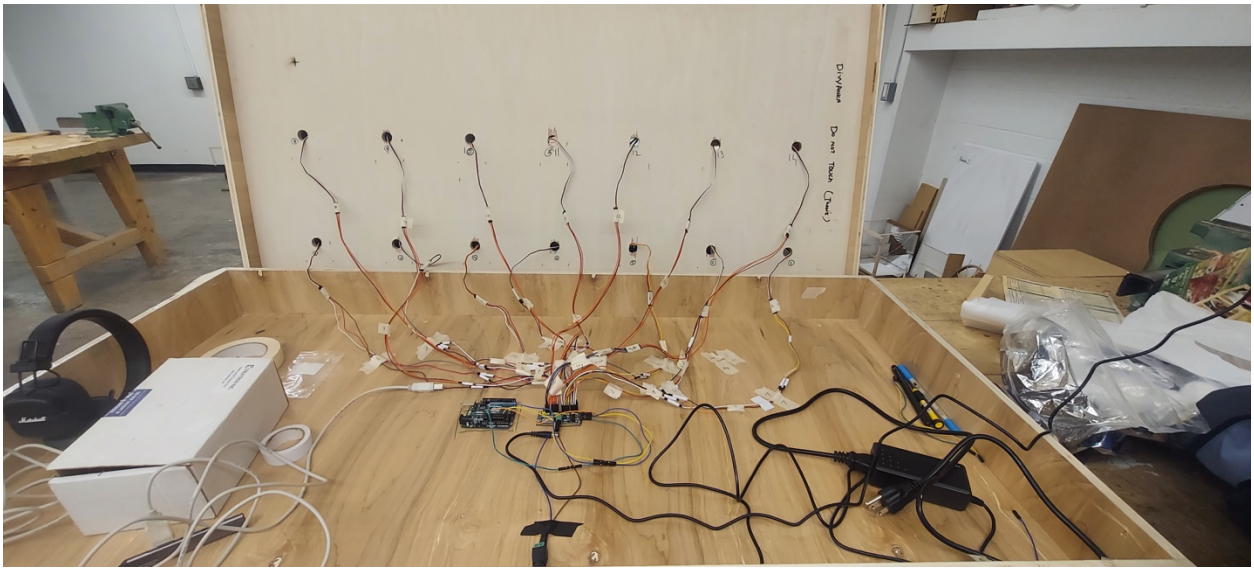


Figure 49: Electronics inside the box with wires, servo, Arduino uno, and pca9685

Figure 50: 3D components attached to the box with servos

Appendix E

Reflection notes from the exhibition, where visitors were invited to share their experiences by writing their impressions on cards located in the exhibition space.

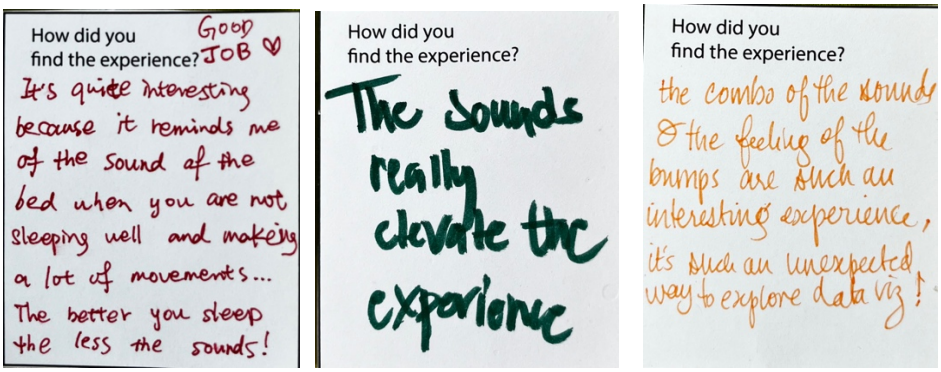


Figure 51: Reflection notes for sound (Left, Middle, Right)

The sound element was not initially planned, but through conversations with visitors, I discovered that many people associated the sounds with white noise often used to aid sleep. One person compared the noise to the creaking and shifting experienced during restless nights, which was a fascinating insight. Overall, the sound created a calming atmosphere and enhanced the experience by providing a more engaging experience with the bumps.

