“I Keep Coming Back to My Phone”: **An Ambient, Reflective and Tangible Approach Towards Digital Wellbeing**

Designing a Ubiquitous Artifact for Enhancing the Digital Wellbeing of Smartphone Users

Suhaib Aslam

In supervision of dr. Rúben Gouveia (Interaction Design Group), dr.ir. Edwin Dertien (Robotics and Mechatronics Group), dr. Jelle van Dijk (Human Centered Design Group) & prof.dr. Dirk Heylen (Human-Media Interaction Group)

Master Thesis (July 2020) | MSc Interaction Technology | University of Twente

0 Preface

ABSTRACT

Uncontrolled, brief smartphone revisitations are a prevalent issue. Much of typical smartphone usage is shown to consist of short, repetitive revisitation habits which can have negative consequences for mental health. Despite its prevalence, uncontrolled revisitation remains largely untapped in digital wellbeing interventions. This is the case despite the degree of control over device usage forming the centrality of digital wellbeing. To fill this gap, this project investigated how to support smartphone users in becoming more in control of their revisitation behaviors. To that end, it first explored how to design digital wellbeing artifacts that can help smartphone users take better control over their device usage. This led to five design principles that entailed designing for: revisitation feedback, lived experience, being reflective, being tangible and being ambient. These principles were then embedded in the "Revisitation Reflector", a digital wellbeing artifact designed to help users become aware of and reflect on their smartphone revisitation patterns. Fully functioning prototypes of this artifact were subsequently deployed in the field. Based on the field study, a number of findings were uncovered regarding the sensemaking associated with the device, and regarding the role, design and impact of the device. The findings ranged from how users appropriated the device to themselves and how they interpreted its feedback, to how it evoked inquiry and reflection in users' everyday lives, and how its tangible medium and revisitation metric were perceived. Together, these findings provide guidelines and future opportunities on designing for digital wellbeing through employing the untapped, pertinent metric of revisitation; and through an ambient, reflective and tangible medium that has so far not been widely adopted for the digital wellbeing domain. The project will be completely open sourced to help researchers and designers create and research their own digital wellbeing artifacts. It aims to spark a new narrative for what it means to design for digital wellbeing.

PROBLEM SPACE, GUIDING QUESTIONS, CONTRIBUTIONS AND MAIN RESEARCH QUESTION

It is clear that digital devices, particularly, smartphones are becoming increasingly pervasive. This pervasiveness has been met with increasing impulsiveness in the habits that characterize how smartphone users typically interact with their phones. This can reach levels where some users might stop feeling in control of their digital behaviors. Such control forms the cornerstone of the emerging trend of digital wellbeing, "...the user's feeling of control over device use is central to digital wellbeing..." [66]. Thus, supporting users in this regard presents the

opportunity to design, develop and test digital wellbeing tools that help them achieve greater control over their device usage.

One such smartphone usage habit that is directly linked to control, is quite prevalent, can have dire consequences, and is underutilized by current digital wellbeing interventions. That habit is revisitation. Revisitation is when one revisits (or comes back to) one's phone. Revisitation is a really prevalent smartphone usage habit. A common theme in unwanted smartphone habits is that of unintended, impulsive and/or continuous checking of smartphones [27,52,81]. For example, a smartphone user might repeatedly and automatically be unlocking their phone to check their screen for notifications [81]. These short, frequent revisitations repeat over time and form a substantial part of smartphone usage–as shown by three longitudinal studies (N=136, N=15, N=12) [81].

Research done by a popular digital wellbeing app found out that most people check their phones, on average, 58 times a day. 70% of these use sessions last less than two minutes, and 25% last two to ten minutes (N=11,000) [112]. Their results show that indeed most of smartphone usage consists of repetitive checking behaviors, and that 95% of those checks are very short (less than 10 minutes). Similarly, a study by Yan et al. shows how the biggest proportion of smartphone usage comprises brief checking sessions each of which lasts not more than 30 seconds [110]. Falaki et al. have also reported a prevalence of short bursts of application usage (10-250 seconds) [32] and similarly Böhmer et al.'s study has shown how the average application session is quite brief (only lasting 72 seconds) [14].

Another three-month long longitudinal study (N=165) showed how smartphone usage consists mostly of sessions of various revisitation categories [52]. They come up with a model (based on app revisitations) that is able to explain 92% of variability of smartphone use [52]. Thereby they show how representative revisitation is of typical phone usage [52]. Overall, based on their findings, they call on researchers for using and viewing revisitation as a first step in the direction of "addressing the more fundamental driving forces that shape our use of smartphones, and indeed of technology in general" [52]. Consequently, revisitation does indeed form a fundamental force also regarding the digital wellbeing of smartphone users. This is because it influences their feeling and actual level of control over device usage (which forms the centrality of digital wellbeing from the aforementioned definition); and because it encompasses a major part of their smartphone experience and habits.

Despite its relevance, prevalence and strong link to digital wellbeing, revisitation is underutilized by current digital wellbeing interventions. Based on meta-analyses, it is clear that current interventions do not have revisitation as an explicit goal or something that users could get feedback on. In a review of 367 apps for "digital self-control" [67], there was no app that utilized revisitation. None of them had revisitation as their goal or as something users could track or get insights and feedback on. Same holds true for the 42 apps that were analyzed in another review [74]. There was no consideration for the dimension of users coming back to their phone and how long they take before doing so. This is an underexplored opportunity, as revisitation can be a highly common habit that is directly linked to the 'control' aspects of digital wellbeing.

By now, based on the related work presented so far, three things stand out. Firstly, revisitation is a highly prevalent smartphone habit that forms a substantial part of usage sessions. Secondly, revisitation and checking habits are quite relevant to consider as they can affect a user's control over smartphone usage (digital wellbeing) and can have adverse psychological, social, physical and health-related effects. Thirdly, revisitation is highly underutilized in current digital wellbeing interventions. Overall, then, there is a significant opportunity to have revisitation as a focus within digital wellbeing applications; not only because of how common it is, but also because of how impactful focusing on it can potentially be.

These findings and points are precisely why these themes of control over smartphone usage (the foundation of digital wellbeing) and of revisitation form the basis of this project's problem space. They inherently shape smartphone users' digital wellbeing. In order to address this problem space through designing, developing and testing a concrete digital wellbeing artifact, the following **guiding questions (GQs)** were constructed to guide this project and its activities:

(GQ1) What principles for designing for digital wellbeing can be used to design an artifact to help smartphone users gain greater control over their device usage?

- **(GQ1.1)** What can the relevant, novel design principles for designing for control over device usage be?
- **(GQ1.2)** What are the specific values that can be prioritized from the chosen design principles?
- **(GQ1.3)** What concept can be designed and implemented based on the prioritized values?

(GQ2) What are the results of conducting a field study on an artifact that has been based on the identified design principles?

- **(GQ2.1)** How do users make sense of such an artifact's feedback?
- **(GQ2.2)** What do they think of the role of the artifact and its effect on smartphone usage?
- **(GQ2.3)** What are their impressions of the artifact's design?

(GQ3) What implications can be derived from the field study's findings?

- **(GQ3.1)** What do the findings mean when using them to reflect on the artifact and on the field study?
- **(GQ3.2)** What do they mean when reflecting on the chosen design principles and on designing for digital wellbeing in general?
- **(GQ3.3)** Could additional opportunities for designing for digital wellbeing be derived from literature?

Due to the qualitative, 'designerly' nature of the project, these questions are by design meant to be explorative and generative. As such, the three primary guiding questions (GQ1, GQ2 and GQ3) can be viewed more as general research directions (*not* research questions) to help answer the main research question that is given below. Their sub-questions then help formalize what the exact investigation approach was. This way of abstract formulation of questions was also chosen because the entire project is centered around designing for greater control over smartphone usage. And as has already been discussed, revisitation can have a major impact on this degree of control. Incorporating this metric in such a project is also what makes the defined questions explorative. The nature of revisitation is that of a dimension which so far is not typically presented to smartphone users themselves (in an ad hoc manner). It has not been used as a dimension that users can base their digital wellbeing goals on or as a dimension that users can track and get feedback on.

As such, incorporating it as a trackable metric and as a feedback metric in an intervention is by nature poised to be highly explorative. To enable this, the chosen guiding questions were meant to allow bottom-up emergence of insights regarding how to design an artifact for control over device usage; as well as regarding what the outcomes and implications of field testing such an artifact are. These guiding questions are quite expected of and obvious from the project's process but are explicitly included here to serve as reading and narrative aids. They explicate which questions different parts of the thesis address and were inspired by.

All in all, then, this project aims to make three main contributions tied to the aforementioned guiding questions:

1. Synthesizing design principles for supporting users to be more in control over their smartphone use, as well as designing and developing an artifact based on those principles.
2. Distilling findings on how users perceive such an artifact and how it affects their smartphone use, through field testing it.
3. Generating guidelines and implications on designing artifacts for digital wellbeing in general and using this project's approach in particular.

As will become clearer reading along the rest of the dissertation, these contributions were aimed to be made by employing the untapped, pertinent metric of revisitation; which demands a different design material that has so far not been widely adopted for the digital wellbeing domain. One that is reflective, ambient and tangible and that is focused on the lived experience of smartphone users. Together this metric and medium are geared towards helping smartphone users feel and be more in control over their smartphone usage. This culminates into the **main research question** that this project aims to answer:

What effect does giving users ambient, tangible and reflective revisitation feedback have on them and their smartphone usage?

STRUCTURE OF THIS DISSERTATION AND ITS LINK TO THE GUIDING QUESTIONS

The dissertation is divided into four parts, the **first three** of which form the core work of this project.

Part one starts with investigating digital wellbeing; what it is, why it matters and what has already been done regarding it. It then goes on to consider revisitation and its link to digital wellbeing (and control over smartphone usage). The relevance, prevalence and underutilization of this metric are considered. Finally, the foundations of this project are laid down in the form of the five opportunistic design principles for creating useful, novel interventions for digital wellbeing. These principles address **GQ1.1** ("What can the relevant, novel design principles for designing for control over device usage be?"). Besides reviewing these principles in a broad way based on literature, this part also prioritizes and filters out specific values from the five principles. These form the prioritized values to be actually embedded into the digital wellbeing artifact to be designed. These prioritized values help answer **GQ1.2** ("What are the specific values that can be prioritized from the chosen design principles?").

Part two is where the most crucial aspects of the project lie. It considers the case study of the "Revisitation Reflector", a digital wellbeing artifact that is based on the revisitation metric. In this part the Revisitation Reflector's concept and its implementation are discussed, together with an overview of how the prioritized values were embedded in the Revisitation Reflector; these address **GQ1.3** ("What concept can be designed and implemented based on the prioritized values?"). Next, this part considers a field study on the Revisitation Reflector. The procedure of and findings from the study are presented; which together address **GQ2.1** ("How do users make sense of such an artifact's feedback?"), **GQ2.2** ("What do they think of the role of the artifact and its effect on smartphone usage?") and **GQ2.3** ("What are their impressions of the artifact's design?").

Part three takes a step back and looks at the project from a zoomed-out perspective. It looks at what general insights and guidelines can be derived from the project, as well as the limitations and future opportunities at hand. This is done, firstly, by using the field study's findings from the previous part as a lens for having a

reflective discussion on the artifact and the study. This discussion helps answer **GQ3.1** ("What do the findings mean when using them to reflect on the artifact and on the field study?"). Subsequently, the findings are used as a lens to reflect on the five chosen design principles and on designing for digital wellbeing in general, through which **GQ3.2** ("What do they mean when reflecting on the chosen design principles and on designing for digital wellbeing in general?") is addressed.

Part four consists of supplementary material. Besides providing appendices and references, it reconsiders related literature. It does that with a specific focus on uncovering additional future opportunities regarding digital wellbeing based on two prominent themes that arose from the project. This part, therefore, helps answer **GQ3.3** ("Could additional opportunities for designing for digital wellbeing be derived from literature?").

The **main research question** ("What effect does giving users ambient, tangible and reflective revisitation feedback have on them and their smartphone usage?") is, then, primarily answered by **parts two and three**.

TABLE OF CONTENTS

Part I: Digital wellbeing and designing for it

This part aims to consider what forms the problem and solution space for this project. It focuses on what aspects of digital wellbeing to design for and why they matter. It lays the focus on designing for control over smartphone usage for the rest of the dissertation. It distills the main insights from related work on digital wellbeing, on control over smartphone usage and on relevant, novel interaction technologies for this domain. These insights culminate into a set of five opportunistic design principles for creating useful, novel interventions for digital wellbeing. These form the ethos of the artifact that is designed and tested later on in the dissertation; and the ethos that forms the basis of guidelines that emerge from the project. These principles address **GQ1.1 ("What can the relevant, novel design principles for designing for control over device usage be?").** Besides reviewing these principles in a broad way based on literature, this part also prioritizes and filters out specific values from the five principles. These form the prioritized values to be actually embedded into the digital wellbeing artifact to be designed. These prioritized values help answer **GQ1.2 ("What are the specific values that can be prioritized from the chosen design principles?").**

All in all, this part considers the themes of:

- Importance, relevance and current state of digital wellbeing
- Being in control of smartphone usage, revisitation habits of smartphone users and the link between the two
- Five opportunistic principles for designing useful, novel digital wellbeing interventions

1

Relevance and the Current State of Digital Wellbeing

Digital wellbeing is intended to inform the problem space of this project. Digital wellbeing is an emerging trend that is gaining increasing importance both in research and in industry. Digital devices are becoming increasingly ubiquitous, and the boundary between the digital and real world is becoming increasingly blurred. This blurring has begun to reach extents at which some individuals no longer feel in control of their digital behaviors. Through giving users the right tools, they can be empowered to take greater care of their digital wellbeing. But what is digital wellbeing? Why does it matter? What has already been done to counter it and what else could work? This chapter is going to try to provide some answers to these questions to make designing for digital wellbeing more informed and sensible.

DEFINING DIGITAL WELLBEING

An *informal* meta-analysis of the 22 position papers for the designing for digital wellbeing workshop at the Computer Human Interaction (CHI) 2019 Conference [62] provides a sensible starting point for defining digital wellbeing (the meta-analysis is by one of the organizers of the workshop). Fundamentally the meta-analysis makes the point that the entire group of researchers working on the topic (a group of 32 individuals) called for having a definition that goes beyond the current synonymity of digital wellbeing with mere screen time reduction or management: "All participants wanted to move beyond a focus on screen time" [62]. However, there was no firm consensus on what this definition could precisely be.

The meta-analysis draws a distinction between two possible directions for such a definition: A narrow one and a broad one [62]. The narrow one is aligned with the definition that views digital wellbeing as the degree to which a user perceives their digital device usage to be well-aligned with their personal, long-term goals [66]; "That is, the user's feeling of control over device use is central to digital wellbeing, with the added constraint that use must be well aligned with their long-term goals." [66]. This narrow definition direction is also aligned with how Google frames digital wellbeing in its recently launched digital wellbeing initiative: "We believe technology

should improve life, not distract from it. We're committed to giving everyone the tools they need to develop their own sense of digital wellbeing." [113]. This narrow definition direction has to do with a user's subjective, phenomenological alignment between their personal digital wellbeing goals and their digital behaviors.

On the other hand, the broad definition direction is aligned with the definition that views digital wellbeing as something that constitutes a myriad of quite broad aspects and domains like psychological wellbeing, life satisfaction, education, health, environment, safety, community etc. [90]. The meta-analysis highlights how both these narrow and broad definition directions have their own challenges. The narrow one neglects aspects like cyber safety, climate change, social injustice etc., whilst the broad one might be too impractical to bridge such a huge set of concerns with technology [62]. Nonetheless, ultimately it is emphasized that both definitions have value, and that it is most crucial that one of the two is explicitly chosen.

There is also another set of dimensions that can be used to categorize various digital wellbeing approaches: (i) what is affected, (ii) in what direction and (iii) for whom [62]. Regarding (i), subjective wellbeing was the most common effect that was investigated (other effects included physical health, work engagement, self-transcendence etc.) [62]. Subjective wellbeing has to do with how an individual cognitively and affectively evaluates their life [62]. Regarding (ii), most of the papers were about a "net increase" approach to wellbeing, where the focus was on balancing the costs and benefits of digital technology [62]. There were many as well that emphasized the need to go beyond merely reducing the harm of technology overuse, and to focus on ways of increasing wellbeing [62]. Finally, regarding (iii), almost all of the papers focused on an individual technology user as their social unit of analysis [62]. Specifically, it was often about addressing individual wellbeing, self-control and/or self-improvement.

This project takes the narrow definition of digital wellbeing as its starting point, manifesting how digital technology can often be designed to capture a user's attention for purposes that lead to a lack of control over device usage. It also embraces the ethos of incorporating users' subjective wellbeing in the process and going beyond mere screen time and beyond simply reducing harms of technology overuse. The rest of the specifics regarding the definition will still stay open for emergence from the design principles that are going to be considered later on in the dissertation.

RELEVANCE OF DIGITAL WELLBEING

Now that digital wellbeing has been defined a bit, it is important to discuss why it matters in the first place. Pew research center has conducted in-depth research on the matter in collaboration with academic experts, and its report ([4]) provides several themes that highlight the relevance of the problem: *"digital deficits; digital addiction; digital distrust/divisiveness; digital duress; and digital dangers"*.

To start with, the *digital deficits* theme outlines how people's cognitive capabilities are negatively impacted by high amounts of digital technology usage [4]. Specifically, people's abilities regarding analytical thinking, memory, focus, reflection etc. are hampered by continuous digital connectivity [4]. Pew turns to a quote by Nicholas Carr (a popular author on technology and culture) to describe this issue: "We now have a substantial body of empirical and experiential evidence on the personal effects of the internet, social media and smartphones. The news is not good…the kind of constant, intrusive connectedness that now characterizes people's lives has harmful cognitive and emotional consequences. Among other things, the research reveals a strong association, and likely a causal one, between heavy phone and internet use and losses of analytical and problem-solving skill, memory formation, contextual thinking, conversational depth and empathy as well as increases in anxiety." [4].

The next theme Pew addresses is *digital addiction.* Here it is about how the 'internet economy' is fundamentally built upon principles of monetizing users' attention, where many online products and services are centered around tools to keep users hooked to them [4]. Amongst several others, Pew turns to David Rosenthal (a retired chief scientist at Stanford University) to provide commentary on this: "The digital economy is based upon competition to consume humans' attention...Economies of scale and network effects have placed control of these tools in a very small number of exceptionally powerful companies. These companies are driven by the need to consume more and more of the available attention to maximize profit...Thus these companies will consume more and more of the available attention by delivering whatever they can find to grab and hold attention...The most effective way to do this is to create fear in the reader, driving the trust level in society down..." [4]. This shows that digital addiction is not just limited to negative effects for individual users, but that its effects can trickle towards mistrust and fear across the entire society.

Continuing on from this, the *digital distrust/divisiveness* theme is about how individual agency is suppressed and negative emotions like fear, outrage and mistrust are weaponized–leading to divisions like social isolation, societal distrust etc. [4]. Amongst other correspondents, Pew cites Judith Donath, author of "The Social Machine, Designs for Living Online", "If your objective is to get people to buy more stuff...If your goal is to manipulate people...Keeping people in a continual state of anxiety, anger, fear, or just haunted by an inescapable, nagging sense that everyone else is better off than they are can be very profitable...to be used to reduce well-being because a population in a state of fear and anxiety is a far more malleable and profitable population." [4].

Digital duress is about an increase in stress, anxiety, depression, inactivity etc. from aspects of digital lives like information overload, mistrust, decline in interpersonal skills etc. [4]. The claim the report makes is that digital technologies could possibly have the potential to consume users' time and attention to the degree that they will often start functioning under duress (a constantly alert state) [4]. Jason Hong a HCI professor from Carnegie Mellon University is one of the experts who shares his opinion in the Pew report, "...Today, we now also have organizations that are actively vying for our attention, distracting us with smartphone notifications, highly personalized news, addictive games, Buzzfeed-style headlines and fake news. These organizations also have a strong incentive to optimize their interaction loops...There are two major problems with these kinds of interactions. The first is just feeling stressed all the time, due to a constant stream of interruptions combined with fear of missing out. The second, and far more important, is that engagement with this kind of content means that we are spending less time building and maintaining relationships with actual people..." [4]. Therefore, it is clear that the capitalistic motives of technology companies driving digital technologies are inherently about creating anxiety, addiction and a continuous sense of missing out amongst their users.

Digital dangers theme addresses how the organization of the internet and rapid evolution of digital systems has led to threats regarding security, democracy, privacy etc., as this evolution has done little to recognize the negatives emerging through digital technology due to the strong economic and social drivers behind it [4]. One of the experts Pew reviews, Tiziana Dearing (a Boston College professor) says on the matter, "People's well-being will be affected for the worse by digital technology for three reasons. 1) Because we have evolved as interpersonal, social creatures and therefore are unable to adapt to the behaviors, needs, even maybe the wiring required to thrive socioemotionally and physically in a digital world at the pace that digital change will require. 2) Because digital technology – from design to algorithms – has evolved without sufficient consideration of social empathy and inherent bias. 3) Because we have not figured out how to mitigate the ability that certain forms of technology have created to be our worst selves with each other. Don't get me wrong. Technological developments hold tremendous potential to cure disease, solve massive human problems, level the information

playing field, etc. But our ability to adapt at a species level happens on a much slower cycle, and our human behaviors get in the way." [4].

Besides research from the Pew Research Center, a paper on bringing positive psychology to digital wellbeing interventions also discusses several negative effects of digital lives [88]: *Self-Absorption, Digital Satisficing, Immediate Gratification, Confronting our Digital Detritus and Continuous Stimulation*. *Self-absorption* has to do with the tendency of digital technology like smartphones to give their users a socially isolating image ("I am busy"), where the users have an inward focus whilst using apps that deal with their personal tasks, games, entertainment, preferences etc. [88]. This removes them from their surroundings.