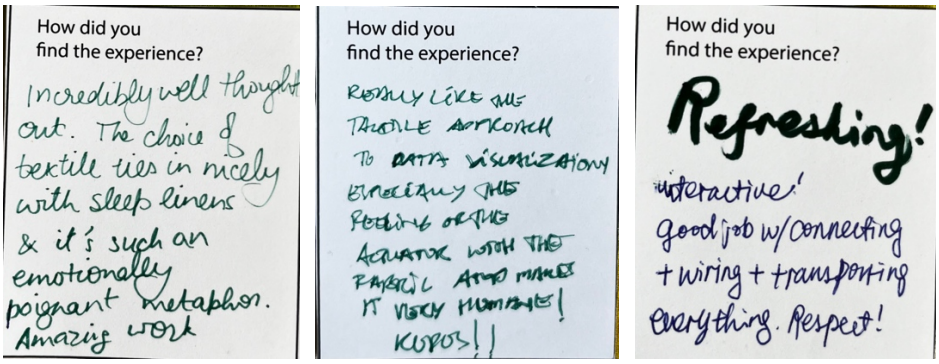


Figure 52: Reflection notes for fabrication (Left, Middle, Right)

In the fabrication process, the use of fabric added a human touch to the experience, as one individual remarked that the choice of textile aligned well with the theme of sleep. People appreciated the softness of the fabric, which they associated with bedsheets and blankets.

Through conversations, I found that many individuals enjoyed the aesthetic appeal of the engravings and were intrigued by the legend, which helped them understand the different sleep ranges.

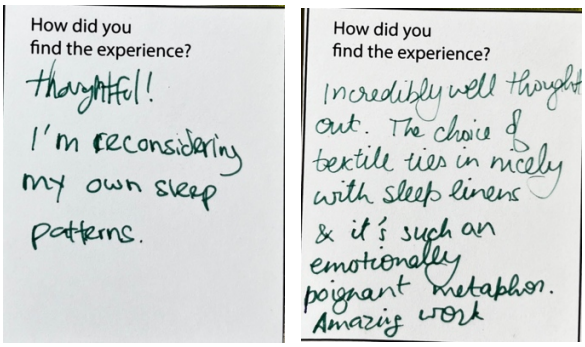
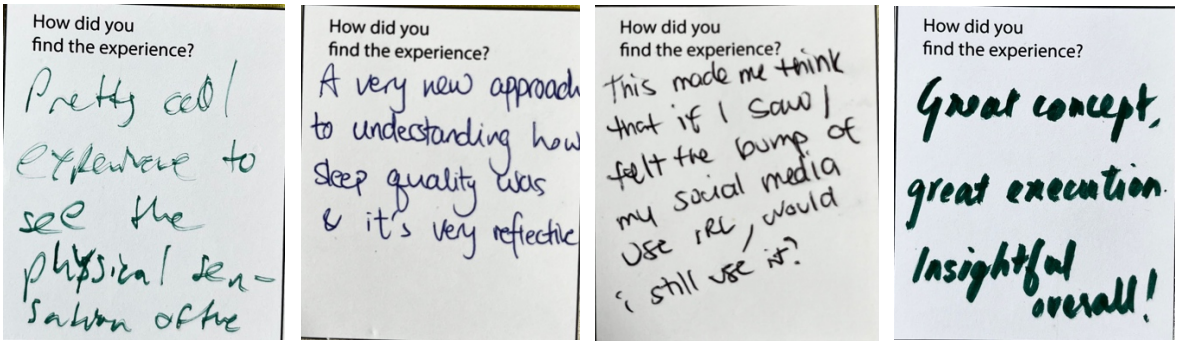


Figure 53: Reflection notes for impact of the experience (Left And Right)

While engaging with the data through touch, visitors could distinguish between good and bad sleep days and expressed curiosity about the reasons behind my poor sleep on certain days. This prompted them to empathize with my experiences and reflect on their own sleep patterns after viewing the visualizations. One visitor experienced a strong emotional response and closed her eyes, expressing that the bumps made her feel alive, comparing the experience to the sensation of a heartbeat.



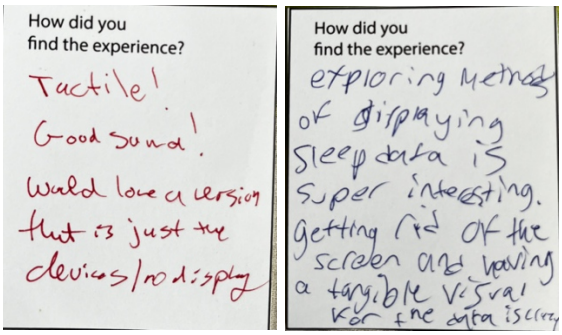


Figure 54: Reflection notes of positive feedback of overall visualization

Appendix F

Code for the servo motor. This is a self-modified code from Adafruit example file for all 14 servo motors.

First 7 servos

```
/*************************************************
  This is an example for our Adafruit 16-channel PWM & Servo driver
  Servo test - this will drive 8 servos, one after the other on the
  first 8 pins of the PCA9685

  Pick one up today in the adafruit shop!
  ------> http://www.adafruit.com/products/815

  These drivers use I2C to communicate, 2 pins are required to
  interface.

  Adafruit invests time and resources providing this open-source code,
  please support Adafruit and open-source hardware by purchasing
  products from Adafruit!

  Written by Limor Fried/Ladyada for Adafruit Industries.
  BSD license, all text above must be included in any redistribution.
 *************************************************/

#include <Wire.h>
#include <Adafruit_PWMServoDriver.h>

#define SERVOMIN 150  // this is the 'minimum' pulse length count (out of 4096)
#define SERVOMAX 600  // this is the 'maximum' pulse length count (out of 4096)


uint8_t servonum = 0;

void setup() {
  Serial.begin(9600);
  Serial.println("6 channel Servo test!");

  pwm.begin();

  pwm.setPWMFreq(60);  // Analog servos run at ~60 Hz updates

}

void loop() {
  for (int angle = 0; angle <= 10; angle += 1) {
    delay(50);
```

```
    pwm.setPWM(0, 0, angleToPulse(angle * 4));    //0 to 40
    pwm.setPWM(1, 0, angleToPulse(angle * 6));   //0 to 60
    pwm.setPWM(2, 0, angleToPulse(angle * 4));   //0 to 40
    pwm.setPWM(3, 0, angleToPulse(angle * 6));  //0 to 60
    pwm.setPWM(4, 0, angleToPulse(angle * 16)); //0 to 160
    pwm.setPWM(5, 0, angleToPulse(angle * 16)); //0 to 160
    pwm.setPWM(6, 0, angleToPulse(angle * 8));   //0 to 70
    delay(100);                             //time duration
  }
  for (int angle = 10; angle >= 0; angle -= 1) {
    delay(50);
    pwm.setPWM(0, 0, angleToPulse(angle * 4));    //0 to 20
    pwm.setPWM(1, 0, angleToPulse(angle * 6));   //0 to 40
    pwm.setPWM(2, 0, angleToPulse(angle * 4));   //0 to 20
    pwm.setPWM(3, 0, angleToPulse(angle * 6));  //0 to 40
    pwm.setPWM(4, 0, angleToPulse(angle * 16));    //0 to 140
    pwm.setPWM(5, 0, angleToPulse(angle * 16));    //0 to 140
    pwm.setPWM(6, 0, angleToPulse(angle * 8));   //0 to 40
    delay(100);                             //time duration
  }
}

/*
 * angleToPulse (int ang)
 * gets angle in degree and returns the pulse width
 */
int angleToPulse(int ang) {
  int pulse = map(ang, 0, 180, SERVOMIN, SERVOMAX);  // map angle of 0 to 180 to Servo min and Servo max
  Serial.print("Angle: ");
  Serial.print(ang);
  Serial.print(" pulse: ");
  Serial.println(pulse);
  return pulse;
}
```