Digital satisficing occurs when we are content with and complacent about whatever we manage to find online (without thinking critically about it) when we are thinking of a question or are problem solving [88]. *Immediate gratification* is reliance on instant fulfilment of everyday needs and requests without expending much effort; such expectation of immediate gratification can seep to other situations and in general as well, which can cause unnecessary frustration and dissatisfaction [88]. *Confronting our digital detritus* has to do with continuously evaluating the digital traces we leave in the past and using that to e.g. gauge our worthiness [88]. This can make us either increasingly competitive by always wanting to do better or depressed at how we have not been able to achieve much [88]. Finally, *continuous stimulation* occurs due to the continuous presence and ubiquity of digital devices that enables very convenient and continuous information flow (and stimulation) in the form of continuous entertainment (e.g. music, games, videos), social media or the internet [88].

All in all, there were ten themes discussed in this section that highlight the significance of the current potential negative impact of digital technology: *digital deficits; digital addiction; digital distrust/divisiveness; digital duress; digital dangers; self-absorption; digital satisficing; immediate gratification; confronting our digital detritus; and continuous stimulation*. Together these themes lay a strong case for research, design and innovation in this space of enabling individuals to retake control of their digital lives and to help them consciously care about their digital wellbeing–so that some first steps can be taken towards avoiding these negative consequences.

CURRENT DIGITAL WELLBEING INTERVENTIONS (DIGITAL APPS)

Most of the innovation and initiatives in the space of digital wellbeing are currently confined to digital apps for smartphones, web browsers or computers. This section will present an overview of such apps, the features they have, what works, what is missing etc. A good starting point is provided by a paper that analyzed design features from 367 apps for "digital self-control" on Google Play, Chrome Web Store, and Apple App Store [67].

From the 367 analyzed tools, 74% possess the most common feature category which involves blocking or removing distractions [67]. Within this "block/removal" category, 44% of the apps targeted blocking [67]. This involves putting hurdles for accessing distracting functionality by completely blocking access to distractions; by enforcing time limits on them; by enforcing a quota on the number of times they can be launched before blocking; or by enforcing time lags before accessing them. An example here is of the Google Chrome extension called "Focusly" [67]. Focusly allows users to block their access to specific websites, and if they want to unblock such a site, it forces them to press ordered sequences of arrow keys [114]. Within the same "block/removal" category, 38% tools took the alternative route of reducing, rather than blocking, distractions [67]. This was done by removing distracting website elements (like social media newsfeeds); by removing general distracting content a user is exposed to when surfing the web; by removing functionality irrelevant to the task at hand; or

by limiting the functionality available on a device's home screen. An example of a tool that reduces distractions is that of "News Feed Eradicator" [115], which simply removes a user's Facebook newsfeed and replaces it with motivational quotes.

The second most common feature category found by [67] was that of "self-tracking" which was present in 38% or 139 of the 367 analyzed tools. Tools within this category involved enabling users to record their digital history, gave them visualizations of their device usage data or displayed timers to allow them to track the times they spend on different tasks. For instance, "RescueTime" enables users to track their laptop usage data and gives them visualizations about it [112]. Quite a significant portion of these self-tracking category tools focused on enabling users to track and visualize the time they manage to *not* spend on their digital devices (e.g. the "Checkout of Your Phone" app [116] that does exactly that) [67].

The third most common feature cluster in [67] was that of "goal advancement" which was present in 35% of tools. The tools within this cluster were about guiding users towards intended, right tasks when they use their digital devices [67]. This could be through reminders of time goals or task goals or through reminders of more general personal goals/values. Many tools in this category were also about prompting users to set explicit goals regarding their app or device usages or regarding their tasks [67]. A small percentage of these apps allowed users to compare their behaviors against their set goals. An example here is that of "Todobook" [117] that replaces a user's Facebook newsfeed with their to-do list to remind them of their tasks or that of "Time" [118] which is a countdown timer that provides continuous reminders of a user's tasks if they leave the app itself.

The fourth and final most prevalent feature category is related to "reward/punishment" [67]. Here the tools are geared towards giving users rewards or punishments depending on their device or app usage. Tools here involved gamification (collecting points, leaderboards, social sharing etc.) or representation of 'points' through a certain lifeform which is negatively impacted if a user exhibits unwanted digital behaviors (e.g. the "Forest" app [119] has virtual trees which can be killed if a user does not care for them by staying away from distractions). There are also several tools that bring this reward/punishment system to the real world by e.g. having users lose actual money if they spend too much time on distracting websites ("Timewaste Timer" takes some of your bank account sum if you spend too much time on Facebook [120]) or by giving users discounts if they do exhibit appropriate digital behavior (the "MILK" tool [121]) [67].

Based on their analysis of the 367 digital wellbeing related tools, [67] highlight three possible research opportunities that are unveiled by the prevalent design features of these tools. These three directions all present prevalent features that have not yet been tested in research studies regarding e.g. their efficacy or generalizability of their design principles. The first direction concerns, "responsibility for a virtual creature" [67]. The direction is about coupling device usage aspects to the wellbeing of a virtual creature (in the case of the "Forest" app this is done through virtual trees [119]). This direction is novel (in terms of research) because it uses somewhat of a 'visual pets' approach–but a variant where, instead of the typical approach of 'feeding' their pet through taking action, a user has to abstain from action (e.g. by not using their smartphone) [67].

The second direction concerns, "redirection of activity" and is about tools that redirect a user's unwanted, distractive activity to a website that is more aligned with their productivity goals [67]. This direction is interesting because apps aiming for it try to automate new habits such that if or when a particular context occurs, it is used by the user as a cue for shifting to a desired response [67]. Such tools can, therefore, be interesting as ways to investigate how redirection of activity can scaffold the shift the control of personal goals over unwanted, impulsive habits [67]. The third direction is about, "friction to override past preference" and

deals with tools that add extra commitment to user preferences regarding their access restriction by forcing them to do some extra task or overcome an obstacle before letting them overwrite the blocking of access [67].

Another review of existing apps by Rofarello and Russis [74] provides further insight into what are the most prevalent current trends and gaps regarding digital wellbeing tools. They analyzed 42 digital wellbeing smartphone apps from Google Play Store, and classified their features into two clusters with each cluster having its own categories. The "self-monitoring" cluster had "tracking" (phone times, app times, app checking) and "data presentation" categories (phone usage summaries, app summaries, charts, social comparisons) [74]; and the "interventions" cluster had "phone interventions" (timers, blockers, feature redesigns), "app interventions" (app timers, app and notification blockers) and "extra features" (motivational quotes, rewards) categories [74].

Regarding the first cluster on tracking and visualizing data, the most prevalent features distilled from the analysis of 42 apps were about tracking usage data of users and presenting it to them [74]. 15 apps were so called "phone-level apps" that provide data visualizations regarding phone usage, 12 apps were "app-level" which allowed tracking and visualizations regarding apps usage, and 15 apps had both phone and app-level tracking and visualizations [74]. 57% of the analyzed apps give "phone summary" which are visualizations of phone time usage or of phone unlocks [74]. 50% of the apps give "app summary" where they visualize statistics on app usage times or app opening frequencies [74]. Regarding the mode of visualization, 60% of the apps use charts, and 38% use email summaries or home-screen widgets [74]. Some also allow users to compare their statistics with those of other users.

The other cluster on using interventions to give users control over distractions involved features that use interventions to suppress the addictive nature of phones and apps [74]. This was present at "app-level" where users could have timers notify them if they use an app for an undesirable amount of time, where users could block app usages or where they could block app notifications [74]. This was also present at "phone-level" where users could have timers and blockers to limit or block phone usage as a whole [74]. Besides these clusters, there were apps that used motivational quotes to support users or give them rewards for meeting digital wellbeing goals [74]. There were also features that held novel potential but were underutilized by existing apps. These involved "automatic interventions" through inferences from user data, or "dynamically redesigning the phone UI" to prevent impulsive app usage habits (by e.g. randomizing distracting apps' locations) [74].

Not only did [74] analyze existing 42 apps, but they also did a thematic analysis on 1,128 user reviews of such apps and on a longitudinal study (with 38 participants) of an app they custom-designed with the most common digital wellbeing features. Based on these three aspects of their study, [74] propose various broader implications for the design of digital wellbeing interventions. Firstly, their research shows that most of the state-of-the-art digital wellbeing apps are not targeted towards enabling users to form new habits, but that they are designed to enable users to break existing unwanted habits (through self-tracking) [74]. There is a need to overcome this gap by incorporating more habit formation strategies by inclusion of approaches that enable 'healthy', wanted behaviors to become persistent and turn into habits through e.g. positive reinforcement or providing trigger cues [74]. Habit formation can especially take into account the contextual awareness that smartphones bring, by e.g. dynamically suggesting habits to users based on their locations or digital addictive behaviors [74].

Secondly, the current intervention apps underutilize social supporting techniques [74]. Whilst users of such apps want the ability to compare their digital behavior statistics with those of others or want to interact with other users, only a handful of apps provide this [74]. Self-control can be stimulated significantly by social support from networks [45] and incorporating more social support techniques can help with that [74]. This can go beyond just enabling statistics comparisons between users. It could involve (as users themselves

suggested) e.g. letting users play 'social games' with one another where they can set goals, get rewards for successes and penalties for failures [74].

Thirdly, users of digital wellbeing apps actually want restrictive solutions to put limitations on their overuse of smartphones [74]. Users themselves acknowledge that solutions that can be overwritten or are unrestrictive are insufficient for transforming users' smartphone usage behaviors [74]. In their 'in-the-wild' study, [74] also found out that if such apps can be bypassed, then users simply snooze or stop their interventions–rendering such apps futile in actually suppressing addictive behaviors. Therefore, it is suggested that there should be better and further utilization of actually restrictive interventions that are difficult to overwrite and that penalize users if they try to do so [74].

Lastly, the studies in [74] show that digital wellbeing apps should be targeted at the "app-level" rather than at "phone-level". They should also provide user statistics that are accurate and explainable. In their 'in-the-wild' study, [74] also found out that users are more likely to abide by interventions that limit specific apps' usage; and in their analysis of user reviews of digital wellbeing apps they also found out that phone-level apps fall short for being really useful users. Moreover, again the reviews showed that errors regarding the accuracy of visualizations of tracked data have a substantial impact on the usability and perceived usefulness of such apps [74]. This can be especially dissatisfying or misleading because users might not be able to tell whether spikes in data are actually manifesting an addictive behavior or whether they are merely caused by bugs [74].

This section tried to present an overview of the existing digital wellbeing apps, their most prevalent features and design characteristics, and the design recommendations that can be distilled from them. It should be visible that digital wellbeing interventions are becoming increasingly prevalent and their gaps present a lot of untapped research potential. Using virtual creatures, redirecting user activity, leveraging delays for self-control or enhancing users' self-efficacy can all be interesting avenues to explore. At the same time, being more inclusive towards: habit formation, contextual awareness, app-level interventions, restrictive solutions and social supporting techniques–can all be enhance digital wellbeing tools.

It must be stressed that this section only gave an overview of the *current state of the art* of digital wellbeing interventions to help understand what has already been done. It discussed the current medium of digital apps and the metrics used in those apps. Neither this conventional digital medium nor these conventional metrics are used in the rest of the project in their entirety. This is because there are more relevant, novel gaps than these that will subsequently be discussed. They warrant the need to **go beyond this digital medium and the traditional metrics** therein. This will become clear in the following chapters and parts of the dissertation.

WHAT ELSE COULD WORK TO EMPOWER DIGITAL WELLBEING?

Now that some existing digital interventions for digital wellbeing have been considered, further insights from literature can be explored that could hold opportunities for enabling digital wellbeing for individuals. They can help better understand the digital wellbeing space but are not crucial for this dissertation's focus. They can be found in Appendix A. The approaches considered are: Facilitating disconnection, positive psychology, balancing user resources and tracking screen time. All potential approaches have the aspect of enabling genuine user satisfaction in common. It is all about facilitating users and technology designers to rethink what matters in digital interactions and to give users the possibility to forge a path for their digital lives that is not driven by motives that can be detrimental. It is also about learning from screen time tracking and going beyond it in digital wellbeing applications.

2

Smartphone Users' Revisitation Habits and Their Link to Being in Control of Device Usage

So far, the current strategies to digital wellbeing have been considered. But what smartphone usage habits or behaviors should such digital wellbeing interventions target for maximizing their relevance and impact? Besides helping answer this question, taking a step back and finding the most prevalent smartphone usage habits can also reveal opportunities that are currently untapped by digital wellbeing interventions. The previously discussed narrow definition of digital wellbeing (current project's basis) can itself provide a starting point for this search. The definition was, "...the user's feeling of control over device use is central to digital wellbeing...". So, it puts the subjective feeling of control (as well as actually having objective control) over device use in the centrality of digital wellbeing. This theme of 'control' (both subjective and objective control) forms the foundation of what digital wellbeing means within the context of this project. This chapter, first, discusses a model for analyzing this "control" from a psychological perspective. Next, it considers a very common smartphone usage habit linked to "control" and to digital wellbeing: Revisitation. It also considers the prevalence, relevance and underutilization of this habit. Together, this control aspect of digital wellbeing and the habit of revisitation form the main focus of the problem space of the rest of this project.

DUAL SYSTEMS MODEL AND SELF-CONTROL

When thinking about personal informatics systems, goals and habits are of primal focus. Often the purpose of such systems based on user data is to enable users to accomplish their (wellbeing) goals and in the long-term to transform their habits; with the higher order ethos being connected to a better health, greater productivity, better wellbeing etc. for the users.

Since this project is mainly geared towards the "control" aspects of digital wellbeing, it makes sense to start with a model that helps to think about and systematically address these concepts of goals, habits and control–as well as the link between them. This model is known as the "the dual systems model of self-regulation" [67]. In this model there are two systems: system 1 and system 2. When system 1 is in control, that is when our behavior is a consequence of *habits* or instinctive processes that emerge through external stimuli and/or internal states; here the behavior is 'automatic' and does not require conscious attention [67]. It is the non-conscious, automatic part of the dual systems model. On the other hand, system 2 is when our behavior results from *goals*, intentions and rules that are contained in the conscious working memory [67]. This system is then about the deliberate and conscious part of the dual systems model. As an example, system 1 is in control when one is exhibiting instinctive responses like scratching one's itching skin or picking up one's smartphone to check for notifications simply out of habit [67]. System 2 is in action when one has the explicit goal to send an email to a colleague and takes out one's phone to achieve that goal.

Now, in the context of (digital) wellbeing, it is "self-control" that links these two systems (and consequently non-conscious habits and conscious goals). In simplest terms, in the dual-system model, self-control means to use one's conscious system 2 to overrule the automatic system 1 when the two are in a conflict of control [67]. Using the above example of instinctively checking one's smartphone for notifications, self-control would be suppression of that system 1's habit at a family dinner to fulfill system 2's goal of not checking smartphone notifications when in social gatherings [67]. What determines whether this self-control is exercised or not? In simple terms, it is determined by a cost-benefit analysis of the expected value gain from exercising self-control, and this analysis metric is called the "expected value of control" (EVC) in neuroscience [95]. The higher their EVC, the more likely a user is to exercise successful self-control [95].

There are three main factors that impact EVC (*reward, expectancy and delay*). Firstly, the greater the quantity of *reward* an individual expects they can obtain (or the lower the loss they have to endure), the higher the EVC gets [67]. The authors demonstrate this with a scenario where introducing a financial cost to a user each time they check their phone can help make the overall EVC more favorable towards self-control [67]. Secondly, EVC increases as an individual's perceived *expectancy* or likelihood to exercise self-control (and thus lead to the results tied to it) increases [67]. In the phone notifications checking scenario, the more confident a phone user is in their ability to exercise self-control, the more likely they become to actually exercise it. Thirdly, EVC decreases the longer of a *delay* there is for their perceived reward to become available to an individual [67]. For our scenario, if a phone user had to pay a financial cost to checking their phone notifications, but only after a decade from each time they checked their phone, they would be less likely to exert self-control; as the delay for potential financial savings would be too much.

The dual systems model and the EVC concept together help psychologically analyze various tools geared towards self-control-based wellbeing [67]. There are various categories of such tools. "Goal advancement" tools enable users to reflect on and become consciously aware of their wellbeing goals; this is meant to empower them to exercise system 2's self-control in the first place by giving it an explicit rule or framing to act on [67]. "Reward/punishment" tools enable self-control through impacting EVC; here, system 2's self-control capabilities are enhanced through increasing EVC through e.g. extra rewards for exercising self-control [67]. "Block/removal" tools are much more minimalist in their approach; they merely remove features or content that can stimulate undesirable, automatic system 1 habits [67]. Finally, "self-tracking" tools also mostly enable users to simply become consciously aware of their relevant behavioral patterns and wellbeing-related data so that they have a greater awareness of what their system 1's automatic impulses are up to [67]. This last category of

"self-tracking" tools is going to become particularly important as it is going to be the focus behind the intervention that was designed in this project.

REVISITATION: A RELEVANT, PREVALENT AND UNDERUTILIZED HABIT LINKED TO 'CONTROL'

Continuing on with this theme of control over smartphone usage, revisitation is a very common habit that appears to be highly relevant for 'control' over device usage, and yet is completely underutilized in existing digital wellbeing interventions. Revisitation is what the name says it is. It is when one revisits (or comes back to) one's phone. A common theme in unwanted smartphone habits is that of unintended, impulsive and/or continuous checking of smartphones [27,52,81]. From the above discussed "dual systems model of self-regulation", such impulsive behavior is characterized by system 1. For example, a smartphone user (without consciously realizing) might repeatedly and automatically be unlocking their phone to check their screen for notifications [81]. These short, frequent revisitations repeat over time and form a substantial part of smartphone usage–as shown by three longitudinal studies (N=136, N=15, N=12) [81]. Not only do Oulasvirta et al. show users' habits of continuous returns to the smartphone, they also show how such revisitation or checking habits may increase overall phone usage by being gateways to further use and to other applications [81]. So, not only are checking and revisitation behaviors quite prevalent, they can also increase the overall screen time.

There is a lot more evidence on how prevalent short bursts of revisitation are. A study by Yan et al. showed how the biggest proportion of smartphone usage is quite brief [110]. That study showed that half of a user's mobile phone usage consists of brief checking sessions each of which lasts not more than 30 seconds (the duration between unlocking and locking the phone) [110]. Falaki et al. have also reported a prevalence of short bursts of application usage (10-250 seconds) [32] and similarly Böhmer et al.'s study has shown how the average application session is quite brief (only lasting 72 seconds) [14].

Another three-month long longitudinal study (N=165) showed how smartphone usage consists mostly of sessions of various revisitation categories (e.g. short-term revisitation lasting a few minutes versus longer-term revisitation lasting several minutes or hours) [52]. They reveal distinct application revisitation clusters (e.g. social media, internet browsing and messaging applications being in the category of rapid, fast revisitations within a few minutes), and also distinct revisitation profiles of users (e.g. users who check their phones within a few minutes of previous checks, as well as those who wait longer than that before revisiting their phones) [52]. What is astonishing about their study is that they come up with a model (based on app revisitations) that is able to explain 92% of variability of smartphone use [52]. Thereby they show how representative revisitation is of typical phone usage [52]. Overall, based on their findings, they call on researchers for using and viewing revisitation as a first step in the direction of "addressing the more fundamental driving forces that shape our use of smartphones, and indeed of technology in general" [52]. Their project stresses the need for using the prevalent smartphone behavior of revisitation as a methodology in itself for studying smartphone habits [52].

Besides these, a popular digital wellbeing app looked at smartphone usage data of 11,000 users and also found pressing statistics [112]. They found out that most people check their phones, on average, 58 times a day. 70% of these use sessions last less than two minutes, and 25% last two to ten minutes [112]; their results show that indeed most of smartphone usage consists of repetitive checking behaviors, and that 95% of those checks are very short (less than 10 minutes). What is quite crucial to note is that they also show that whilst these sessions might be short, "they can set off a chain reaction of events that take over our days.". They found out that 50% of use sessions start within 3 minutes of the previous one–indicating, just like [81], that short bursts of

smartphone checking lead to a perpetual cycle of even more checking and even more smartphone usage. Another research project done by Qualtrics [84] shows that, "millennials check their phones on average 150 times a day", which is again a surprisingly alarming number showing repetitive checking behaviors or habits. It is, therefore, no surprise that a former VP of a social media giant says, "The short-term, dopamine-driven feedback loops we've created are destroying how society works..." [106]. This reflects the potential negative consequences of these short-term checking behaviors that are driven by continuous feedback loops.

So, there is evidence that smartphones and the apps and services therein are particularly prone to revisitation [27,29,32,52,81,110]. Checking habits are especially a characteristic of smartphone usage [81]. Compared to, for instance, laptops, smartphones are checked and revisited a lot more often (for shorter durations) and their total usage time in a study was twice as much as laptops [81]. Smartphones have a design meant to be portably carried and used by users 24/7, with flexible uses possible for different users and purposes [27]. Smartphones have features, applications and experiences that can trigger continuous instant gratification in users [27]. Their ability to provide users with instant access to continuously changing content paves the path for checking habits [81]. Furthermore, their size, diversity of applications, ubiquitous nature and flexibility (physically and temporally) are all aspects that increase the likelihood of continuous checking behaviors from emerging [77].

With checking and revisitation habits, smartphone usage can slip out of a user's control. This is partly because often smartphone usage behavior is itself able to act as a reward for sustaining itself–thereby leading to a loop of continuous checking or revisitations [27]. There are several features or experiences (e.g. winning games, receiving new notifications, finding new media content, unlocking new features) that a smartphone can offer that can act as gratifying rewards for a user's psyche [105]. These 'rewarding' aspects trigger pleasurable emotions and feelings in users–thereby increasing the chance and potential for such habits to re-engage users [7]. This is how repeatedly checking one's smartphone can turn into a habit (automatic 'system 1' action) or even an addiction [27]–where a user is no longer in control over their device usage (which forms the centrality of our digital wellbeing definition). Indeed, habitual uses of smartphone can lead to addictive smartphone behavior [27]. Such addictive behaviors (with a high degree of lack of control over device usage) are linked to inferior mental health and are correlated with anxiety and depression [29].

Continuing on with 'control', psychologically speaking, overusing smartphones can be associated with not being able to control impulses for wanting to return to the phone (or to applications within it) [27]. When smartphone users experience continuous, automatic impulses to unintendedly keep checking their smartphones [27], they are facing a degree of lack of control over phone usage that can interfere with daily lives [89]. These urges can be triggered by internal or external cues like one's mood, notifications, various situations, people around oneself and one's past actions [27]. Not only can they interfere with daily lives, but they can also reach a level where their use becomes annoying in social situations (at e.g. restaurants and family gatherings) [27]. Amongst other habits, impulses to check a smartphone continuously can also lead to a degree of dependence on it that is so much that its removal can create feelings of discomfort or even panic attacks [111]. If one's smartphone is not within immediate reach, that can lead to stress or anxiety [19]. There are even phantom phone vibrations increasingly reported by smartphone users–despite there being no incoming vibrational notifications [57]. This indicates how crucial it can be to give smartphone users tools that they can use to sustain and/or gain control over their smartphone use.

The findings laid out here should all show that revisitation is a very relevant and prevalent dimension to not only study digital wellbeing but also measure it. As already mentioned, Jones et al. [52] call on researchers to utilize and view revisitation as a fundamental habit that shapes smartphone usage. What can also be inferred from this and other checking habits studies discussed above is that revisitation inherently shapes smartphone

users' digital wellbeing. This is because it influences their feeling and actual level of control (control being the central value of digital wellbeing according to our definition from [66]); as well as because it encompasses a major part of their smartphone experience and habits.

Based on what has been discussed, it should be apparent that revisitation quite directly affects how impulsive (and therefore how controlled) a user is with their smartphone usage, as well as what their common usage patterns are. It must be emphasized that "revisitation" in the context of this project does not only refer to a user coming back to their phone, but like [52] also to the time duration they take to come back–i.e. besides counting a revisitation instance, also measuring how long a user takes before revisiting their phone that instance. So, having counts for revisitations within various time intervals (time taken to return to phone) to form a revisitation pattern–e.g. 10 revisitations within 1 minute of previous phone use.

Whilst there are indeed studies like those mentioned above that have investigated checking and revisitation habits in a post hoc manner through e.g. data analysis and modeling, the revisitation dimension has not been utilized when designing digital wellbeing interventions. It has not been utilized as a smartphone usage dimension to measure and give users feedback on, and also not as a metric to base the goal or purpose of a digital wellbeing intervention on. This is despite how common and negatively consequential revisitation can be, as the rest of this section shows.

Earlier on in this dissertation, a large number of digital wellbeing interventions were discussed. None of these interventions had revisitation as an explicit goal or something that users could get feedback on. For example, in the already discussed 367 apps for "digital self-control" [67], there was no app that utilized revisitation. None of them had revisitation as their goal or as something users could track or get insights and feedback on. Same holds true for the 42 apps that [74] analyzed. There was no consideration for the dimension of users coming back to their phone and how long they take before doing so. This is an underexplored opportunity, as revisitation can be a highly common habit that is directly linked to the 'control' aspects of digital wellbeing. Self-tracking of and feedback on revisitation might hold substantial untapped potential for enabling users to take control of their smartphone checking impulses.

By now, based on the related work presented so far, three things stand out. Firstly, revisitation is a highly prevalent smartphone habit that forms a substantial part of usage sessions. Secondly, revisitation and checking habits are quite relevant to consider as they can affect a user's digital wellbeing (control over smartphone usage) and can have adverse psychological, social, physical and health-related effects. Thirdly, revisitation is highly underutilized in current digital wellbeing interventions. Overall, then, there is a significant opportunity to have revisitation as a focus within digital wellbeing applications; not only because of how common it is, but also because of how impactful focusing on it can potentially be.

3

Five Opportunistic Principles for Designing Useful, Novel Digital Wellbeing Interventions

It has already been discussed what digital wellbeing is, why it matters and what has already been done regarding it. The very prevalent and relevant smartphone usage habit of revisitation and its relevance has also been discussed. It is clear that revisitation holds a lot of potential for designing digital wellbeing interventions. Besides this, there are further design principles that such interventions can be based on for them to be novel from an academic standpoint and useful from a user perspective. These principles are inspired by literature on related topics like personal informatics, ambient interfaces and digital wellbeing. This section will discuss these five design principles or untapped opportunities for designing for digital wellbeing.

These principles were chosen because of their novelty (and consequently interestingness for personal informatics), fit with the digital wellbeing problem space and because of their relative prevalence and relevance in related literature. They have to do with what revisitation feedback to give users. Equally importantly, they also have to do with how to best deliver that feedback–both in terms of the medium and in terms of the strategy, purpose or approach of delivery. At first glance, it might seem that these principles consist of too many sub-elements to be realistically embedded in an artifact or a design. That is correct. Not all the aspects of each principle can actually be embedded in an artifact or a design, and not all of them have an equal priority. Which is why from each broad principle, specific aspects or values are filtered out and prioritized.

This filtration is done by two explicit and two implicit metrics. The **two implicit ones are novelty and relevance**. The reason these are implicit is because (as was already discussed earlier), all the principles and the aspects therein were selected in the first place based on their novelty and relevance as judged with respect to related and background work. So, all the elements within the respective principles are in some way embedded in

existing work in terms of relevance and novelty–filtration on those two metrics is already done by choosing the selected design principles in the first place.

The **two explicit metrics are nature of revisitation and feasibility**. Feasibility has to do with having a design that is able to fulfill various constraints of the study. These included implementation/development constraints, time constraints, resource constraints, user privacy requirements and the effect of COVID-19 on resource availability. The second explicit metric, "nature of revisitation" is something that was briefly mentioned at the dissertation's start. It has to do with revisitation being a dimension which so far has not been utilized as something that users can base their digital wellbeing goals on or something they can track and get feedback on. As such, incorporating it as a trackable metric and as a feedback metric in an intervention is by nature poised to be highly explorative. It is expected to be something unfamiliar to users as it is something that has not yet been tried in interventions.

Based on these two explicit metrics (feasibility and nature of revisitation), then, the elements within the five broad design principles are given a second look; and those values that fit these metrics the most are prioritized and filtered to be actually embedded in the digital wellbeing artifact to be designed. Under each design principle, an overview will be given of the **specific priority values** filtered from the broader content of each principle–including **justifications** on why those specific values were prioritized. These values can then form the basis for the digital wellbeing artifact that is designed later on in this project. They can help guide how to best design the human-data interaction that the artifact would mediate.

DESIGNING FOR REVISITATION FEEDBACK

Earlier on in this dissertation, it was made clear that revisitation is a highly prevalent and relevant smartphone habit, which is highly underutilized in digital wellbeing interventions. Revisitation is a highly prevalent smartphone habit that forms a substantial part of usage sessions. A common theme in unwanted smartphone habits is that of unintended, impulsive and/or continuous checking of smartphones [27,52,81]. Smartphone users exhibit clear habits of continuous returns to the smartphone, which also increase overall phone usage by being gateways to further use and to other applications [81]. The biggest proportion of smartphone usage is quite brief [110]. There is a prevalence of brief bursts of application usage lasting 10-250 seconds [32] or lasting 72 seconds [14]. These checking behaviors can be formalized as revisitations; smartphone usage consists mostly of sessions of various revisitation categories (e.g. short-term revisitation lasting a few minutes versus longer-term revisitation lasting several minutes or hours) [52].

Smartphones and the apps and services therein are particularly prone to revisitation [27,29,32,52,81,110]. Repeatedly checking one's smartphone can turn into a habit or even an addiction [27]–where a user is no longer in control over their device usage (which forms the centrality of our digital wellbeing definition). Such addictive behaviors (with a high degree of lack of control over device usage) are linked to poor mental health, anxiety and depression [29]. Furthermore, impulses to check one's smartphone continuously can also lead to a degree of dependence on it that is so much that its removal can create feelings of discomfort or even panic attacks [111]. If one's smartphone is not within immediate reach, that can lead to stress or anxiety [19]. This indicates how crucial it can be to give smartphone users tools that they can use to have control over their smartphone use.

At the same time, however, revisitation has not been utilized as a smartphone usage dimension to measure and give users feedback on, and also not as a metric to base the goal or purpose of a digital wellbeing intervention on. The review of [67] discussed 367 apps for "digital self-control" none of which utilized revisitation or something similar. None of them had revisitation as their goal or as something users could track or get insights and feedback on. Same holds true for the 42 apps that [74] analyzed. There was no consideration for the dimension of users coming back to their phone and how long they take before doing so. So, this is clearly an underexplored opportunity, as revisitation is a prevalent habit that is directly linked to the 'control' aspects of digital wellbeing.

How should, then, an intervention be designed for giving feedback on revisitation? Before answering this, it first needs to be considered how to quantify revisitation. "Revisitation" in the context of this project does not only refer to a user coming back to their phone, but just like in [52] also to the time duration they take to come back–i.e. besides counting a revisitation instance, also measuring how long a user takes before revisiting their phone in that instance. So, having counts for revisitations within various time intervals (time taken to return to phone) to form a revisitation pattern–e.g. 10 revisitations within 1 minute of previous phone use, 5 revisitations within 8 minutes of previous phone use etc.

Obendorf et al.'s work provides the theoretical basis for such classifications of various revisitation categories based on a user's inter-visit duration (the time it takes for them to come back to a webpage) [79]. Their work employs a triadic classification of revisitation; where it is short-term, medium-term or long-term depending on how long a user takes to revisit. The work of [1] and that of [52] employs a finer approach to revisitation classification's resolution (as opposed to only three classes). They use what is called a "revisitation curve" that captures a user's, an app's or a webpage's revisitation pattern. In their works, this pattern is encapsulated in 15 exponentially distant bins or classes of "inter-visit times", where each bin captures the frequency of revisitations within its respective inter-visit time. These bins can be normalized and thereafter used to plot a histogram–a smoothed out version of which forms a "revisitation curve". In [1] and [52], the following 15 bins were used: 1, 2, 4, 8, 16, and 32 minutes; 1, 2, 4, 8, 16, 32, 64, 128, 256 hours and above. As Jones et al. [52] summarize, "A revisitation curve characterizes an app by its 15-dimensional vector, where each dimension corresponds to the frequency of revisits within the corresponding bin." This can be done at the micro-level of apps or at the macro-level of the phone of a particular user (across all apps) [52].

So, a revisitation vector or pattern (comprising revisitation bins) is how revisitation can be quantified. For this project this revisitation has to be turned into feedback that a smartphone user can use to self-track and reflect on their revisitation. This is because of how underutilized it is in digital wellbeing interventions despite its prevalence and relevance. Self-tracking of and feedback on revisitation might hold untapped potential for enabling users to take control of their smartphone checking impulses. Revisitation can be a first step towards "addressing the more fundamental driving forces that shape our use of smartphones..." [52].

The nature of revisitation–within the context of this study–is that of a dimension which so far is not typically presented to smartphone users themselves (in an ad hoc manner). It has not been used as a dimension that users can base their digital wellbeing goals on or as a dimension that users can track and get feedback on. As such, incorporating it as a trackable metric and as a feedback metric in an intervention is by nature poised to be highly explorative. It is expected to be something unfamiliar to users as it is something that has not yet been tried in interventions. So, there are not yet any established principles or clear normativity on how to design for this metric. This also means that there is no indication of whether giving users feedback on this metric will even be perceived as relevant by them and, if so, in in what ways. For the same reasons, it is also difficult to know how users would want to set revisitation goals and what those goals would be. Imposing an a priori bias by assuming what should matter to a user regarding revisitation is also something that should be avoided if we are to let users

express by themselves what really matters to them and how (although, this does still assume that revisitation itself matters could potentially matter to them in the first place).

Because of this nature of revisitation, self-tracking can be a useful first step towards investigating a digital wellbeing artifact or intervention centered around revisitation. Earlier on, the dual systems model was considered together with the EVC concept from [67]. They were used as lenses to analyze the main existing approaches to self-control related digital wellbeing applications. Revisitation was also earlier on derived from self-control, thus, this model can be useful to select the approach to designing a revisitation related intervention. From the available four approaches in [67] ("goal advancement", "reward/punishment", "block/remove" and "self-tracking"), self-tracking suits a revisitation centric intervention the most because of the nature of this dimension as discussed above, as well as the constraints of the project. Since the first three categories in this aforementioned list have to do with goals, normativity or a combination thereof, self-tracking emerges as the clear approach to focus on as a first step. Because as mentioned above, a revisitation oriented intervention is going to be highly explorative–without any preconceived goals or notions of what is good or bad (and so what should be blocked or removed, or what should be rewarded or punished). Furthermore, from the perspective of EVC and the dual systems model, "self-tracking" can enable users to become consciously aware of their relevant behavioral patterns and wellbeing-related data so that they can achieve a greater awareness of what their system 1's automatic impulses are up to [67]. Such awareness can be a first step towards changing such unwanted behaviors [7,60].

Furthermore, people cannot alter their motivation and actions well without paying attention to self-tracking of their relevant behavior or actions [7]. People also need to be able to monitor the conditions in which such behaviors occur, as well as their effects [7]. Individuals also selectively filter different aspects of their tracked habits and ignore those that matter less to them (depending on their values, the significance of tracked habits, self-perception, mood etc.) [7]. So not only can self-tracking of revisitation help smartphone users take a first step towards altering their motivation and actions (should they find that necessary), it can also help this project uncover what aspects of revisitation tracking and feedback do users filter out, make sense of and/or appropriate to themselves or their situations. Enabling people to become aware of their own past rate of activity [104] can result in them accelerating or decelerating that rate [15]; further showing how enabling users to track their revisitation and feeding back that self-tracked information to them can help them self-regulate their revisitation the way they find most suitable to themselves.

One way to approach this could be to track smartphone users' revisitation patterns and intuitively feed them back to the users. This can help because past revisitation (due to its sequential and temporal nature) can be a predictor of future revisitation [52]; and, therefore, might help users become aware of what their past revisitation pattern has been like (and implicitly how it could become if they keep continuing as they have in the past). Reflection in the form of thinking about past experiences, thoughts or insights is triggered by (visual) cues which is the first step towards more deeper reflection and behavior change [83]. Furthermore, providing feedback in the form of persistent visual cues based on tracked behaviors can be an effective approach for enabling habit formation [98]. That can be quite useful because focusing on habit formation can enable more mindful use of technology (within the digital wellbeing realm) and is more likely to enable long-term adoption of the desired behavior [58].

All in all, enabling users to self-track and get feedback (visual cues) on their revisitation patterns can help them self-regulate their revisitation, as well as potentially take a first step towards forming new, preferable habits regarding revisitation. Based on this, the following aspects of this principle are prioritized and summarized for designing digital wellbeing artifacts:

Designing digital wellbeing interventions that utilize revisitation as their metric of purpose, tracking and feedback

Incorporating revisitation, as it is a highly prevalent, relevant and underutilized smartphone habit.

- Common theme in unwanted smartphone habits is that of unintended, impulsive and/or continuous checking of smartphones [27,52,81].
- The biggest proportion of smartphone usage is quite brief [110]. There is a prevalence of brief bursts of application usage lasting 10-250 seconds [32] or lasting 72 seconds [14]. These checking behaviors can be formalized as revisitations.
- Smartphones and the apps and services therein are particularly prone to revisitation [27,29,32,52,81,110]. Repeatedly checking one's smartphone can turn into a habit or even an addiction [27]–where a user is no longer in control over their device usage (which forms the centrality of our digital wellbeing definition).
- Such addictive behaviors (with a high degree of lack of control over device usage) are linked to poor mental health, anxiety and depression [29]. Furthermore, impulses to check one's smartphone continuously can also lead to a degree of dependence on it that is so much that its removal can create feelings of discomfort or even panic attacks [111].
- Despite all this, revisitation has not been utilized as a smartphone usage dimension to measure and give users feedback on, and also not as a metric to base the goal or purpose of a digital wellbeing intervention on. None of the 367 digital wellbeing apps discussed in [67] utilized revisitation or something similar. Same holds true for the 42 digital wellbeing apps that [74] analyzed.

Tracking revisitation patterns and intuitively feeding them back to users through visual cues.

- In [1] and [52], a revisitation pattern can be quantified in a vector of 15 exponentially distant bins of "inter-visit times", where each bin captures the frequency of revisitations within its respective inter-visit time.
- Giving smartphone users feedback on such a pattern can help because past revisitation (due to its sequential and temporal nature) can be a predictor of future revisitation [52]; and, therefore, might help users become aware of what their past revisitation pattern has been like (and implicitly how it could become if they keep continuing as they have in the past).
- Reflection in the form of thinking about past experiences, thoughts or insights is triggered by (visual) cues which is the first step towards more deeper reflection and behavior change [83].
- Feedback in the form of persistent visual cues based on tracked behaviors can be an effective approach for enabling habit formation [98].

Enabling self-tracking of and feedback on the revisitation metric.

- There is not yet any established principles or clear normativity on how to design for revisitation. This also means that there is no indication of whether giving users feedback on this metric will even be perceived as relevant by them and, if so, in in what ways. For the same reasons, it is also difficult to know how users would want to set revisitation goals and what those goals would be.
- Self-tracking can be a useful first step towards investigating a digital wellbeing artifact or intervention centered around revisitation. Since unlike e.g. rewards/punishments, goal advancement or feature blocking, self-tracking avoids normativity. It also aligns with the "nature of revisitation" criterion discussed at this chapter's start, making it the clear approach to focus on as a first step.
- Self-tracking can enable users to become consciously aware of their relevant behavioral patterns and wellbeing-related data so that they can achieve a greater awareness of what their system 1's automatic impulses are up to [67]. Such awareness can be a first step towards changing such unwanted behaviors [7,60]. People cannot alter their motivation and actions well without paying attention to self-tracking of their relevant behavior or actions [7].
- Self-tracking of revisitation can help smartphone users take a first step towards altering their motivation and actions (should they find that necessary), it can also help this project uncover what aspects of revisitation tracking and feedback do users filter out, make sense of and/or appropriate to themselves or their situations.

DESIGNING FOR LIVED EXPERIENCE

Rooksby et al. [87] did qualitative user research which showed how personal informatics (PI) systems (of which digital wellbeing interventions are a subset of) are actually viewed, used and adopted by users as part of their diverse life stories. Individuals were shown as not mere trackers or users of PI systems, but people who used PI systems or explained self-tracking within and in terms of their everyday experience (their lives, worries, ambitions, interests, careers etc.). As such, [87] show personal informatics systems to be much more about the lived experience of users than they are typically considered to be. Different personalities, circumstances and interests of different users mean their lived experiences, and consequently, their appropriation of PI systems to themselves and their lives are completely unique [87].

Personal tracking of, even screen time in particular, can facilitate a diversity of user-driven purposes (e.g. reducing phone usage, increasing productivity and keeping a personal life log) that can last for a variety of usage periods (e.g. long-term or short-term usage) [86]. This indicates that different users' PI systems should be designed to be appropriable to them and whatever contexts, needs and purposes they find interesting [86]. Not even the way in which screen time data is presented to users is "raw" [86]. It is highly dependent on how users make sense of it in practice. Representation of screen time data involves several deign choices that influence user perception (How should data be segmented? When should users be presented with data?) and is a matter of balancing representation with practice [86].

Rooksby et al. [87] use the "lived informatics" concept to encapsulate this direction. With that they mean this phenomenon of how users use information and uncover its meaning in their everyday, day-to-day lives. Instead of adopting a position where this is considered in a minimal way (that users experience their everyday lives *in addition to* PI systems), [87] are much more profound about it and highlight that PI *is done over* a range of everyday lived experiences and activities. Hence it is unfeasible to make the assumption that users merely want to do rational data collection and that they want to take action only after all the data has been thoroughly analyzed [87]. There is a need to go beyond viewing users as rational self-trackers who have a bunch of trackers, with each tracker having a clearly defined function. This lived informatics approach leads to many design considerations for PI systems that can help taking into account the users' lived experiences [87].

The recommendation that stands out the most is to "design for interweaving, not just integration" [87]. This is about designing PI systems such that they can be interwoven by users into their day-to-day activities and that they can be used alongside other technologies or tools that are already part of the users' lives [87]. This interweaving (rather than an individual technology) is then what is responsible for behavior change. Behavior change possibly arises out of a set of technologies that users interweave over various activities [87]. This is tied in with another recommendation on the importance of recognizing how personal data might most be meaningful in the context it is produced, and that if it is isolated from its context it might lost its genuine meaning [87]. Tying this to smartphone usage data, users' everyday life and routines are reflected in their screen time data (or even in the absence of such data) [86]. This relation of screen time data with everyday lived experience can be positively leveraged by designers, but it should be carefully considered regarding user privacy–as it could reveal too much information about an individual's life [86].

Overall, then, all these recommendations are inherently about creating interventions that incorporate the phenomenological, lived experience of users. Based on them, the following aspects of this principle are prioritized and summarized for designing digital wellbeing artifacts:

Designing digital wellbeing systems to interweave with users' everyday lives and the subjective experiences they contain

Allowing appropriation to users and their lives in their own unique ways.

- Different users' PI systems should be designed to be appropriable to them and whatever contexts, needs and purposes they find interesting [86]. Appropriation possibilities should enable users to use PI systems in their own unique ways that are not pre-defined by designers [122].
- A PI system should allow different users, with different personalities, circumstances and lived experiences, to appropriate PI systems to their lives is their own completely unique ways [87].

Being geared towards interweaving into everyday, lived experiences.

- This is about designing PI systems such that they can be interwoven by users into their day-to-day activities [87].
- It is about incorporating the phenomenological, lived experience of users. As users use information and uncover its meaning in their everyday, day-to-day lives.
- PI *is done over* a range of everyday lived experiences and activities. Hence it is unfeasible to make the assumption that users merely want to do rational data collection and that they want to take action only after all the data has been thoroughly analyzed [87].
- Users' everyday life and routines are reflected in their screen time data [87].

DESIGNING FOR BEING REFLECTIVE

Personal informatics as a field inherently has reflection-related notions embedded in it. One of the definitions regarding personal informatics systems shows this as these systems are meant to "help people collect personally relevant information for the purpose of self-reflection and gaining self-knowledge" [60]. Li et al. also have reflection as one of the stages in their personal informatics model (the second last stage where a user reflects on their data) [60]. Such a reflection phase in that PI model forms the basis for the final stage of the model that involves a user taking action for actually changing their behavior based on the insights gained from reflecting on their personal data [60].