Rest seven servos

```
/*************************************************
  This is an example for our Adafruit 16-channel PWM & Servo driver
  Servo test - this will drive 8 servos, one after the other on the
  first 8 pins of the PCA9685

  Pick one up today in the adafruit shop!
  ------> http://www.adafruit.com/products/815

  These drivers use I2C to communicate, 2 pins are required to
  interface.
```

```
  Adafruit invests time and resources providing this open-source code,
  please support Adafruit and open-source hardware by purchasing
  products from Adafruit!

  Written by Limor Fried/Ladyada for Adafruit Industries.
  BSD license, all text above must be included in any redistribution.
 ************************************************/

#include <Wire.h>
#include <Adafruit_PWMServoDriver.h>

// called this way, it uses the default address 0x40
Adafruit_PWMServoDriver pwm = Adafruit_PWMServoDriver();

#define SERVOMIN 150  // this is the 'minimum' pulse length count (out of 4096)
#define SERVOMAX 600  // this is the 'maximum' pulse length count (out of 4096)

uint8_t servonum = 0;
void setup() {
  Serial.begin(9600);
  Serial.println("6 channel Servo test!");

  pwm.begin();

  pwm.setPWMFreq(60);  // Analog servos run at ~60 Hz updates


}

void loop() {
  for (int angle = 0; angle <= 10; angle += 1) {
    delay(50);
    pwm.setPWM(0, 0, angleToPulse(angle * 8));    //0 to 80
    pwm.setPWM(1, 0, angleToPulse(angle * 12));   //0 to 120
    pwm.setPWM(2, 0, angleToPulse(angle * 2));   //0 to 20
    pwm.setPWM(3, 0, angleToPulse(angle * 6));  //0 to 60
    pwm.setPWM(4, 0, angleToPulse(angle * 9)); //0 to 90
    pwm.setPWM(5, 0, angleToPulse(angle * 7)); //0 to 70
    pwm.setPWM(6, 0, angleToPulse(angle * 8));   //0 to 80
    delay(100);                                 //time duration
  }
  for (int angle = 10; angle >= 0; angle -= 1) {
    delay(50);
    pwm.setPWM(0, 0, angleToPulse(angle * 8));    //0 to 80
    pwm.setPWM(1, 0, angleToPulse(angle * 12));   //0 to 120
    pwm.setPWM(2, 0, angleToPulse(angle * 2));   //0 to 20
    pwm.setPWM(3, 0, angleToPulse(angle * 6));  //0 to 60
```

```
    pwm.setPWM(4, 0, angleToPulse(angle * 9));    //0 to 90
    pwm.setPWM(5, 0, angleToPulse(angle * 7));    //0 to 70
    pwm.setPWM(6, 0, angleToPulse(angle * 8));   //0 to 80
    delay(100);                                  //time duration
  }
}

/*
 * angleToPulse(int ang)
 * gets angle in degree and returns the pulse width
 * also prints the value on seial monitor
 */
int angleToPulse(int ang) {
  int pulse = map(ang, 0, 180, SERVOMIN, SERVOMAX);  // map angle of 0 to 180 to Servo min and Servo max
  Serial.print("Angle: ");
  Serial.print(ang);
  Serial.print(" pulse: ");
  Serial.println(pulse);
  return pulse;
}
```

Diagram for servo motors. This diagram was taken from the Adafruit website for reference of 16 servo motors (Have permission)