Li et al. define reflection as, "looking at lists of collected personal information or exploring or interacting with information visualizations". Baumer argues that such a colloquial definition of what constitutes reflection in PI is insufficient for providing guidance regarding how we might design for reflection [9]. That, together with an analysis of "reflective design" and "slow technology" approaches, leads to the dimensions of reflective informatics that conceptually define reflection and provide guidelines on how to design interfaces that facilitate reflection on personal data [9]. It is stressed, however, that these dimensions are simply meant to be generative, conceptual tools to inspire design–as opposed to being prescriptive, stage-based or fully exhaustive [9].

The three dimensions of reflective informatics that Baumer highlights are: (A) Breakdown, (B) inquiry and (C) transformation [9]. Starting with (A), *breakdown*, moments of breakdown often coincide with reflection. Breakdowns can arise from puzzling or doubtful situations [16]; they can also result from surprising, uncertain or conflicting moments, or "interesting phenomenon" in general [92]. When it comes to designing for reflection through breakdown, the subtle approach involves incorporating support for dealing with breakdowns. Such support can help form a better match between technological tools and human practices (which could in turn promote reflection) [9]. The more provocative approach involves drawing attention to or even actively fostering breakdowns and thus creating reflection moments [9].

Moving on to consider (B), *inquiry*, especially when it is conscious and intentional, forms the basis of many reflection frameworks [9]. Indeed, reflection can even be conceptualized as inquiry [16]. So, facilitating inquiry and creating opportunities for it is directly tied to designing a system for stimulating reflection. In [16] reflection is conceptualized in a similar way to the scientific process of creating, testing, refining and retesting hypotheses. Facilitating such an iterative, curiosity-driven process of testing and refining hypotheses regarding personal informatics can be one way to design for reflection [9]. Another way revolves around a conceptualization of reflection involving re-examining knowledge that one already knows [75]; and in this direction designs can enable users to explicate what tacit knowledge they have, so that they can re-examine that knowledge in a reflective manner. Inquiry can also be fostered by enabling a critical dialogue between an individual and the (normative) values underlying a design [8] or enabling an individual to investigate the origins of knowledge they are presented with. At a basic level, designing for inquiry can mean giving users feedback on their past behaviors or actions through cues that allow or encourage inquiry [9]. Some examples in [9] discuss regarding designing for inquiry have to do with enabling users to review and reflect on past experiences through past personal data. Other examples involve enabling group discussions on past experiences or involve systems that contain discrete 'reflection' spaces that are specifically geared towards enabling explorative inquiry into personal experiences [9].

For (C), *transformation*, the focus is on personal change-making. Here reflection is about going beyond examining the present state of affairs and instead trying to envision alternatives for a future state. What designing for transformation, there is a need to enable users to make changes to the fundamental conceptualizations of a situation [9]. This means that PI systems geared towards reflection through transformation need to go beyond the typical paradigm where a particular design embodies a single, pre-determined conceptualization of a situation [9]. This is evident in the example of ChatterBox [40] which presents concatenated snippets of random text from office emails as discrete statements. Those statements are incomprehensible if a user approaches them with the normative technological approach of efficient and fast productivity. Instead, they only make sense once the user's approach is transformed to one which is more focused on 'slowness' of technology.

The themes (A), (B) and (C) discussed above were overall, big picture strategies for designing reflective informatics in general. Mols et al. [73] create a "design space for supporting everyday life reflection". Their conceptualization of such a design space can also provide ways to think about designing technological systems that can serve as a "reflection partner" for individuals with a focus on everyday lives. Technological systems can *trigger* reflection, *support* reflective processes or facilitate the *capture* of reflections [73]. These three possible roles are not mutually exclusive, and a particular system can also exhibit different roles at different moments in a reflective process [73].

A *trigger* role involves a trigger that nudges a user to reflect. Such a trigger can be some content (e.g. presenting data, media or even ambiguous data visualizations to provide a reflection direction) [73]; some direction which suggests a reflection type without constraining the content for it (e.g. telling a user to on the positives and negatives of a situation without specifying it) [73]; or it can be some opportunity that suggests that there is or could be time and space for reflection without specifying any further constraints [73]. A *support* role involves supporting a person's process of reflection either after a system has triggered the reflection or if the person has initiated it themselves [73]. Support can be in the form of enabling exploration of layers in data collected by the system, enabling exploration of personal data in a playful manner or it can simply be enabling a process of guided choices [73]. [73] encourage the use of subtle prompts and "embodied questions". E.g. their "PeelAway" concept has embodied layers designed to be peeled off one by one to get deeper and deeper into the underlying aspects of a thought or problem.

Another notable form of support is where an environment is created to encourage reflection by e.g. putting a metaphorical distance between a user and their current activities. In the third role of *capturing* reflections, systems can help finalize the reflective process by helping users with externalization of their thoughts, insights and reflections [73]. This can help bring "peace of mind" and can help create content triggers for the future. Technological systems serving as reflection partners can have one of the three roles for facilitating reflection: *trigger* role, *support* role or *capture* role [73]. It is important to re-emphasize that a particular system can partake in multiple roles at the same time or have different roles at different points in time.

Besides these three roles, [73] show three most prevalent strategies for stimulating reflection, where reflection can be: *dialogue driven, information driven, or expression driven* [73]. These three roles together with these three strategies form a 3x3 design space matrix, on which various applications can be positioned on various places; such that the role(s) incorporated in a particular system can be manifested through one of the strategies for reflection. This can be illustrated through the example of a project in [73] called "Life Tree". That project exhibits both a *trigger* and a *support* role, and these roles are manifested through an *information driven* approach. "Life Tree" is an art piece hung on the wall. The patterns in the art are abstract representations of user data (e.g. stress, activity, health). These artistic patterns can serve as triggers (*trigger* role) by encouraging a

user to further and more closely examine the art to discover patterns or surprises, but they also serve as non-obtrusive, peripheral reflection support (*support* role) by minimally creating a space of or encouragement for reflection. The project utilizes the *information-driven* approach because (as discussed below) it relies on presenting some form of data to the user [73].

Moving onto further details of the three strategies, *dialogue driven reflection* is where verbalized dialogue (written or spoken) is used to drive reflection [73]. This can be done by e.g. questions or prompts that encourage reflection. Questions that a probe a user regarding their feelings, the associations they are thinking of, their mood, their perceived motivations etc. can create a dialogue between a system and its user [73]. *Information driven reflection* is about driving reflection by presenting information or data [73]. Such an approach is particularly common for enabling pattern exploration or facilitating behavior change. Information driven reflection can be targeted towards uncovering information which might typically be invisible to a user [73]. It can also be aimed towards helping compare different data cuts or it can instead use ambiguity of data representations to encourage reflection [73]. Information driven reflection can also support a very explorative investigation of data by proving multiple views on it [73]. Finally, *expression driven reflection* has to do with enabling users to express themselves by externalizing their thoughts and feelings [73]. This can be open-ended and entirely user-driven, or it can be more guided and structured [73]. It can also take the shape of e.g. enabling users to create abstract representations of themselves that then trigger them to self-reflect [73].

A design space for everyday reflection was just discussed. It has the limitation of being a generative space rather than a process that describes the sequential stages a user might go through when they reflect (in the context of their personal data). Here, another work might help. Pirzadeh et al. come up with a three-stage reflection model based on how users typically experience the process of reflection [83]. Reflection in the form of thinking about past experiences, thoughts or insights is triggered by cues that create some form of "inner discomfort" (positive or negative) [83]. Such cues can be hardships, achievements, social contact, special and infrequent events, travel etc. They jostle individuals and stimulate them to think about what has happened [83]. These triggers start a "mind wandering" process as they afford a pathway for individuals to jump from one past thought to another; thereby facilitating the establishment of connections between past experiences and enabling a critical analysis of the current situation (based on what came before it) [83]. Such a critical analysis can reveal patterns in experiences that an individual goes through, and those patterns can foster even more reflection [83]. So, triggers lead to mind wandering which leads to critical analysis [83]. After such analysis, an individual gains a new perspective and learns from it. Based on the patterns that an individual uncovers regarding their personal experiences, they can learn and try to improve themselves in various ways [83].

Overall, various this subsection highlights that reflection in the context of personal informatics systems can come in a wide variety of forms. They vary in the medium they employ, in the type of reflection they foster and in the degree of reflection they enable. What all of them have in common is enabling self-knowledge through presenting personal information to users. Based on this, the following aspects of this principle are prioritized and summarized for designing digital wellbeing artifacts:

Designing digital wellbeing interfaces that act as information-driven triggers for inquiry

Serving as a trigger for nudging users towards reflection.

- A *trigger* role involves a trigger that nudges a user to reflect. Such a trigger can be some content (e.g. presenting data, media or even ambiguous data visualizations to provide a reflection direction) [73].
- Triggers lead to mind wandering which leads to critical analysis [83]. After such analysis, an individual gains a new perspective and learns from it. Based on the patterns that an individual uncovers regarding their personal experiences, they can learn and try to improve themselves in various ways [83].
- Nudges towards reflection can "help people collect personally relevant information for the purpose of self-reflection and gaining self-knowledge" [60].
- Reflection is an important stage in personal informatics models like [60]. Reflection phase in that PI model forms the basis for the final stage of the model that involves a user taking action for actually changing their behavior based on the insights gained from reflecting on their data [60].
- Trigger was, specifically, chosen because the artifact to be designed is meant to help smartphone users take a first step towards reflection and inquiry–rather than necessarily make a big change to their behavior. As that is not aligned with the previously discussed "nature of revisitation", as well as the feasibility of the study. A trigger approach fits well with this open-ended artifact approach, and it leaves room for bottom-up emergence of what type of reflection and behavior change is relevant to users of the to-be-designed digital wellbeing artifact.

Facilitating and creating opportunities for inquiry.

- Inquiry, especially when it is conscious and intentional, forms the basis of many reflection frameworks [9]. Indeed, reflection can even be conceptualized as inquiry [16]. So, facilitating inquiry and creating opportunities for it is directly tied to designing a system for stimulating reflection.
- Reflection as inquiry is conceptualized in a similar way to the scientific process of creating, testing, refining and retesting hypotheses [16]. Facilitating such an iterative, curiosity-driven process of testing and refining hypotheses regarding personal informatics can be one way to design for reflection through inquiry [9].
- Inquiry can also be fostered by enabling a critical dialogue between an individual and the (normative) values underlying a design [8] or enabling an individual to investigate the origins of knowledge they are presented with.
- At a basic level, designing for inquiry can mean giving users feedback on their past behaviors or actions through cues that allow or encourage inquiry [9]. Some examples in [9] discuss regarding designing for inquiry have to do with enabling users to review and reflect on past experiences through past personal data.
- Inquiry was chosen because it fits entirely with the exploratory nature of the study. By enabling users to form, test and refine their own hypotheses, inquiry leaves room for emergence of whatever users find interesting and whatever way they want to make sense of the feedback presented to them. An inquiry approach enables designing an artifact without many pre-conceived notions of how users should make sense of their data and what will be the most important cues and insights for them.

Enabling information-driven reflection.

- *Information-driven reflection* is about driving reflection by presenting information or data [73]. Such an approach is particularly common for enabling pattern exploration or facilitating behavior change.
- Information driven reflection can be targeted towards uncovering information which might typically be invisible to a user [73].
- It can also be aimed towards using ambiguity of data representations to encourage reflection [73].
- The project utilizes the *information-driven* approach because relies on presenting some form of revisitation data to the user.

DESIGNING FOR BEING TANGIBLE

Tangible interfaces are user interfaces where a user interacts with digital data through the physical environment and/or embodied means. The reason they present an impactful opportunity for building PI systems is because an analysis of related work ([49, 55]) shows that there is a greater chance of a user creating a stronger emotional bond with their interface device if the user interface is physical rather than digital (like apps typically are) [107]. Furthermore, tangible interfaces go significantly beyond mobile apps (related to wellbeing) in terms of providing additional sensing capabilities, and in terms of more effective capabilities regarding inputs (e.g. more intuitive self-reporting) and outputs (e.g. more suitable personal data communication especially for accessibility by all users) [107]. Overall, what then sets them apart especially with respect to digital means is that tangible interfaces provide "new, intuitive ways to interact with and visualize data", and tangible interfaces provide greater convenience and additional functionality for both the aforementioned inputs and outputs [107].

Most importantly, by not creating a dependence between new, desired behavior and the presence of a smartphone, tangible interfaces are more likely to enable longer term engagement with digital wellbeing data, as well as more longer-term habit formation [98]. Which is logical. It is difficult (perhaps not even 'designerly') to rely on a smartphone to give its user feedback on its own usage. Such an approach is quite prevalent in current purely digital interventions ([67,74]), but is paradoxical and could create a perpetual cycle: One is relying on having to come back to one's smartphone in order to track and get feedback on how one is using it.

The tangible and embodied interfaces paradigm also aligns with the way humans naturally make sense of their surroundings and experiences through sensory and cognitive means [26]. Making sense of ourselves is crucially driven by "embodied and felt experiences" [26]. There is a strong need to recognize that the living bodies and their sensations cannot be isolated from context, and therefore, we need to go beyond purely cognitive interfaces for sensemaking [26]. Sensemaking works at a sensory level, driven by bodily sensations and sensory knowing, both of which are prevalent in everyday lives Sensemaking is inherently embodied, and the embodied means of sensemaking in everyday experiences [26] can be leveraged through tangible interfaces for PI systems.

Tangible user interfaces bring 'physicality' to typical data visualizations through physical objects that are linked to digital representations [65]. With such an approach, there is potential for a novel approach to data representations that involves encoding of data in the affordances and experiences enabled by the representation [46]. Here data insight is facilitated through a human's natural abilities to sense the way something feels or is experienced. Such experiential data representations can leverage humans' natural interactive instincts and thereby allow researchers to enable data insight in a more natural and intuitive manner [46].

To enable a greater cooperation between a human user and a computational PI system, and to keep the user in the loop, there is a need for cyber-physical systems that serve as "supporting interaction technologies which make the human available" [80]. Tangible interfaces are such technologies that provide a direct way to keep the human user available by relying on their embodied self (or at least not by pulling them out of the 'real world' and into the virtual one of e.g. a smartphone). Moreover, again regarding PI systems, merely showing users visualizations of sensed data or sensor readings does not lead to increased insight regarding behavior change; but what can lead to that is having enhanced understanding of current user situations [80]. When it comes to PI systems specifically geared towards digital wellbeing, tangible interfaces can provide unique opportunities for

incorporating physical interaction restraints like controlling lights (if a restraint-driven approach for self-regulation is employed) [55]. Tangible interfaces can also be used to a create "digital wellbeing agents" that that can bring a physical dimension and enhanced persuasive and restrictive mechanisms to PI systems–with the possibility to be usable in diverse use contexts [55].

Tangible interfaces hold the potential to replace traditional self-reporting as they allow users to report their typically difficult to communicate inner states in real-time and through easier methods (compared to e.g. having to rely on diary entries) [107]. Whilst the use of tangible interfaces can be quite exciting for users, their design and functionality need prioritizing to enable long-term engagement [107]. Tangible interfaces can make traditional wellbeing treatments more "accessible and user-centric" and are more engaging due to their abilities regarding encoding various data (e.g. different moods) in tangible feedback (e.g. colored lights) [107]. They also counter a privacy concern that users targeting a particular wellbeing goal might have: A user might only want to share their personal data (regarding their behavior at hand) with individuals they trust to act responsibly with the user's interests in mind [107].

By potentially offering the possibility to enable users to encode their personal data or states in the tangible interface's output in a way that is tailor-made to them, such an interface can limit the number of people who can decode the users' states being displayed by the interface [107]. Tangible interfaces allow users to communicate their inner states or personal data privately, they can be easier to use than e.g. words, and they enable user to monitor their own data over time, all of which can have benefits over traditional methods [107]. Tangible interfaces provide the possibilities to include sensors for additional data collection or for intuitive interaction methods, and they also enable unique input/output capabilities that can be e.g. tactile, movement-related, haptic, sound-related, touchable or visual [107]. This can enhance their educational, sensing and behavior change potential regarding wellbeing, when compared to traditional approaches [107].

This pairing of various sensors with tangible, real-world feedback is a significant plus point of tangible interfaces for improving users' wellbeing [107]. The sensing part can involve physiological signals (e.g. HRV, EEG, HR, EDA) or inputs like force and movement. These inputs allow automatic detection of relevant measures related to an intended behavior (e.g. stress detection). They are coupled with unique and engaging feedback or output possibilities like dynamic tactile feedback, movement, vibrotactile feedback, haptic feedback or even massage motors [107]. Here e.g. haptic feedback can recreate a sense of touch to emotionally reach a user or dynamic tactile feedback can influence a user's movement [107].

So, overall, tangible interfaces can sense certain wellbeing measures and provide real-time, novel feedback regarding them; with special characteristics that make them more engaging than alternatives. Based on this, the following aspects of this principle are prioritized and summarized for designing digital wellbeing artifacts:

Designing digital wellbeing interventions as tangible artifacts

Being tangible/physical.

- Being tangible can offer more effective capabilities regarding its output or feedback (e.g. more suitable personal data communication especially for accessibility by all users) [107]. That can enable "new, intuitive ways to interact with and visualize data" and can allow greater convenience [107].
- Tangible interfaces are an example of "supporting interaction technologies which make the human available" [80].
- Tangible interfaces can be used to a create "digital wellbeing agents" that that can bring a physical dimension and enhanced persuasive and restrictive mechanisms to PI systems–with the possibility to be usable in diverse use contexts [55].
- Tangible interfaces can make traditional wellbeing treatments more "accessible and user-centric" and are more engaging due to their abilities regarding encoding various wellbeing related data in tangible feedback (e.g. colored lights) [83].
- Merely tangible, rather than truly "embodied", interfaces are considered because the tangible interfaces are more feasible to achieve, have less development constraints, less sensing requirements and require less training/learning time from participants. They also could be easier to prototype in the limited time and resources available due to the COVID-19 situation.

Utilizing a tangible medium decoupled from a smartphone.

- By not creating a dependence between new, desired behavior and the presence of a smartphone, tangible interface are more likely to enable longer term engagement with digital wellbeing data, as well as more longer-term habit formation [98].
- It is difficult (perhaps not even 'designerly') to rely on a smartphone to give its user feedback on its own usage. Such an approach is quite prevalent in current purely digital interventions ([67,74]), but is paradoxical and could create a perpetual cycle: One is relying on having to come back to one's smartphone in order to track and get feedback on how one is using it.

DESIGNING FOR BEING AMBIENT

Ambient interfaces also hold a unique opportunity to be integrated with personal informatics systems. Ambient interfaces are meant be working in the background or periphery of one's attention [6] and are meant to deliver the essence of information through quick glances [69]. The primary justification behind their inclusion is the potential they hold to mitigate a few significant design issues regarding PI systems: Burdensome usage of PI systems and easy accessibility of feedback [38]. Users can find it hard to interpret a PI system's feedback to them, and they can also face the burden of maintaining such systems and fulfilling their use requirements [38]. Ambient displays or ambient awareness can help improve the user experience of PI systems by requiring only minimal user attention [38]. The overall burden of PI systems can even be diminished by through ambient interfaces which give feedback or present information to users in a manner that only requires minor attention from them [20].

There are design recommendations to leverage such interfaces to explicate the user-system interaction status and to inform the user about the degree of their progress towards their goals–all without burdening the user too much [38]. Work on information visualization provides guidelines on how to best approach such visualizations in order to provide users with as much clarity and usefulness as possible [19, 69]. Such guidelines revolve around: reducing the time it takes to answer questions, creating confidence and knowledge on data, aiding with insight generation and follow-up questioning, and distilling the crux of data being presented [97]. Gulotta et al. describe the essence of all such guidelines for designing ambient interfaces or displays in two factors that result in users leaving PI systems: First being the user perception that a system lacks usefulness, and second being the user perception that a system requires too much maintenance [38].

Based on these two factors, the authors suggest the need for ambient displays to be designed consciously to convey appropriate usefulness [38]. They suggest e.g. using metaphors from nature to convey information in an unobtrusive manner [38]. The work of [38] refers to UbiFit as an example of a PI system that, because of its abstract and glanceable information representation, enhanced reflection on user goals and behaviors. Another ambient system [39] visualized energy consumption through a lit power cord and yet another one [49] experimented with information representations using natural metaphors of water and wind that can shift back and forth between being ambient (in the background) and being explicit (in the foreground). [53] give a similar idea for designing "implicit interactions" with the possibility for there to be dynamic shifts in the attentional demand of such interactions; where e.g. an alarm clock is in the attentional foreground when the user sets it, but it shifts to the background when it indicates its 'alarm set' state.

Glanceable displays (e.g. watchfaces of smartwatches) are strongly related to ambient interfaces as well. Like ambient interfaces, they are meant to be in the periphery of one's attention and be able to convey information by quick glances. Presenting abstract, quickly digestible information at locations of frequent gazing can help individuals self-regulate particular behaviors [37]. The two most common properties that characterize the design space of glanceable displays are: "abstract" and "integrates with existing activities" [37]. "Abstract" is quite prevalent in existing prototypes and products [37]. Displaying data abstractions (rather than raw data) to users enables them to perceive and make sense of information without requiring much conscious thought and attention [41]. This can enable rapid awareness of and reflection on one's habits and behaviors [22]. "Integrates

with existing activities" has to do with interweaving the ambient feedback into frequent activities or frequently accessed locations to make it more likely to be glanced (e.g. in one's peripheral vision) [37].

There is a whole paradigm of reflection that is really suited to ambient interfaces. It has to do with enabling individuals to exercise "reflection-in-action". Reflection-in-action concerns reflection of "practitioners in the midst of a performance to inform the action currently in progress" [3]. So, this type of reflection happens in-situ amidst an ongoing activity; instead of as a post-hoc event once the activity is finished [3]. Reflection-in-action is, therefore, about ongoing performance and the situation at present [3]. It is immensely dependent on context and is interleaved with ongoing performance (meaning it occurs *'in action'*) [3]. It also occurs over very short time-frames due to its momentary, situational nature [3]. Whilst it is somewhat conscious, it mostly relies on "tacit know-how" and intuition to ensure it is not disruptive to ongoing practice [3]. Focusing on designing for reflection-in-action can be especially useful for breaking individuals out of their "over-routinized" activities, and for helping them become more responsive and receptive to changes in their everyday practices [3]. Due to their ability to be very unobtrusive and subtle, and due to their ability to spatially and ubiquitously distribute relevant information or feedback, ambient interfaces discussed in this section are a strong candidate for interaction technologies geared towards enabling reflection-in-action. Amongst others, the project in [3] provides clear evidence for this potential of ambient interfaces to act as enablers of reflection-in-action.

All such projects and directions give significant evidence to support the prospect of inclusion of ambient interfaces in PI systems, and also show the opportunity that lies there on further researching ambient visual representations of a PI system's output. Based on this, the following aspects of this principle are prioritized and summarized for designing digital wellbeing artifacts:

Designing digital wellbeing systems that are unobtrusive and glanceable

Being in periphery and delivering the essence of information through quick glances.

- Ambient interfaces can mitigate a few significant design issues regarding PI systems: Burdensome usage of PI systems and easy accessibility of feedback [38].
- Ambient displays or ambient awareness can help improve the user experience of PI systems by requiring only minimal user attention [38].
- Overall burden of PI systems can even be diminished by through ambient interfaces which give feedback or present information to users in a manner that only requires minor attention from them [20].

Presenting abstract, glanceable information and integrating with existing activities.

- Presenting abstract, quickly digestible information at locations of frequent gazing can help individuals self-regulate particular behaviors [37].
- Displaying data abstractions (rather than raw data) to users enables them to perceive and make sense of information without requiring much conscious thought and attention [41]. This can enable rapid awareness of and reflection on one's habits and behaviors [22].
- Such feedback should be designed for interweaving into frequent activities or frequently accessed locations to make it more likely to be glanced (e.g. in one's peripheral vision) [37].

OVERVIEW OF THE FIVE OPPORTUNISTIC DESIGN PRINCIPLES

After all their details above, below the are five chosen principles for designing for digital wellbeing within this project.

Part II: Revisitation Reflector–A case study on digital wellbeing

This part considers the case study of the "Revisitation Reflector"; a digital wellbeing artifact that is based on the revisitation metric that has already been discussed in the previous part. Next, it considers the concrete Revisitation Reflector artifact that was designed based on these prioritized values. The process of reaching the artifact's concept, the artifact itself, its design, its implementation decisions and how the prioritized values are embedded in it are all thoroughly considered. All this helps address **GQ1.3 ("What concept can be designed and implemented based on the prioritized values?").** Finally, a field study where the artifact is tested in the wild is considered; its procedure and findings are presented, which together address **GQ2.1 ("How do users make sense of such an artifact's feedback?"), GQ2.2 ("What do they think of the role of the artifact and its effect on smartphone usage?")** and **GQ2.3 ("What are their impressions of the artifact's design?").**

Overall, this part considers the themes of:

- Priority values/requirements for this case study's artifact derived from the five opportunistic design principles
- Revisitation Reflector: final concept and implementation
- Field study on the Revisitation Reflector

4

Revisitation Reflector: Concept and implementation

CONVERGING TO A CONCEPT DIRECTION

So far, various elements and aspects of five opportunistic design principles for this case study were discussed. Based on the criteria of feasibility, nature of revisitation, novelty and relevance, a handful of specific values were prioritized from all the various aspects of these design principles. Next, based on all that was learned from related work discussed thus far, several concepts were ideated. This process was done without letting feasibility affect the ideation. These concepts were grouped together in various clusters or directions. Once several concepts (and concept directions) were generated, there had to be a convergence towards a few directions. For the convergence to a few directions, a feasibility analysis was done based on how implementable the concepts in that direction would be with the available expertise, time and resources.

There were three concept directions or themes that were eventually chosen: (i) creating a toolkit that lets users design their own digital wellbeing artifact/agent with their own digital wellbeing metrics, goals etc.; (ii) creating a tangible artifact focused specifically on giving revisitation feedback; and (iii) adopting a modeling approach and trying to model and analyze users' smartphone habits based on existing datasets. These concept directions were chosen primarily based on feasibility. Each of the three chosen concepts had concrete, real-world building blocks tied to it that would ensure that the concept would actually be implementable. Concept direction (i) could be built upon Google's open source digital wellbeing experiments on various digital wellbeing aspects [google]; concept direction (ii) could be implemented using a smartphone framework (called AWARE) for background data collection on smartphone usage, in combination with an IoT device like a Raspberry Pi or ESP32 for tangible feedback; and concept direction (iii) could be centered around modeling libraries and some existing datasets of long-term smartphone usage across hundreds of users.

Next, preliminary, rapid and minimal experimentation and prototyping was done regarding all three concept directions to get a better idea of their feasibility and also how specific concepts arising from them could

concretely take shape; basically, to get a better, more concrete 'feel' for the three concept directions and see how they could be shaped to fit with the project's design principles. After such a concrete understanding was developed for all the directions, a single direction had to be chosen and turned into a single concept. For this, all three concept directions were rated on the following five criteria (in order of importance): COVID-19-proofness (e.g. degree of active, in-person user involvement required); feasibility; appropriability to the study's prioritized design principles and values; replicability/scalability (e.g. whether many copies of the intervention could be made); and being open-source. Based on the ratings, concept direction (ii) was chosen as the most suitable concept for turning into a final prototype.

FINAL CONCEPT: REVISITATION REFLECTOR

The convenient part about selection of the concept direction (ii) from above was that it was already quite focused: "creating a tangible artifact focused specifically on giving revisitation feedback". At a high level, there were two functionalities needed to make this work. Firstly, being able to sense a user's smartphone revisitations, and secondly, being able to give tangible feedback to the user based on the sensed revisitations. For the first function, an existing, open source and widely researched framework was used for collecting, amongst a lot of other possibilities, smartphone usage data. This framework is called AWARE [34] and it appears in many studies, e.g. [11,12,21,33,94,108]. It collects this data automatically whilst running in the background, without requiring any extra effort from the users.

For the second function, a Raspberry Pi in combination with a high-density LED stick was used in order to display the revisitation feedback. But before the feedback could be displayed, the sensed data from a user's phone had to be received to be processed. This data sensed from a user's phone by AWARE was sent to and stored in a database server. The Raspberry Pi would then be able to retrieve the required data from that server. These components and the flow of the process between them is visualized in figure 1. They together form the implementation of the concept that came to be known as the, "Revisitation Reflector".

The way the Revisitation Reflector works can be boiled down to a number of sequential steps. First, the AWARE app running in the background of the user's smartphone continuously tracks the phone's screen state (on, off, locked or unlocked). A time stamped local database is kept of the tracked screen states. This local database is synced with an online database server also hosted by the AWARE platform. This syncing happens every five minutes. At the same time, the Revisitation Reflector's two main components (Raspberry Pi and LED stick) are in action.

Every twenty minutes, the Raspberry Pi queries the remote database server to check when it was last synced with the user's phone i.e. when the user's phone last sent AWARE's recorded screen status data to the server. If there has been a sync somewhere within the past hour, then AWARE fetches from the server all the tracked screen states' data collected so far. The Pi then processes this data. This involves selecting data whose timestamps lie within the past hour. A 'revisitation vector' for the past hour is then extracted from this past hour screen states data. This vector is simply a vector of eight revisitation bins with inter-visit times of: 1, 2, 4, 8, 15, 30, 45, and 60+ minutes. It shows the relative percentage of the number of times a user revisits their phone within 1, 2, 4 ,8, 15, 30, 45 or 60+ minutes following a previous phone use. The revisitation vector, thus, captures the relative revisitation pattern for a user. This pattern then needs to be converted to visual feedback for the user.

This is where the LED stick component of the Revisitation Reflector comes in. Each LED on the 8-LED stick corresponds to a revisitation bin (figure 2). The value (relative, normalized revisitation percentage or likelihood)

of each bin informs the color of its corresponding LED (figure 2). In this way, the screen states' data tracked from a user's phone is turned into tangible, visual feedback on their revisitation pattern. This revisitation pattern is updated every twenty minutes, and it manifests the user's revisitation behavior from the past hour from the time at which the update occurs. The overall process's overview is presented in figure 1.

There are also three error codes that appear to indicate to users if there is something hindering the functioning of the system. These are displayed through distinctively colored, slow LED pulsations. The entire LED stick slowly fades in and out in pink, white or yellow colors to display these codes (colors that are not part of the revisitation feedback palette). These colors indicate: the user's Wi-Fi network not being connected; the user's phone Wi-Fi not being connected or the user's phone data not syncing with the remote database server. They let the user be aware of why the revisitation feedback might not be updating and what could a simple solution be (like simply making sure their Wi-Fi is still connected).

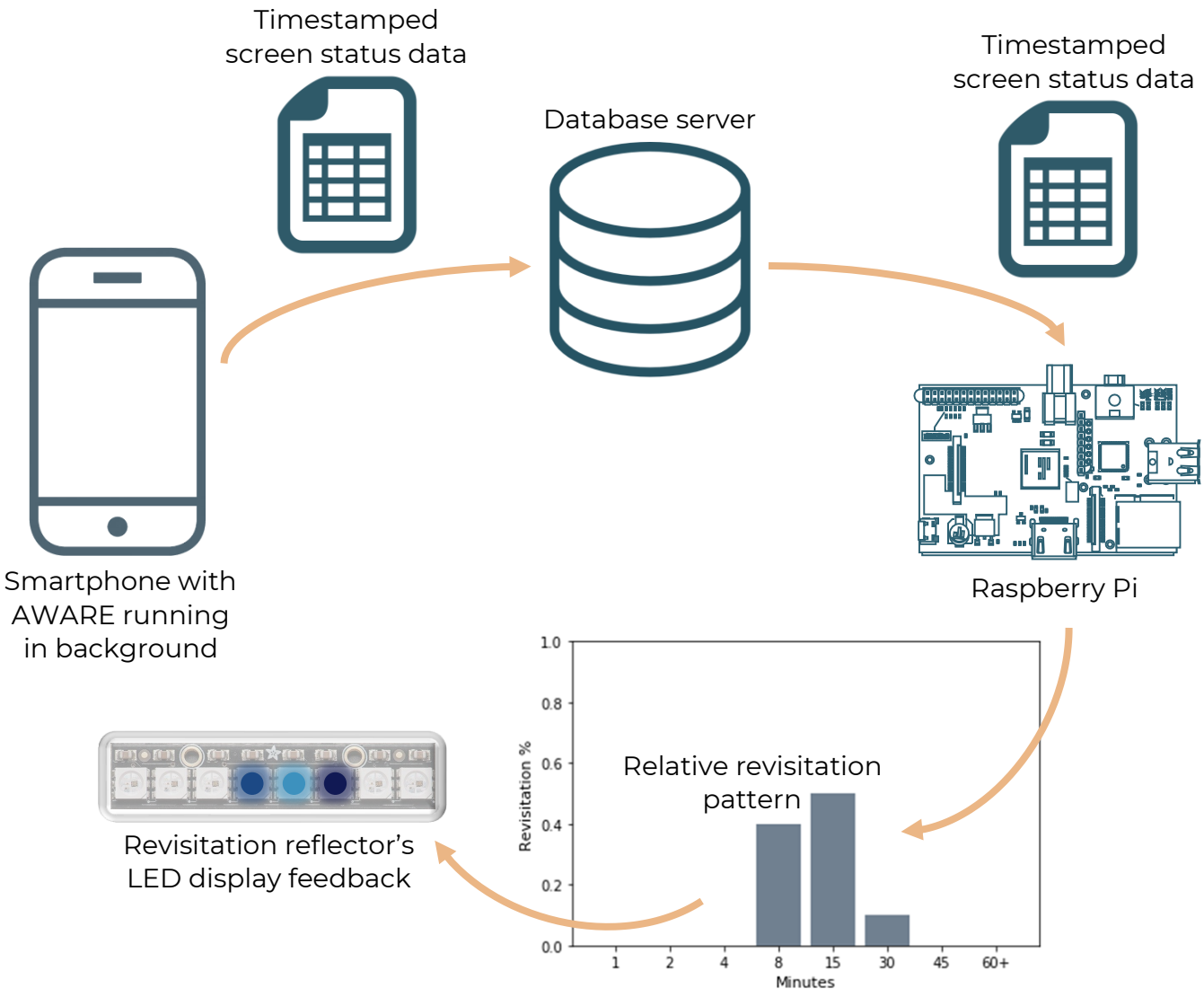


Figure 1: Overview of the Revisitation Reflector's Workings

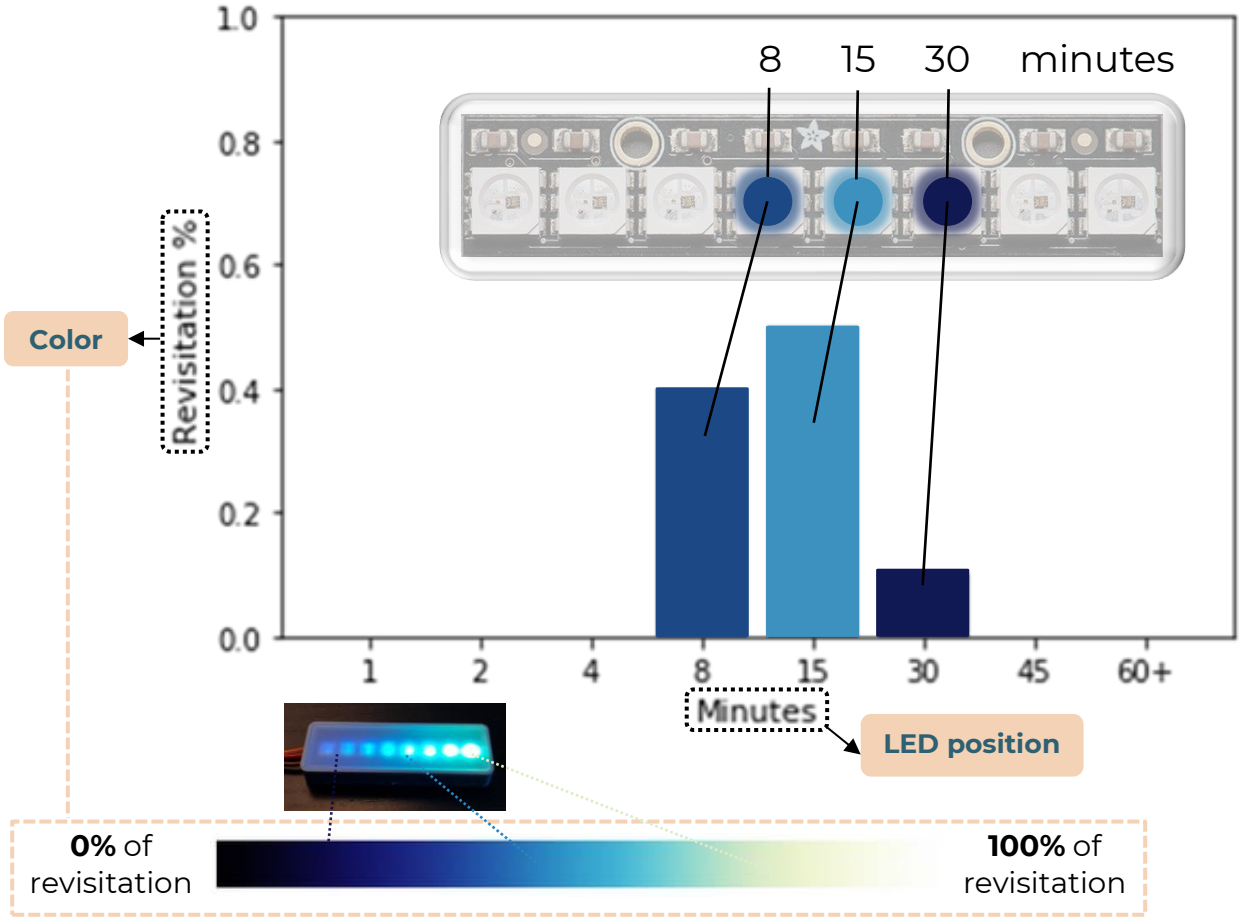
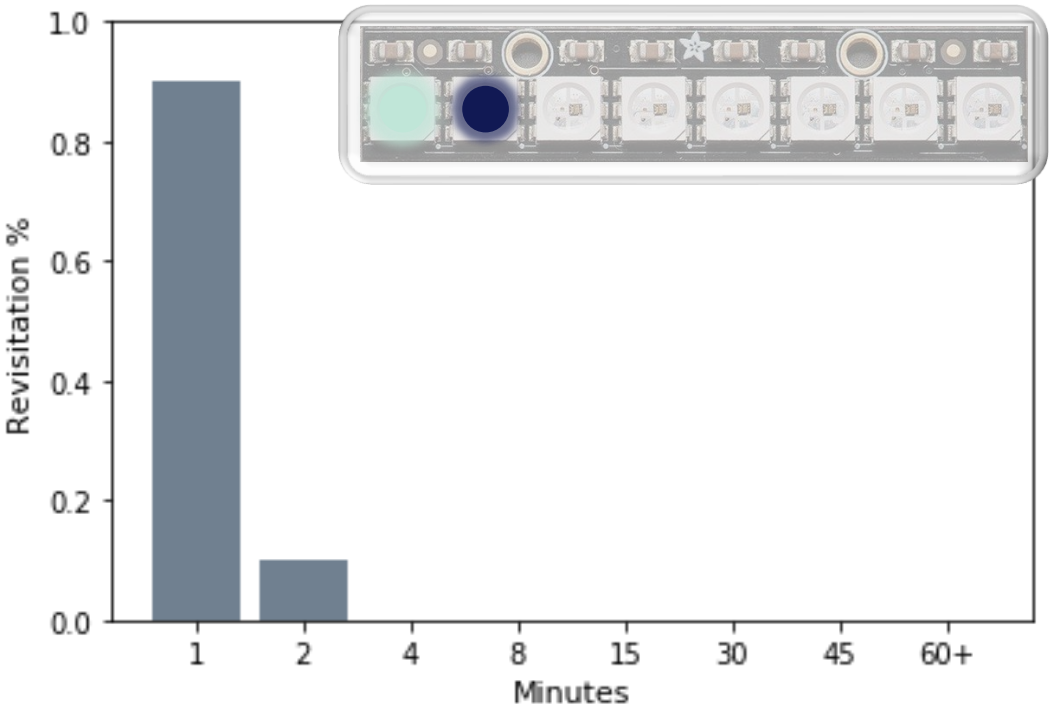


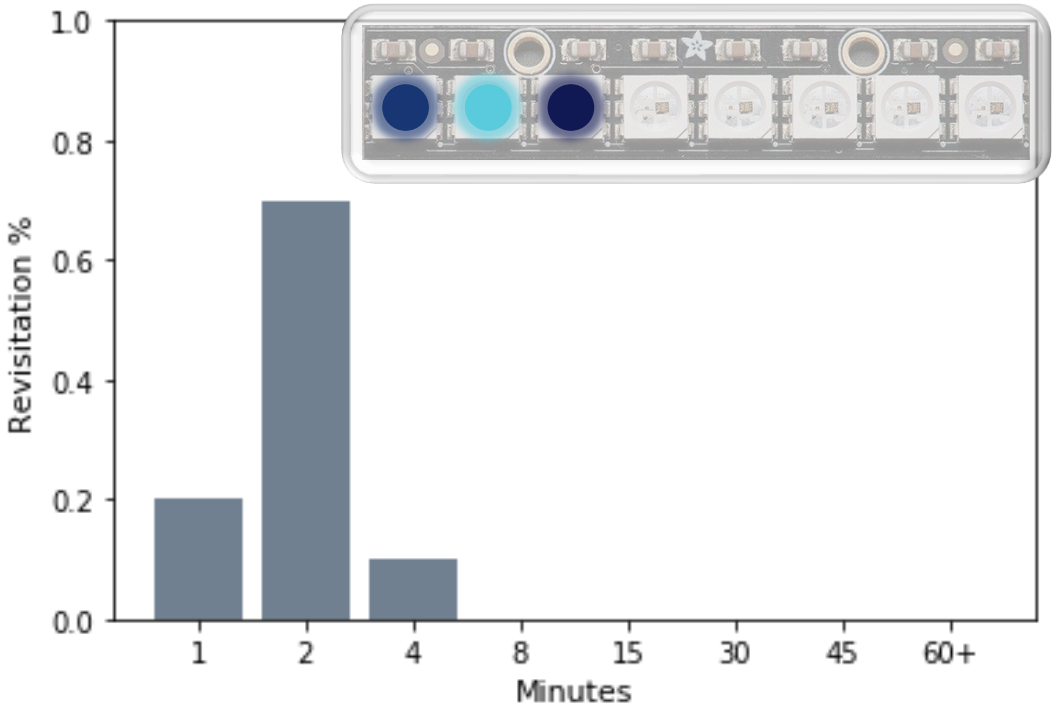
Figure 2: How a user's revisitation pattern is encoded in the Revisitation Reflector's LED feedback

EXAMPLES OF REVISITATION FEEDBACK

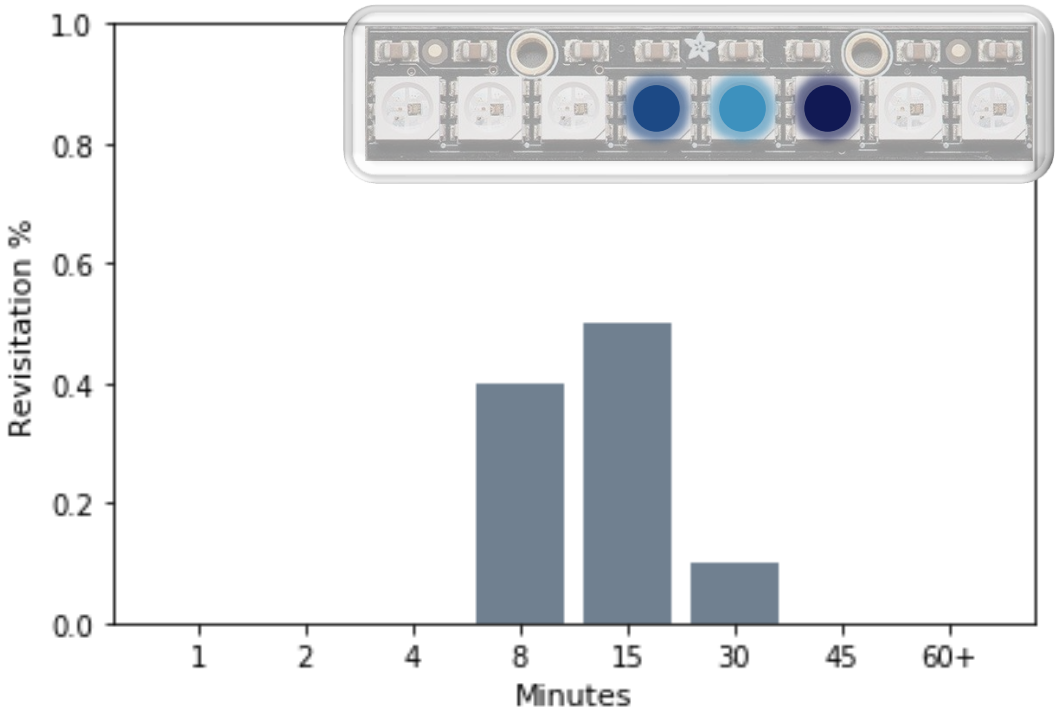
Below are examples of various types of revisitation feedback. They show how various revisitation patterns were transformed to the LED display's feedback. It must be stressed that these colors do not exactly represent how the feedback looked like when viewing the LEDs in the real world. These colors are merely a *very rough approximation* of what the LED feedback was, as capturing true color photos of LEDs is a difficult task that was not a necessary part of this project. The next section will also explain how this LED feedback was adjusted to ensure that it appeared as true as possible to the intended palette from figure 2 above.