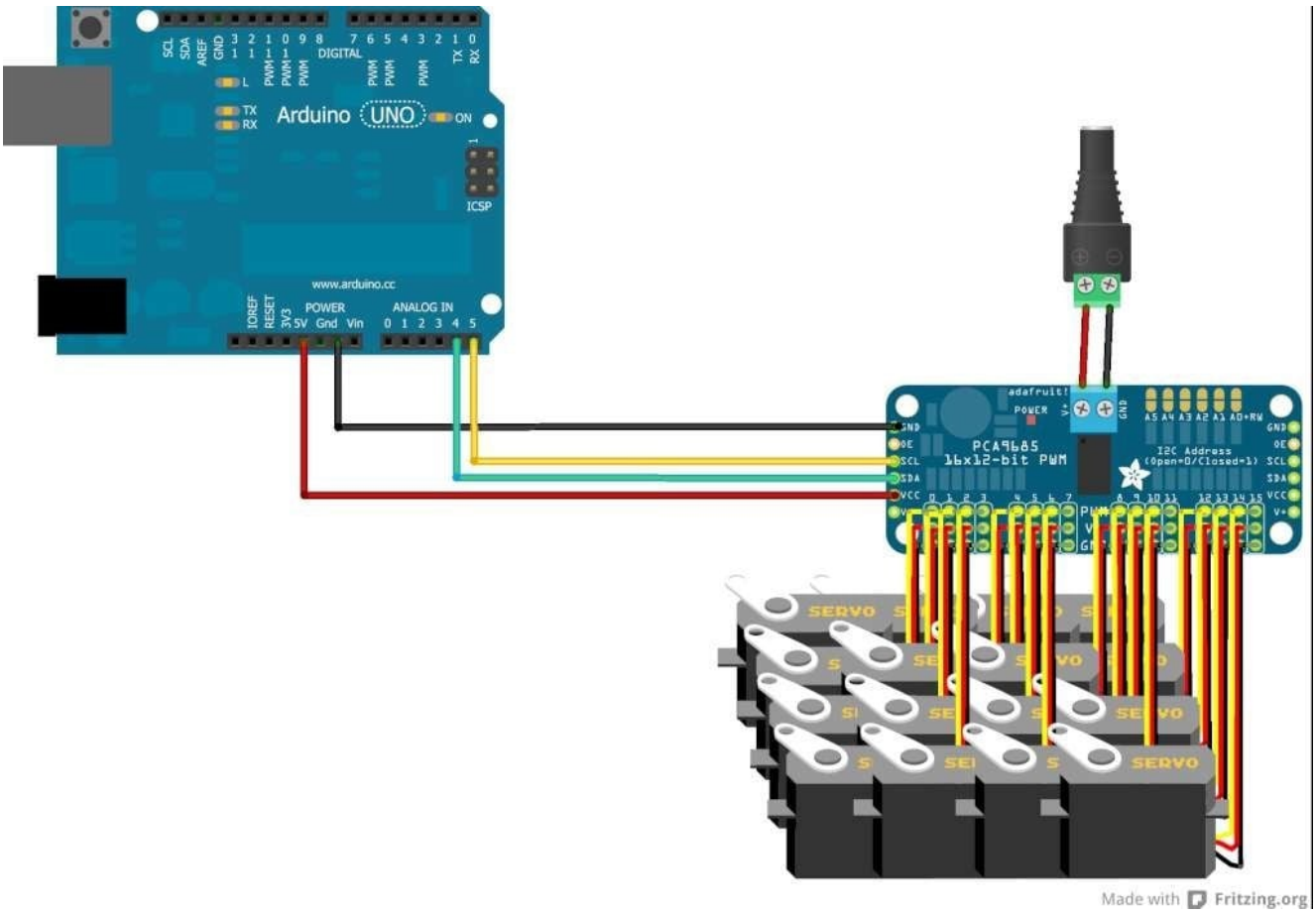


Figure 55: Diagram for 16 servo motors (Adafruit) Earl, Bill. “Adafruit PCA9685 16-Channel Servo Driver.” Adafruit Learning System. Accessed April 18, 2024. https://learn.adafruit.com/16-channel-pwm-servo-driver?view=all.