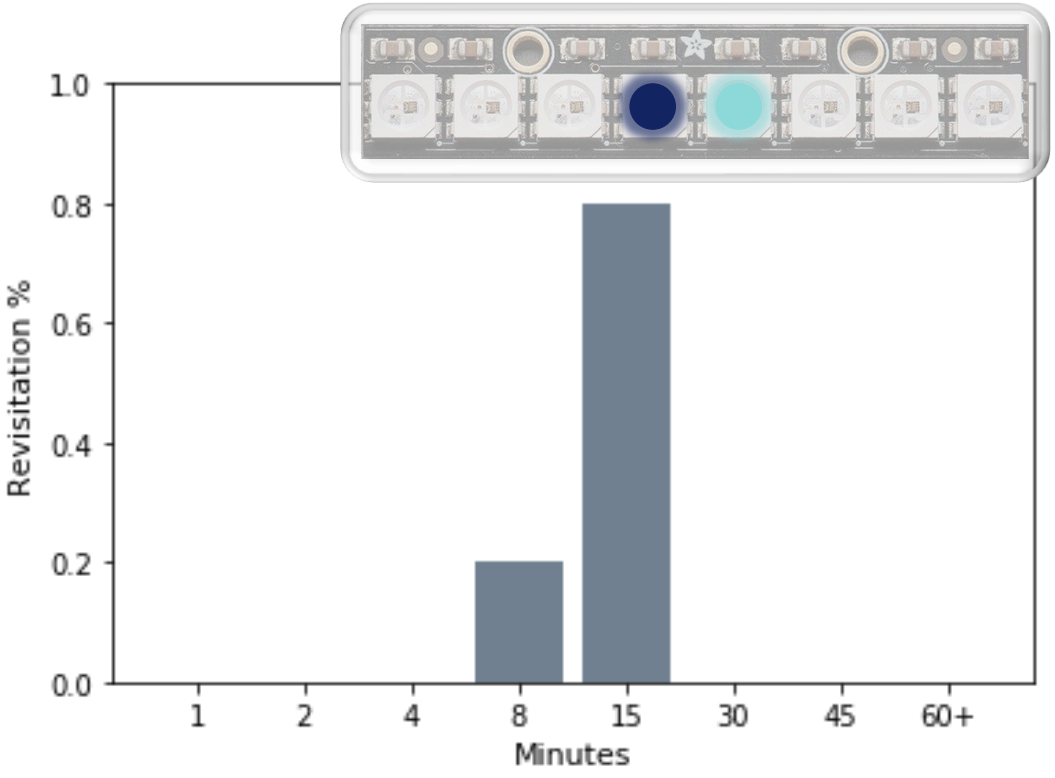
Fast revisitation



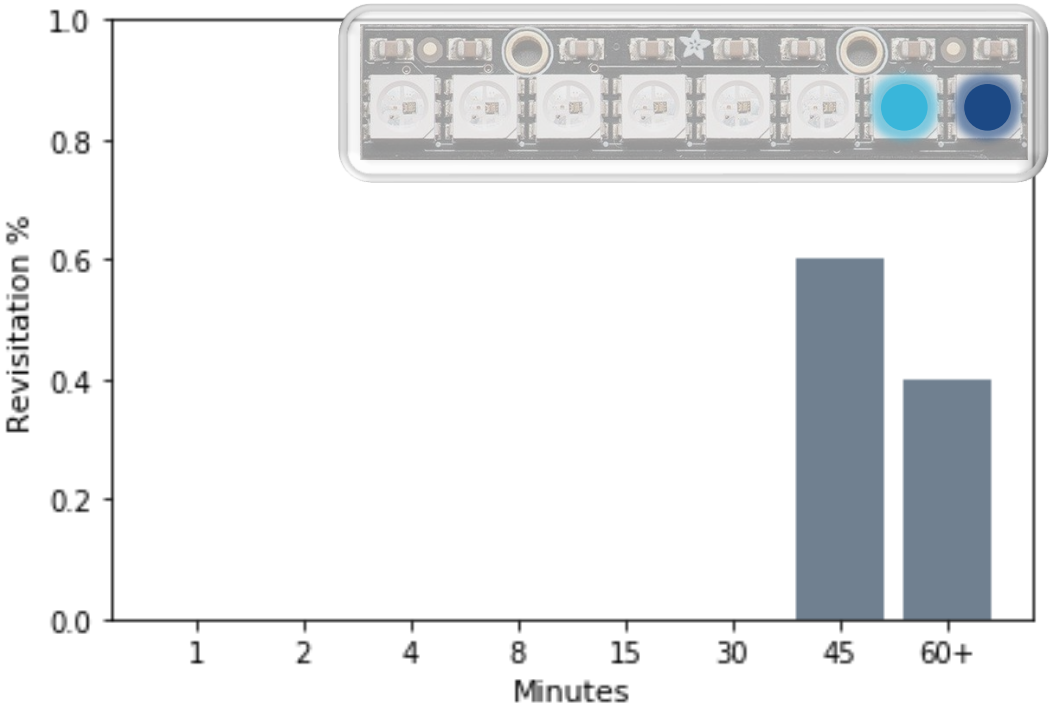


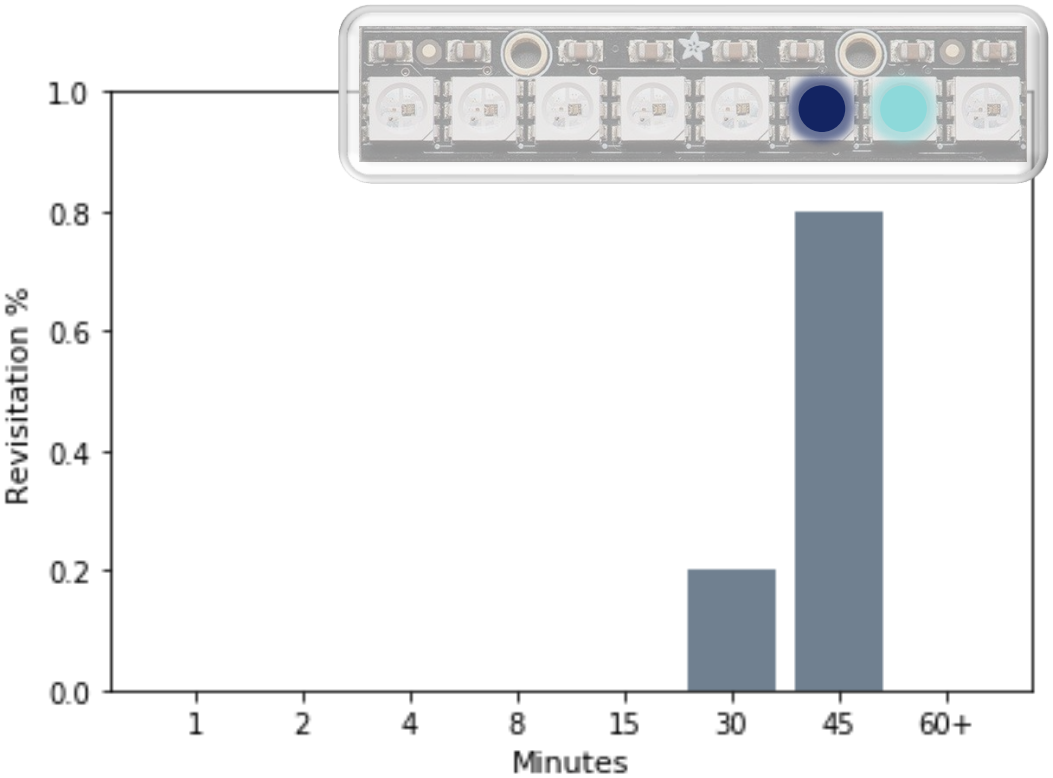
Medium revisitation



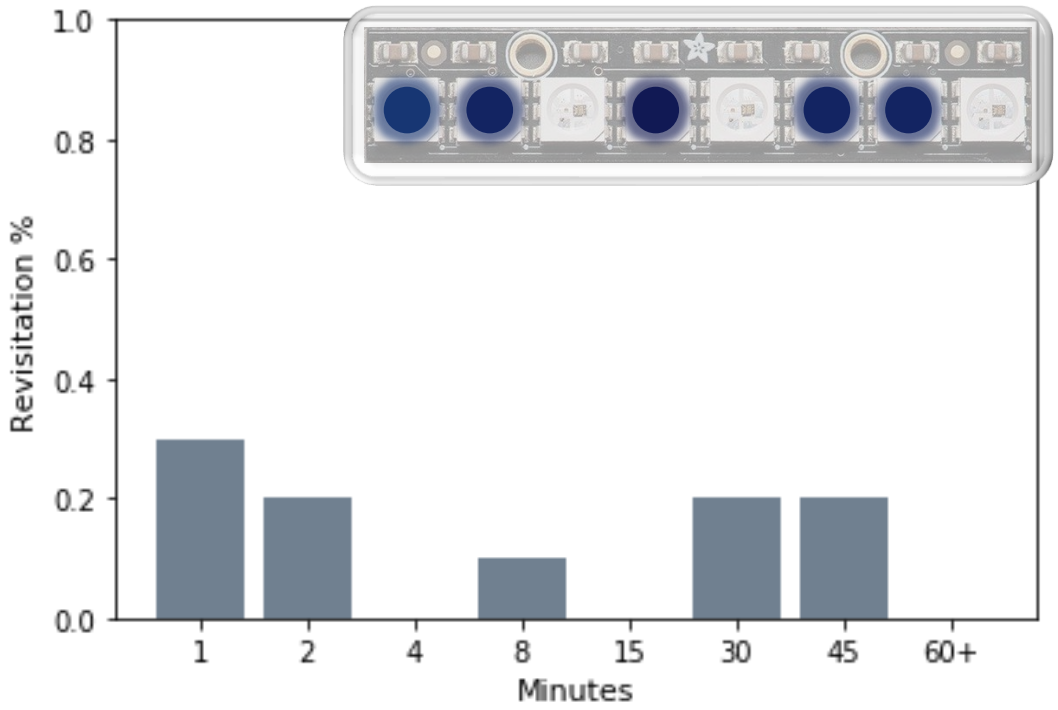


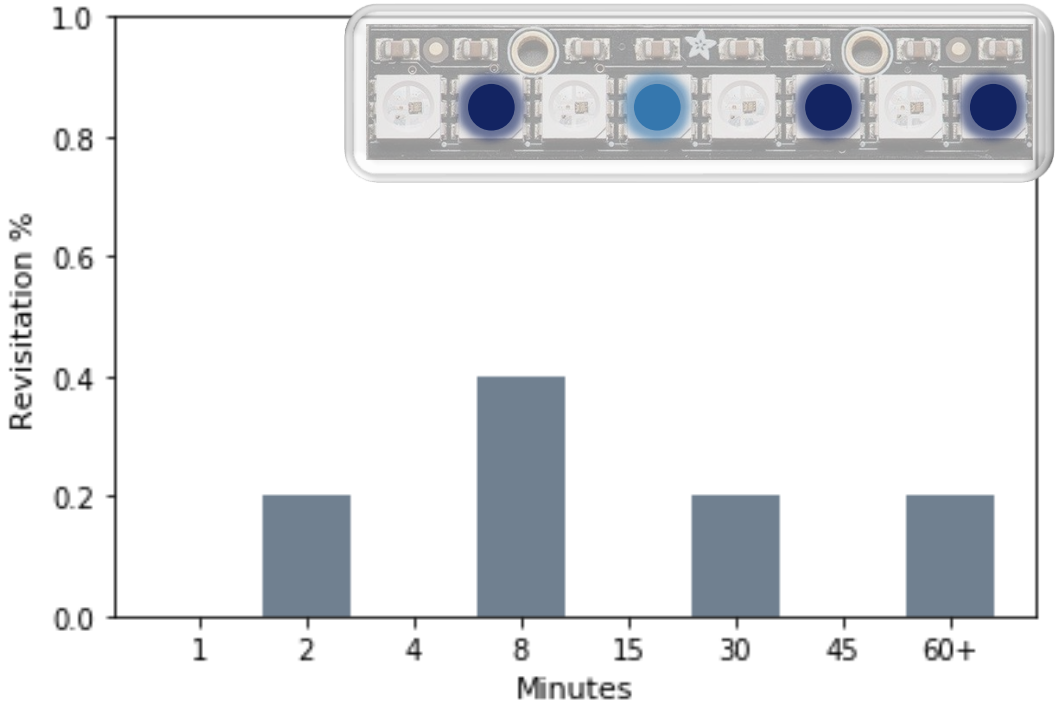
Slow revisitation





Hybrid revisitation





IMPLEMENTATION DECISIONS AND THEIR JUSTIFICATIONS

Many concrete implementation decisions were made when developing prototypes of the Revisitation Reflector. These decisions were made after careful thought and consideration. All of them had systematic justifications

behind them based on literature, the chosen design principles and values, preliminary testing with the researcher and with one pilot test participant or best practices. The list below presents an overview of the implementation decisions that were taken when building the Revisitation Reflector:

- Revisitation pattern of the past one hour is shown.
- Revisitation pattern updates every twenty minutes.
- Screen state data collected by the AWARE app on a user's smartphone is synced every five minutes with the remote database.
- The color palette shown in figure 2 was used to encode the relative revisitation percentages. The color palette was applied to the LEDs in combination with gamma correction.
- Revisitation was used as the metric to track and give feedback on.
- A vector of relative revisitation percentages was used to define the feedback output of the display.
- The feedback displayed is based on a 'revisitation vector' for the past hour. This vector is simply a vector of eight revisitation bins with inter-visit times of: 1, 2, 4, 8, 15, 30, 45, and 60+ minutes.
- The form with a cased Raspberry Pi and a cased, compact high-density LED stick.
- Raspberry Pi with an LED stick was used as the hardware components.
- AWARE was used as the smartphone app or framework to track a user's revisitation data.

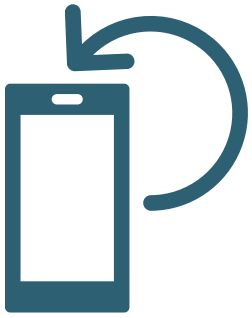
As already said, these decisions were based on comprehensive and systematic justifications. **The table in Appendix B outlines these justifications behind the implementation decisions.**

THE FIVE DESIGN PRINCIPLES EMBEDDED IN THE ARTIFACT

Earlier on, the priority values for this case study's artifact were derived from the five opportunistic design principles. These were already presented in chapter 3. That chapter presented these priority values together with related insights from literature. These values were meant to be embedded in the artifact to be designed. For brevity, this section merely lists below an overview of those values in the way that they were embedded in the Revisitation Reflector artifact. The question of **how** exactly those values were concretely embedded in the artifact is discussed in Appendix C. It also discusses the **systematic, practical and literature-related justifications** for why these specific values were chosen to be embedded in the artifact; and more importantly, **why** they were embedded in the chosen forms and ways.

Designing for revisitation feedback: Designing digital wellbeing interventions that utilize revisitation as their metric of purpose, tracking and feedback

The Revisitation Reflector:



- Is fundamentally based on revisitation and giving users awareness of their revisitation habits.
- Incorporates revisitation as a metric to give users feedback on, as well as a metric that the artifact's purpose is based on. Revisitation Reflector's purpose is to enable awareness and inquiry (reflection) on revisitation. It incorporates revisitation in the same way recommenced by the related studies: a vector of exponentially distant bins of inter-visit times. It uses revisitation at the macro-level of the phone.

- Allows self-tracking of and feedback on revisitation without any pre-conceived normativity, goals, rewards, or punishments–as prioritized earlier.
- Tracks revisitation patterns and delivers persistent feedback on them as visual cues through an LED stick (as recommended). Again, as highlighted in related work, the tracking and feedback lets users become aware of their near past revisitation, as the feedback delivered is always about the past hour revisitation.

Designing for lived experience: Designing digital wellbeing systems to interweave with users' everyday lives and the subjective experiences they contain

The Revisitation Reflector:

- Is appropriable by users for whatever purposes, needs and contexts they are interested in. Users can make sense of it however they want to, they can draw whatever conclusions they think are there and they can set it up in whatever space or context they want.
- Is meant for being interwoven into whatever its user is doing during the day. It does not demand explicit attention or obstruction of daily activities. As recommended, it also does not assume that users just want to do rational data collection and only reflect on it after it has been thoroughly analyzed.
- Is meant to be interwoven in everyday lives and be a part of a user's subjective experiences. Just as discussed in the above points.

Designing for being reflective: Designing digital wellbeing interfaces that act as information-driven triggers for inquiry

The Revisitation Reflector:

- Has a primarily trigger role. It is a trigger through presenting abstract data cues (as recommended), whilst leaving room for bottom-up emergence of what type of feedback, reflection and behavior change is relevant to individual users.
- Is designed to facilitate inquiry. Amongst other things, as recommended by related work, the Revisitation Reflector tries to stimulate a process of creating, testing and refining hypotheses regarding one's revisitation patterns. It does this by having abstract feedback that is constantly updating, so one can try something and try to explore its effect on the feedback outcome. It also enables this by following the recommendation of letting users review and reflect on past experiences through past personal data (by giving them continuously updating feedback on past data). It is also designed without many pre-conceived notions of how users should make sense of their data and what will be the most important cues and insights for them.
- Is inherently information-driven by being based on a user's revisitation data. Such data is typically invisible to a user and uncovering it aligns with information-driven ethos. Again, here, as recommended, somewhat ambiguous data representation (encoding relative revisitation into a LED color palette) is used to help with reflection encouragement.

Designing for being tangible: Designing digital wellbeing interventions as tangible artifacts

The Revisitation Reflector:

- Is a tangible artifact. It gives a physically persistent form to feedback on personal revisitation data and it visualizes it in a way which is novel within the typical digital wellbeing interventions. By being decoupled from a user's phone, it enables the human to stay available in the real world rather than the virtual one. It is based on one of the potentially engaging, effective and accessible modalities of visual (colored) cues.
- Is literally external to a user's phone. Revisitation Reflector is its own discrete device that is completely decoupled from the user's phone and does not require the user to interact with or visit their phone in order to get their current revisitation feedback status.

Designing for being ambient: Designing digital wellbeing systems that are unobtrusive and glanceable

The Revisitation Reflector:

- Is a completely ambient display that is designed to be glanceable. It is designed to be non-obtrusive and be in the periphery by virtue of its size, minimal design and minimal LED feedback. The LED stick relies on just LED colors and positions to give feedback that is glanceable. Since this feedback mechanism is also quite minimal and does not demand explicit attention, it is inherently ambient.
- Relies on using minimal, abstract light feedback. It follows the recommendation of using data abstraction of revisitation pattern, to turn it into simple feedback that is quick to process and is not meant to require much conscious thought or attention. By being in an everyday, domestic context, the display is poised to be gazed at relatively frequently.
- Allows itself to interweave with everyday activities.

5

Field Study on the Revisitation Reflector

OVERVIEW

The procedure of this field study was closely inspired by the methodology of two related studies: [37] and [86]. The field study in Gouveia et al.'s project is related to this project because of its similar focus on glanceable, ambient feedback on personal data [37]. It also has common ground with the project's overall purpose and with its design principle of "designing for being ambient". The field study in Rooksby et al.'s project is related to this project because of its same domain, of digital wellbeing, as well as the similar aim of visualizing and giving feedback on some dimension of users' smartphone usage data [86]. The precise nature of the field study that was conducted in this project is that of field user experience testing, meaning it is about letting participants try the Revisitation Reflector artifact within their natural environments over a longitudinal period [47].

Three identical prototypes of the Revisitation Reflector artifact were created and were then deployed in the field to be used, experimented and tested by seven participants (scheduled in turns due to limited number of prototypes). The study would last at least seven days for each participant and would include at least four days of exposure to the Revisitation Reflector (this duration will be explained later). The purpose of the study was to: gauge participants' impressions on the artifact; investigate how they engage with, make sense of, appropriate and/or use the feedback from the artifact; and find out what effect, if any, did the artifact have on the participants' smartphone usage.

Like [37], the goal of this exploratory study was *not* to evaluate the artifact on its behavior change effectiveness. That is because the study was highly limited in terms of the size and representativeness of its sample, as well as the duration for which each participant could keep and use their Revisitation Reflector. COVID-19's impact on participant and resource availability further aggravated these limitations. So, then overall, like [37], the study was designed in this longitudinal manner and to be carried out in naturalistic, field environments (in the participants' homes) to investigate the participants' experiences with the artifact that would surpass the initial reactions–which would more likely be the case in a short (non-longitudinal) lab study.

Such field deployment within naturalistic conditions would also help with increasing the ecological validity of the findings beyond what would be the case in a short lab study. Within a typical lab setting, it is quite difficult

to "emulate people's environment" or their typical ways of working and going about their lives [47]. Particularly when designing something which is based on IoT (Internet of Things) and something which relies on being situated or localized to a particular (physical) spot, it is important to deploy the prototypes in users' real environments [47]. Revisitation Reflector is both based on IoT and is meant to be put in a spot in one's working or living environment–therefore, a field user experience study suits its testing well.

It must be explicitly stressed, like it was in [37]*, that this study does not make the assumption that the designed Revisitation Reflector directly depicts all the theoretical principles and perspectives that formed the motivation behind its design and implementation. The performance of and impressions on the artifact are influenced as much by the implementation as they are by the design principles that the artifact is based on. This field study, its findings and discussion of those findings together aim to help address this project's main research question of:* ***"What effect does giving users ambient, tangible and reflective revisitation feedback have on them and their smartphone usage?"***

A NOTE ON COVID-19

This field study was carried out in the Netherlands and it coincided with the lockdown and other restrictions/regulations that were enforced due to the COVID-19 situation. This had an impact on a lot of aspects of the study: the way the study was carried out, the availability of resources, scheduling and availability of participants, recruitment of participants etc. The result was that not all the parts of the study were able to be carried out as they would have been intended to in the times without COVID-19. This also meant that not all the findings would translate to COVID-19 free times–and this will explicitly be addressed later.

PARTICIPANTS

In total, there were seven participants recruited through student chat groups and through personal contact in student housing. To qualify for being recruited for the study, the participants had to be at least eighteen years of age and they had to own a smartphone. They also had to be willing to install the associated AWARE app's clone, as well as be willing to participate in the study for at least seven weekdays. They were 21 to 24 years old and consisted of three females and four males. University students were chosen primarily because of accessibility, time constraints, COVID-19 regulations and this being a first exploratory study in the direction of a revisitation-driven, tangible artifact. Indeed, convenience sampling was employed in accordance with [10]. The participant quantity of seven was chosen in accordance with Nielsen's recommendations [76], as well as due to data saturation selection suggested by [10]. A feasibility analysis also helped choose the sampling strategy and amount [10]. All the details regarding such participant-related decisions can be found in Appendix D.

Current behavior stage or readiness to change

Before the study, the current controlled revisitation behavior stage of the participants was gauged. This was done using a 6-item survey (inspired by [70]) where the participants had to choose one option to reflect how much of a "controlled revisitor" (a smartphone user who feels in control over their smartphone use) they were. This was done before they experienced the Revisitation Reflector system or got any information about it. Table 1 and the response key below summarize the results of the survey. As can be seen, the sample was quite diverse in terms of the readiness to change of the participants–in order to retain this diversity, this survey was not used to screen the participants. Despite this diversity, however, the current behavior stage or readiness to change of the participants was not considered or used as a variable in the data analysis or results' interpretation phases. This was done in line with the approach of [37], who chose to not include this as a variable due to their limited

sample size. Their study's sample size was twelve, so this study's size of seven makes it even less appropriate for inclusion of readiness as a variable.

Table 1: Response counts

Response	Frequency
1	1
2	2
3	2
4	0
5	1
6	1

Median response: 3

Response key:

1. Precontemplation phase: individuals have no intention of being controlled revisitors.
2. Contemplation phase: individuals are not controlled revisitors but intend to be soon.
3. Preparation phase: individuals are trying to be controlled revisitors but are not yet regularly so.
4. Action phase: individuals are regularly controlled revisitors, but for less than 6 months.
5. Maintenance phase: individuals are regularly controlled revisitors for 6 months or more.
6. Relapse phase: individuals have relapsed to old habits.

PROCEDURE

In summary, the procedure consisted of the following five steps which will be discussed below:

1. App onboarding
2. AWARE screen status data logging
3. Revisitation reflector system onboarding
4. Letting the user experience the revisitation reflector system
5. Semi-structured interview about the system and the study

First, the participants were onboarded into the study, which included assisting them with installing the AWARE app on their phone and introducing them to the study's overall timeline (and when to expect what). After the onboarding, the participants would start with the study. The study would last for at least seven weekdays. This duration was as long as it was possible whilst sticking to the field study's schedule. The first three weekdays would only involve running the AWARE app on the participants' smartphones. The app would run entirely in the background and would require no interaction or additional action from the participants. The participants would use their phones as they normally would and AWARE would not have any input or interferences with that. Whilst running in the background, AWARE would log timestamped data regarding the screen status of a participant's phone (whether the screen is locked, unlocked, on or off).

After the first three weekdays of the study, the participants were onboarded into the Revisitation Reflector system. This involved assisting them with setting up the system. They were also introduced to the concept of revisitation and to the functionality of the system. This introduction to the system would be supplementing by–along with the Revisitation Reflector–giving participants a short one-pager outlining the current necessities for usage (e.g. keeping the system plugged in and stable Wi-Fi access), as well as some common, easily fixable error signals and how to fix or report them.

After the participants were handed over the system and were taught how to interpret it, the next step was to let them experience it for themselves in their household environment for four weekdays. Again, during this time, the AWARE app (that the participants installed earlier on in the process) would still be running in their phones' backgrounds. The timestamped data collection of screen status would continue. This time, in addition, the Revisitation Reflector would also be pulling that logged data and would be using it to give revisitation feedback to users. The Revisitation Reflector would also internally continuously log its relevant data. This was timestamped data on what the current revisitation pattern (if any) being displayed by the LEDs was, what the status of Raspberry Pi's Wi-Fi was, whether the database server had synced with the participant's phone, whether the participant's phone had Wi-Fi, when did the data collection and feedback giving start etc.

In addition to automatic data collection through participants' phones and through the prototypes, throughout the study (both before and after giving participants the prototype), at a random time towards the end of each day, the participants would also be sent an experience-sampling (ESM) probe. An ESM probe would allow the measuring of the ground truth regarding participants' degree of control [24] over revisitation by collecting their self-reported, subjective feedback about their current feeling of control. It allowed the addition of an extra, quantitative data source that gives more in-situ self-reports [82] of the participants' subjective level of control over revisitation.

After the participants had experienced the Revisitation Reflector for at least four weekdays, a semi-structured interview was conducted with the participants to gain insights into their thoughts and impressions regarding the prototype and the study. The interview was conducted in a semi-structured style, where a set of open-ended and close-ended questions and their follow-ups were prepared [10]. But the interview was allowed to deviate appropriately in terms of the order of questions and in terms of redefining existing questions and defining and asking new ones based on the real-time insights that were being obtained during the interview [10]. This technique of semi-structured interviewing after letting participants test a digital wellbeing intervention in their natural environments was also employed by [86]. Like this project, [86] also had an "interview schedule (i.e. a list of questions)", but that list was not used to direct where the interview would go. The themes that the interview schedule was operationalized from included: 'problem space' of smartphone usage/habits; overall and general impressions of the prototype and the study; design and implementation of the Revisitation Reflector; the impact of the prototype on smartphone usage; and reflection on the COVID-19 situation.

Overall, the procedure was significantly linked to the procedures of the two related studies that were discussed earlier ([37] and [86]). Like both of those studies, participants were given a prototype to try in their household situations. Like those studies, there was automatic data collection during prototype usage (via the participants' phones and via the prototype itself) as well as data collection through interviews after the prototype usage. Whilst this study did not run as long, it was still longitudinal like [37] and [86], and it was done in the field.

For systematic choices, justifications and full details behind the procedure, see Appendix E. There the procedure is more clearly linked to literature as well.

DATA ANALYSIS

The field study's main focus was on qualitative results. Whilst there were a few quantitative data sources that were part of the study, they did not form the main focus due to the limited sample size and limited duration of the study. The first quantitative data source was AWARE's timestamped data regarding the screen status of a participant's phone (whether the screen is locked, unlocked, on or off). The second source was responses to the daily ESM probe with a participant's self-reported degree of control. These sources went through simple

analyses, which were primarily about descriptive statistics and data visualizations. It stayed at a descriptive level due to how limited the data was. For both sources there was also a distinction made between the data portions where participants were without the Revisitation Reflector (baseline as discussed in the procedure) and those where they were being exposed to it. This distinction was made to allow comparisons between the baseline data and the data from when the participants were using the Revisitation Reflector.

Aside from quantitative data, it was actually qualitative data that formed the main focus of the project. This qualitative data was collected through the semi-structured interviews that were done at the end of the participants' study periods. There were both open-ended and close-ended questions, which led to a diversity of data being collected. The interviews were transcribed before undergoing any analysis. After this, the interview data was analyzed using affinity diagramming. This technique was used because of its high frequency of usage in human-computer interaction (HCI) work [13]. Affinity diagramming is considered a strong method for analyzing diverse qualitative data and is common in HCI [44]. Specifically, for this study, affinity diagramming was an appropriate choice for data analysis because of its effectiveness as a method to analyze interview data [13]. It is particularly suitable for analyzing post prototype usage interview data from user studies that involve interactive prototypes [18,78], just like the current study did. And it is particularly helpful for understanding the role of a technological artifact in the everyday life of users [44], which is exactly aligned with Revisitation Reflector's ethos.

The affinity diagramming process recommended by [43] and by [44] were closely followed in the following steps. First part of the affinity diagramming process was to record individual interview quotes on separate cards which were placed one by one on a virtual board. During the process of placing, arranging and shuffling around cards on the board, they were clustered into groups based on their affinity to one another i.e. how similar or relevant they were to a shared topic. Each emergent group was labelled and recursively clustered to basically created hierarchical clusters that categorize the data items (interview quotes) on the individual cards. This recursive clustering repeated until the highest level in the hierarchy only had a few groups, and all the items had been clustered and organized in this bottom-up manner. In this way, affinity diagramming enabled the creation of "successively higher-level categories of data" [44], thereby, allowing abstract findings to appear from the vast array of all the individual qualitative data items.

QUALITATIVE FINDINGS (MAIN FOCUS)

Based on the outcome of the affinity diagramming process, there were several themes and subthemes of qualitative findings **(emboldened)** that were uncovered. Qualitative findings form the main focus for this project's results. Most of these findings surrounded user impressions on the Revisitation Reflector display's sensemaking, role, design and impact. There were also findings to reflect the users' thoughts on the COVID-19 situation's impact on their digital activities. The qualitative findings are **overviewed** at this section's end, and their **syntheses and reflective discussions** are presented and concluded in the next two chapters (chapter 6's conclusions and chapter 7's conclusions).

Sensemaking of display

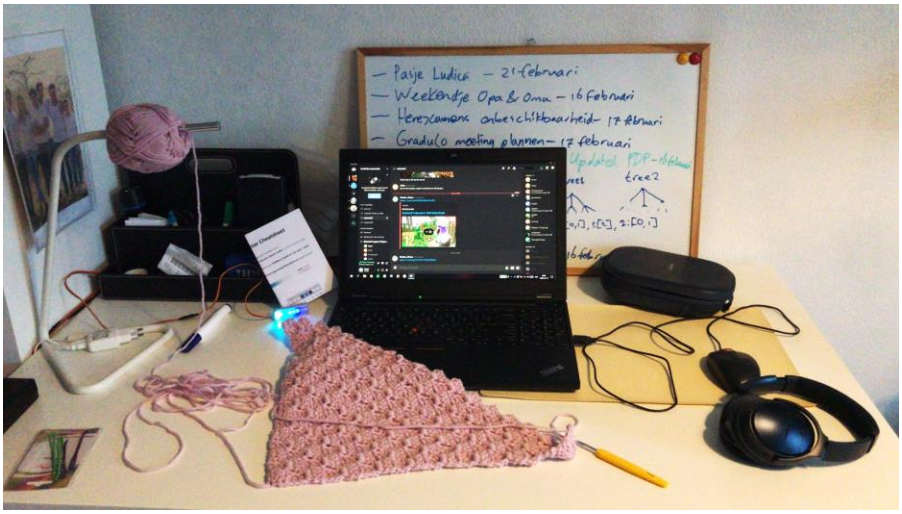
Sensemaking of display had to with its appropriation (usage and meaning making in ways that are not pre-defined by the designer [122]), interpretation of its feedback and perceptions of revisitation itself. All three are in some way related to how users made sense of and defined the Revisitation Reflector display's meaning for themselves, its

normativity, its functioning, its relationship with them, its interpretation and its feedback metric of revisitation.

In-use appropriation of display

The display was designed to be appropriated to various users, contexts, interests and purposes (in ways that were *not* pre-defined by the designer). As such, unsurprisingly, many aspects of its (feedback's) appropriation emerged as it was used by participants. The participants really appropriated the display to themselves and made it their own, as they used it and engaged with it. They did this in three main ways. Firstly, they converged towards specific patterns they would pay particular attention to and regarding which they would define their own meanings. Secondly, they defined and judged for themselves what parts of the feedback were good and bad for them. Finally, they defined their own experimental practices for trying to make sense of the display's feedback and figure out how it worked. The common thread amongst these three aspects is how they all fit into the theme of in-use appropriation of the display. As users used the display, these were the ways in which they gave meaning to what the display's feedback meant specifically for them. Not only what it meant, but also their own unique ways in which they experimented with it, as well as defined what was good or bad for them.

To start with the aspects of users identifying their own priority feedback patterns, **for a particular user, there was often a specific feedback pattern that would trigger reflection or that they would look out for**. For instance, for one participant the triggering pattern was the feedback *not* being distributed and mixed: *"Because my performance was distributed and blue, I didn't really stop and think...because it was usually mixed...I didn't feel the need or urgency to reflect..." (P2)*. Whereas, for another one it was about there being a brighter whiter light somewhere on the display, *"The white light did make think and reflect on my activity in the past hour." (P4)*. When followed up, the other participant actually viewed it as something valuable for reflection to be triggered only by this specific pattern, and not others, that he had chosen for himself: *"I don't think I would've even liked for it to make me reflect if I think I am doing well." (P2).*



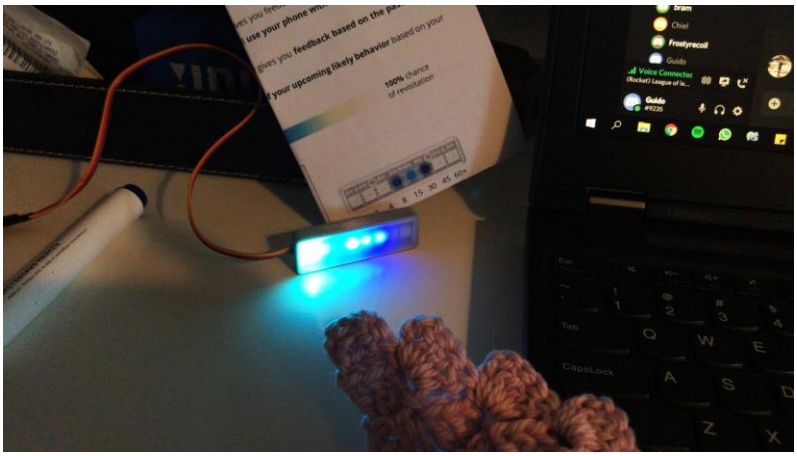
So, as participants would use the display, their self-identified patterns of what the feedback means would emerge. Often these **own patterns of meaning would be regarding the number of lit LEDs**. For example, *"Seeing more lights means more usage for me..." (P1)*, and, *"When it was a full stream of lights, I was often relating that to more phone*

usage." (P6). One participant even explicitly attached more significance and attractiveness to the number of lit LEDs in contrast to their colors, *"Amount of lights is more impressive than color of lights. I was like wow! Four lights. But if there was one light, I was like, 'oh I was once or more times on my phone within the same [revisitation] interval', but more than one light felt more like I visited my phone multiple times." (P3).*

There were also emergent, **own patterns of meaning that would be regarding the color, position or both of lit LEDs.** For example, a common one that participants would look out for was there being a concentration of lights on the left-hand side (so short-term revisitation), *"If I would see the display go more to the left, it would feel to me as an indicator of me not doing well regarding revisitation" (P5)* or *"Now that there is the possibility of white light on the left occurring...I want to lower that as much as possible." (P2).* The opposite–having lights more to the right-hand side–was often then seen as a goal, *"[My goal is to be] getting the lights to the right side and more off..." (P6)* or *"I would try to have the lights would be more to the right...to make sure I visited only after a long time..." (P6).* It was not just about the position at which the lit LEDs were. It was also about their colors for participants, *"In the instances that I saw a bright single light, I knew why that was the case. The white light did make think and reflect on my activity..." (P2).* Although the color was often coupled with the position of that color. One participant, for example, said, *"White stood out from blue...when it was mostly blues and suddenly a white...felt like a lot more change had happened. Plus, it was important where it was on the scale...more right or left." (P2).*

Besides identifying specific feedback patterns to focus on and defining own patterns of meaning, participants also appropriated the display to themselves by judging what feedback aspects were good or bad for them. Such surprising and emergent findings can be classified under **user-defined morality.** Almost every participant directly or indirectly referred to something about normativity or morality being driven by them, already during one of the open questions at the interview's start. This was especially interesting because none of the questions implied or asked for something like this. One comment that shows how morality and judgement was left at the hands of the user is the following: *"I think this was more about awareness rather than judgement. It leaves the judgment up to yourself. Which is good, but also frustrating." (P6).* So, that participant found that morality was for him to decide, and he found that both desirable and frustrating. Indeed, he wanted such morality to lie in his hands, *"I liked it just being a trigger for me to think about my phone usage and reflect on it. So, not give me good or bad results, these many hours, these many times a day..." (P6).*

Another participant wanted the normativity of what feedback matters to decide whether it should be in the 'foreground'; and he wanted himself to be in control of what this normativity entailed, *"I want it to be in the foreground only when there is something necessary for me to see...and that what is necessary for me to see should be decided by me." (P2).* This participant explained how he only also wanted to stop and reflect if he saw something that he thought was undesirable for him, *"If I didn't like a result, then I would stop and ask why. What has caused this bad result?...You only want to reflect when it's not going well, not when doing well." (P2).* When describing the general role of the display, one participant attributed the morality of what habits should be changed to himself, *"It was there and I was being provided with the information of my behavior would imply that I should change my habit if I see it as something that is bad." (P7).* For another participant, because the interpretation of the non-normative, abstract feedback was left completely up to him, he found that as something that allowed him to judge what was good or bad: *"I like the way it doesn't just give you a number or some full bar. It's quite an abstract representation of phone usage. I quite enjoyed that...it was to make me more aware of my phone without putting a label on it. Like whether it's good or bad. It's up to me to make my own interpretation." (P5).*



There were many other comments that highlighted how specifics of the displayed feedback (and consequently the morality of the overall concept) were defined as positive or negative by the participants themselves. Some examples include: *"When I saw an LED spread, for some reason I thought I was doing well...it made me satisfied of my performance." (P2); "The study made me realize that I have a vision that if the lights are more on the left you revisit more often so you're a bad user and vice versa" (P7); "I thought that revisitation in the low numbers is bad and revisitation in higher numbers is good." (P7); "I would see the display go more to the left, it would feel to me as an indicator of me not doing good regarding revisitation." (P5); "If the light was bright but only on the right, then suddenly your revisitations are on the long end of the time range. So, I thought of that as a good thing." (P2).*

Apart from defining patterns of meaning and defining aspects of morality, the final way in which users appropriated the display to themselves was through their experimental practices for trying to make sense of the display's feedback and figure out how it worked. One of the most common ways that users made sense of the display's feedback was through **tinkering with and deliberate manipulation of the display**. One participant was quite explicit about this experimental way of sensemaking, *"I was trying to experiment with the display, so I unlocked my phone more. So that I could see a result." (P4)*. For her, sensemaking was driven by doing artificial unlocks and seeing how they affected the display. Another participant expressed how she at the start was deliberately trying to trigger the lights, *"I tried to trigger the lights on the initial day on purpose..." (P3)*. She explained that such tinkering was especially a significant part of the experience at the start of using the display, *"At first it's quite fascinating. What do they mean? How can I manipulate it? At first, you're not used to it and then you just want to play and experiment with it. Manipulate it and see what happens." (P3)*. Indeed, for her a major portion of the interaction with the display was experimenting and seeing results appear.

Another participant had the same experience, *"Yeah it affected it on some kind of level. When I was using my phone in my room and the LEDs were in my vision...sometimes I would even experiment. This was more in the beginning. I would repeatedly go on my phone and leave it to see if it would affect the display and it did." (P1)*. For some such experimentation and cause-and-effect was explicitly pleasant, *"Display was fun to experiment with and see what your doing is visible." (P4)*. For others it made them want to revisit their phone even more often, *"It made me think about my revisitation. Actually, in a way that I wanted to revisit my phone more often out of curiosity." (P3)*. Some were even very deliberate in manipulating or 'fooling' the display, *"I thought either don't revisit or don't turn off [lock] my phone. So, I sometimes I found myself simply not locking and turning off my phone and just leaving it on the side, to keep the lights off." (P7)*. So, there were instances (also visible in parts of the revisitation data) where some participants were purposely manipulating the display by expressing unnatural behaviors to have it reflect what they intended.

Interpreting feedback from display

When it came to the findings regarding how participants interpreted the display's feedback, there were basically two main specific trends and two generic ones. The specific ones had to with avoiding short-term (fast) revisitation and with feedback on no revisitation. The generic ones had to with the standing out of the amount

of lights and of changes. Starting with one the specific trends, **a common personal (implied or emergent) goal was to reduce the occurrence of fast revisitation feedback on the display**. Participants were often geared towards reducing seeing short-term or fast revisitation feedback on the display (shown by brighter lights being more to the left-hand side of the display). One participant said, *"The slower the revisitation, the better is what I saw as the better." (P3).* So short-term revisitation was interpreted as undesirable by the participant. This was echoed by another participant who mentioned that such feedback would cause him to think more, *"If it was white on the left, I would think more deeply..." (P4).* Indeed, for another participant bright lights on the left-hand side meant lots of short-term checking behavior which he tried to change: *"If I see a lot of white on the left side, then I know it has been a lot of opening and closing...I noticed I turn my phone on and off continuously and repeatedly out of boredom. So maybe for those behaviors it helped me change..." (P2).*

Another specific trend was that **the display being off was considered as significant feedback and it influenced revisitation tendencies.** This is evident from comments like, *"When it became completely off, then I had reflective moments. How can I explain this change?" (P5).* For one participant, the display being off was the most significant form of feedback, *"Most important was that it showed me when I wasn't revisiting my phone at all. After I hadn't used my phone the display would dim out more and more. Throughout the day, it would initially be at the one-minute mark bright green and some other dark blue dots. And then later one-minute mark would become blue and the forty-five-minute would also become dark blue. And eventually it would go off and I would realize I haven't used my phone in an hour now! I found that quite useful..." (P5).* Whilst the display being off was considered significant, it was not always considered positive. For example, *"But other times there would be no lights, which felt disappointing...even though it was technically a good thing because I wasn't too much on my phone, and I did want to see it." (P5).* So, this participant did want the display to be off, but also thought that it being off did not necessarily feel desirable.

Again, the display being off stood out to another participant but not necessarily in a positive way, *"When I was revisiting my phone when I didn't desire it, the display was very present, and when I was not revisiting my phone it would become dimmer blue and more spread out and eventually off. So,*

it's kind of screaming, 'hey you did a lot of revisitations', but it's very quiet about, 'hey you didn't revisit much that much'. Which seems to me as negative reinforcement. So, the wrong behavior becomes obvious from the display and how I define positive behavior becomes a lot more subtle." (P2). Thus, this participant found that the display being off was prevalent, yet making something that he thought was positive (lack of revisitations) quite subtle.

Moving onto the first generic trend, **the amount of lights shown by the display stood out the most.** For instance, one participant correlated the number of lights to the extent of usage, "*When it was a full stream of lights, I was often relating that to more phone usage. More lights more usage." (P6).* Another participant also seemed more focused on the quantity, rather than the position, of lights, *"Yes, if you revisit too often. It's more about the number of times, not really how fast do I go back." (P4).* Yet another participant found the amount of lights more significant than their colors, *"Amount of lights is more impressive than color of lights. I was like, 'Wow! Four lights.'. But if there was one light, I was like, 'Oh, I was once or more times on my phone within the same [revisitation] interval'. But more than one light felt more like I visited my phone multiple times." (P3).*

Indeed, the reason for focusing on the quantity of lights for this and other some other participants was that it gave some idea of the amount of revisitations. As another participant confirms, *"It would also show me how much I was using my phone simply by the [number of] lights. Well, if I was seeing more lights...it would mean I am using my phone more." (P1).* This belief was held by another participant despite her knowing that it is not necessarily true, *"It would give more feeling of information when you see a lot of lights rather than one light. If I saw lot of lights, I felt like I used my phone a lot; rather than if there were less lights, but then brighter and more to the left or so. So, yeah, indirectly the amount of lights says more about behavior than the place of the lights, even though I know that is not true." (P3).* This shows that the amount of lit lights often had stronger and more 'sticky' connotations for participants than their positions or colors.

The other generic trend in feedback's interpretation was that **changes in feedback stood out.** For one participant changes were the cue to do inquiry, "*Every time it would change, I would be like what is it now that has caused this." (P2)*. Indeed, that participant discussed that changes brought active involvement with the display, *"And when it changes, I look it at how did it change right now. Then I am actively involved with it." (P5).* Another participant mentioned how changes were the aspect that brought the artifact into attention, *"When it wasn't changing, there was no reflecting happening and I wasn't paying much attention." (P1)*. For other participants, changes spurred interest or excitement: *"I was very interested when I saw changes." (P7); "I got excited when I saw interesting changes" (P7).* Perhaps a reason for such changes standing out was their ease of noticeability, *"More drastic changes are more drastically displayed, so they are easier to see and change behavior with..." (P5).*

Besides all these general and specific findings regarding interpretation of the display's feedback, there was one finding which was more unexpected: **Trying to interpret, think about and make sense of the display's feedback was in itself a significant part of the user experience** for some participants. One participant expressed how he enjoyed the process of interpretation itself, *"I enjoyed interpreting it. Seeing how my behavior was reflected in the results I was getting. So, thinking about how it happened." (P6).* Another participant expressed how the display made him think about and make sense of the outputted feedback, *"Every time I looked at the display, I would try to understand what it means. I would see, for example, if I have been using my phone more in the past hour than two hours ago." (P7).* Thus, for participants like this, sensemaking and interpretation processes formed a significant portion of the display's user experience. Indeed, another participant said, *"It gave me a new perspective. I would often stop and try to see the meaning behind what I saw." (P1).*

Perceptions of revisitation

The fundamental idea behind the entire prototype was revisitation. As such, many findings were bound to emerge regarding how users perceived this revisitation concept. The first thing which was apparent was that **revisitation was perceived to be a novel concept to be aware of, it challenged personal expectations, it led to unexpected discoveries and/or it was often perceived as useful.** For all participants, revisitation was something completely new to be aware of. For instance, a participant said how he had never before realized his revisitation behaviors, *"Something [revisitation] you usually never really realize how you're doing it. And it tells you that. I never realized I was going to my phone, for example, five times an hour and now you would see a few lights to indicate that." (P4).*

One participant expressed how he had never thought of this metric before and how it went beyond just the number of times the phone is used by bringing in awareness of impulsiveness, *"I never thought of revisitation rate before. I always thought of quantity of looking at your phone throughout the day should be reduced. Impulsiveness of revisitation is very interesting which is something I have been doing a lot, but now I have a name for that." (P6).* Another participant expressed a very similar sentiment of revisitation being a novel metric that was useful to learn and that went beyond amount of time spent on the phone, *"With revisitation, something I had not thought about, as also a measure as opposed to the amount of hours a day. Thinking of this is new for me. A great thing to learn. And then also seeing it displayed and seeing how inconsistent my revisitation is." (P7).*

Besides giving participants, *"a new perspective" (P6),* revisitation also challenged their expectation and led to unexpected insights for them. For instance, one participant was surprised by seeing more longer-term revisitations, *"I feel I grab my phone a lot. So, when it was longer, I was surprised, 'hey, I didn't grab my phone.' Sometimes, it was also unexpected to see how much I spent on short-term, but it was mostly unexpected to see longer." (P6).* For another participant, both too little and too much revisitations defied her expectations, *"Also I would think, 'Really? Did I do this?' Sometimes I thought I looked more often and sometimes I thought, 'Hey, did I revisit so often?' So, sometimes also surprised." (P4).*

Another participant found that the inconsistency or fluctuation of his revisitation patterns defied his expectations, *"I would have expected that I would look at my phone more continuously, so that the state of the*

display wouldn't change constantly throughout the day. But now it fluctuated a lot." (P5). He explained how he expected such inconsistency only during breaks, but that it was more prevalent than that, *"I felt I was more consistent with my phone usage. I thought it was during breaks that I wasn't. But I expected during my study I consistently revisited my phone, so the display shouldn't change much. But now I kept seeing the state change. So, I noticed that there is way more fluctuation in my revisitation during my study period than I expected" (P5).* Another participant was similarly surprised by seeing more changes than expected and having insights that he didn't expect, *"Yeah, I thought I'd see a constant trend of ones and twos. But there were times I didn't use my phone. I had times my lights were spread, all the way to the left or all to the right. It was changing more than I thought...It also showed me that it's not what I thought it was like." (P7).*

There was also a specific common trend regarding how revisitation was perceived: **Impulsive and/or short-term revisitations were considered to make revisitation problematic**. One participant explicitly addressed this in conjunction to wellbeing, *"I did see the link between revisitation and wellbeing. If someone has lots of urges to constantly revisit their phone, it can result in negative wellbeing..." (P5).* For another participant impulsive revisitation was the focus of thinking, *"I've thought of a lot because of this display. Thought of like how I go to my phone without thinking of it. This impulsiveness, I guess, of using my phone..." (P7).* Yet another participant tied problematic revisitation to escapism, impulsiveness and lack of control over phone usage, *"I see it as an issue mostly when it is kind of an escape...if the revisitation follows from desire more than I consciously planned this time to revisit my phone, then I see it as an issue. So, if it's outside my own control. If it's impulsive." (P6).* Something very similar was mentioned by another participant, *"It gets an issue for me when I can't just think by myself. You need to be able to be along with your thoughts...so, frequent, impulsive revisitation would be an issue" (P3).*

Role of display

Themes emergent in this category either had to do with the role of the display in terms of being a reflection trigger, or in terms of its incorporation in users' everyday lives.

Evoking reflection on phone usage

Aligned with its intention, the display turned to be **mainly a trigger for awareness of and/or reflection regarding phone usage.** For example, one participant explicitly addressed likeness for its reflection trigger role, *"I liked it just being a trigger for me to think about my phone usage and reflect on it...to give an idea throughout the day on when and how I use my phone..." (P6).* There were also many comments regarding the display triggering awareness of smartphone usage or revisitation. For instance, a participant discussed how this display triggered awareness and reflection, *"It definitely made me more aware of my phone usage and to think about it a bit more." (P7).*

Another participant mentioned how without the display such awareness or reflection is just absent, *"It definitely made me aware of my phone usage. Before it I wouldn't really think of being on my phone." (P2).* This was echoed even more in another participant's commentary, *"I was aware that, 'hey I am using my phone'. Without it, using my phone would not be something that I would pay attention to. I would not pay attention to doing this activity." (P1).* Along these lines, such awareness of smartphone usage was tied to being more mindful of it, *"I was more aware and mindful that I was using it." (P1).* Similarly, a participant addressed awareness regarding revisitation, *"The display was making me conscious of how much I'm revisiting and using my phone." (P3).* Another participant affirmed, *"It made me more conscious of it [revisitation]. So, it helped me understand better how I use my phone and be more conscious of it." (P7).*

Such awareness, consciousness ore reflection often arose out of intrigue, as again, was the aim of the display. It was clear that often **some specific feedback patterns evoked a desire in users to try to understand the reasons for getting those patterns.** When explaining some of such patterns, a participant addressed this trend of some particular patterns triggering reflection, *"When I was seeing the lights be in some particular pattern, I would go back and reflect on how I used my phone and why it was showing these lights and numbers. So, some of the patterns made me reflect on my phone usage." (P1).* For one participant this triggering pattern was the display being off, *"When it became completely off, then I had reflective moments. How can I explain this change?" (P5).* For another participant, any pattern which he perceived as one that he disliked was reflection triggering, *"If I didn't like a result, then I would stop and ask why? What has caused this bad result?...you only want to reflect when it's not going well, not when doing well." (P2).*

For yet another participant the triggering pattern was seeing short-term revisitation appear, *"Yes, I wanted to understand the feedback and I tried to do especially with short-term revisitation. And making sure especially on short revisitation I tried not to revisit my phone." (P4).* It was not always a specific pattern, however, that triggered reflection. For one of the participants, it was a desire to discover how his behavior was manifested by the feedback, *"I enjoyed interpreting it. Seeing how my behavior was reflected in the results I was getting, so thinking about how it happened." (P6).* Whereas, for another participant the intrigue was piqued by being surprised by the feedback outputted, *"And also I would think, 'Really? Did I do this?' Sometimes I thought I looked more often and sometimes I thought, 'hey did I revisit so often?' So, sometimes I was also surprised and wanted to think more." (P4).*

Besides triggering reflection or awareness through inquiry, it should also be acknowledged that the display did go beyond that in some scenarios. It was visible from several comments that the displayed played a role in **imparting a mindset for sustaining controlled phone usage and for questioning impulsive usage.** For some participants, the display really made them used to being mindful and critical of undesirable phone usage. One participant e.g. said that the display made her keep revisitation and phone usage in mind even when she was out without the display, *"...even when I'm out, it made me think of my phone usage. I did become more conscious of when I'm using my phone and my revisitation rate ..." (P6).* Another participant similarly mentioned that a

mindset for controlled usage had been internalized irrespective of the display's continued presence, *"But now it gave me a mindset to control my usage such that even without the display I'm aware of when I use my phone." (P1).*

For other participants, the display was a means to make them think more about revisitation and changing it if needed. For instance, *"I already had a negative perception of how I use my phone. Now I was forced to think about it more. I also started thinking about revisitation. So, it got me thinking about my habits and it got me thinking about it more and that I should change them." (P7).* Another participant also expressed a similar point, *"It's useful because it does make me aware because phone revisitation is a thing and I do it and maybe I should think about how I do it." (P5).* Again, such continued thinking about impulsive phone usage was something evident in more comments as being imparted by the display, *"I've thought of a lot because of this display. Thought of like how I go to my phone without thinking of it. This impulsiveness I guess of using my phone. And then the times when it happens. And now I think more." (P7).*

A much more common finding within this cluster was that of the feedback providing participants with **cues to hold themselves accountable and to question their impulsive phone usage.** For example, a participant became more controlled about her phone usage because she did not want the display to show uncontrolled patterns, *"Every time I was on my phone, I was like, 'Oh now this is going to be on the display!'" (P1).* She continued on with explaining this role of the display being means to accountability, *"When I was using my phone in my room and the LEDs were in my vision, I was like, 'Yeah, this is now going to reflected on in the device'" (P1).* This was echoed in other comments, where e.g. a participant held himself accountable because he knew revisitations would indeed be shown by the display, *"I was more aware of every time I did do a revisitation and also the length of a revisitation. Because I thought the length of a visitation would come back in the display." (P5).*

Another participant was triggered to hold himself accountable for impulsive phone usage, *"If I'd impulsively reach out for my phone and the LEDs would be off, it made me question why I was getting my phone. And if I didn't have some message, I'd put my phone down." (P6).* Along similar lines, another participant did not want quick checking behaviors to show up on the display and therefore controlled them, *"I felt the need to not continuously open and close my phone anymore. Sometimes I would just close and open it just for the sake of it. I realized that would be registered as false revisitation. So, the display stopped me from that that much...from like the fidgeting with my phone." (P5).* For one participant, the display being off made him question why he would even cause it turn on again and why he would return to his phone, *"I was consciously trying not to open it [phone] that much. And then if I saw it [display] was off, then I wouldn't open my phone to keep the lights off...it would make me ask if it is necessary to open my phone." (P6).*

Ambiently interweaving in everyday life

There were many findings regarding the display's role that related to its interweaving and incorporation in its users' everyday lives in an ambient way. To start with an expected one, it was **perceived as unobtrusive** by all participants. Like one participant explicitly said, *"I liked that it is was not very big and that it was not very obtrusive." (P1).* There were a few comments also about how it was not invasive by being in a user's face, *"It's not really in your face." (P6),* as well as, *"It gives enough feedback without being too much in my face." (P2).* A participant similarly said, *"It was just there and when I wanted to look at it, I was looking at it." (P1).* There were also comments regarding the display being peripheral or the background. For one participant, this shift towards periphery happened as he got more used to understanding the display's feedback, after which he said, *"It got more in the background as time went on...I was getting more used to knowing its feedback..." (P4).*

For others, there were more dynamic shifts between the display being in the background and in the foreground, *"It slipped into background and only really came to the foreground if I saw something I deemed bad...I want it to*

be in the foreground only when there is something necessary for me to see." (P2). Another participant had a similar opinion, *"It was sitting there in the background and sometimes it was taking attention..." (P1).* For another participant it was in the background and shifted towards more explicit attention when there were changes or when it turned off, *"It's not like I put a lot of attention to it, but if I see it turn off...and when it changes, I look it at how did it change right now." (P5).*

Perhaps a significant part of the display's unobtrusive and ambient nature emerged from how the display was almost always considered to be **intuitive to use.** One participant quite explicitly scored it perfectly, *"Intuitive? From 1 to 10, I would say 10. It was quite straightforward." (P1).* Another one also found it really intuitive, *"It was very intuitive. From your explanation, I got it all. From then on, it was just like these basic blocks that I was relating quite easily to the LED. It's very intuitive." (P7).* For that participant the intuitiveness came from the plug and play nature of the display, *"It was easy to use. I just plugged it in. It just started working right away." (P7).*

Along similar lines of unobtrusiveness and intuitiveness, there was another theme related to ambience: It was apparent that the display **integrated with users' 'lived experience'.** Perhaps a comment that most clearly demonstrates how the display just blended into everyday lives is one where the participant compares it to his cactus, *"It was pretty much just like one of my cacti that I have on my desk. It's just sitting there. I am aware of it. It evokes thoughts or feelings..." (P7).* Another participant addressed this integration into his context, *"It fit quite easily into my workplace." (P5).* Whilst it was often physically positioned on focal points, *"It was in the room I was mostly in and it was in a position where I could be focusing a lot on" (P2)*, it was, *"never interfering, and was just there. It allowed everything to continue..." (P2).* Along similar lines, there comments showing that the display would be something there as part of the overall experience during the course of a day with brief glances, *"It was just there and when I wanted to look at it, I was looking at it. Sometimes I would just briefly glance at it to see what it shows." (P1).* But there was general consensus that the display did not interfere with participants' everyday lived experiences. Comments like the following were quite prevalent, *"It was just sitting there, it didn't interfere with anything..." (P6)* or *"It didn't interfere with my activities, but it did catch my attention." (P3).*

Design of display

The themes within the design of display all had to do something with its design and/or implementation. This included how users perceived the display and how there was a clear desire for customization of the display's various aspects.

Users' perceptions of the tangible display

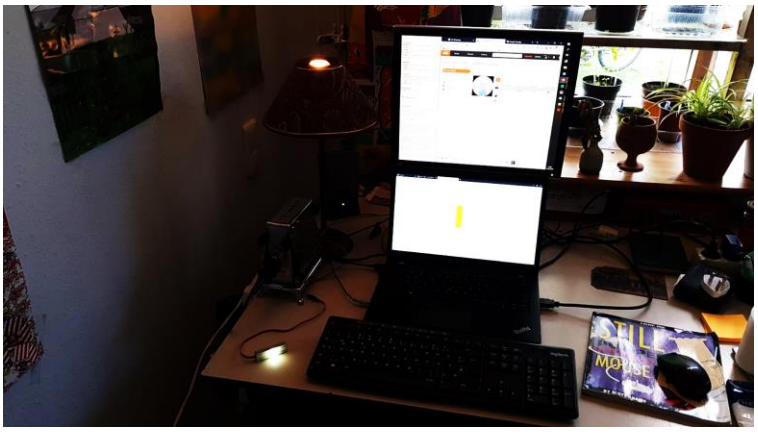
Starting with what the participants thought the display was meant to do, **the display's perceived purpose was often revisitation or impulsive phone usage related.** One of the participants said that the Revisitation Reflector was meant to, *"confront you with extreme, fast revisitation behaviors..." (P6).* Another participant connected this to having more control over regular rechecking behavior, *"I think it is about getting more control over my revisitations...when I come back to my phone..." (P5).* Participants also related this to the display having a role to potentially contribute to habit transformation. One of the comments along this line were, *"It is there to provide feedback to the user on how often they visit their phone and the [revisit] intervals for that. In the hopes that the reflection would change the habit." (P2).*

Another participant discussed, *"I thought the system was meant to make you aware of your revisitation habits and to help you in changing your revisitation habits." (P7).* So, the delivery of revisitation feedback was in itself viewed as a purpose, but it was also tied to changing revisitation habits. There was another form of this role that was perceived by participants. Whilst it did not explicitly address revisitation, it is implicitly strongly linked to revisitation. That role was centered around impulsive smartphone usage habits: *"But the role, umm, I think the role was exactly to show me how impulsive I was with my usage. Going from one minute to longer. To show me how impulsively I was using my phone was the purpose of the display." (P1).*

This way of having a tangible, ambient display was **perceived as a novel way of receiving feedback.** For one participant, it was literally reflected in his comment, *"This is the first time I've been given feedback in this way" (P2).* He continued, *"The feedback style was different. It's not a way you're used to information being encoded in." (P2).* One participant found this novel medium interesting, *"The LED display approach works. It's really interesting to experience feedback in this new way." (P3).* The following comment, amongst other similar ones, shows that not only was the feedback approach novel, but so was the dimension that the feedback was based on: *"I like its abstractness. Looking at your phone usage in a different way. It gave me a new perspective. Instead of constantly thinking like I should be on my phone less." (P6).* Tied to the tangibility that was just discussed, for one participant the external physicality of the display enabled her to pay attention to something novel that she would not notice without such an externalized artifact: *"I was aware that, 'hey I am using my phone'. Without it, using my phone would not be something that I would pay attention to. I would not pay attention to doing this activity. When I am sporting, I know I am sporting, but when I'm on my phone I don't feel like I am on my phone. It feels like it's part of every activity and that it's not separate. With the device it felt a bit more separate." (P2).*

Besides being novel, there was a strong consensus on the tangible display being **perceived as engaging, likeable and/or useful.** Comments like, *"Way better than having on my phone! So, it was nice, felt nice. It felt like an extra device." (P1)*, and *"I think it's nicer than having it on a phone." (P3)*, all painted a picture of a tangible display being likeable. For some this had to indeed do with its physicality, which also made it more engaging or credible for them. One participant said, *"Adding one more thing makes it much more credible for me than having just an app..." (P7).* Another participant highlighted how its external, physical presence makes you confront it, *"I like it. I like to have something tangible. Makes you think as it's there in your face." (P6).* Similarly, physicality is reflected in, *"It's definitely better to also have the display rather than just have an app on your phone. It also makes your goal more tangible when you have something physical related to it." (P7).*

Having a display external to a phone also does not require one to visit their phone to get feedback on their smartphone usage. This is exactly what one of the participants did not want and preferred the display for, *"You must not have to visit an app on your phone to check your revisitation data about the phone itself." (P3).* Another participant noted, *"It didn't urge me to see my phone to see my revisitation. So, that's very helpful." (P5).* One participant gave a reason for this preference that was linked to how the display avoids opening the door towards other apps, *"This is better than an app. Because an app would make me go back to my phone and if I check this app, it might make me visit Facebook as well and it would increase my time on the phone." (P1).*



Therefore, besides being more likeable and engaging, the display was also commonly perceived to be a useful approach. Besides already mentioned comments, one participant attributed this usefulness to the persistence of feedback irrespective of and external to the phone: *"In an app I would only see my revisitation when looking at my phone and now I see the display even when I'm not looking at my phone. So, now even when I'm not looking at my phone, I'm still updated on my revisitation. Which makes it easier to stay in control of my revisitation. Whereas, with an app I'd have to do that while I'm using my phone. Now, I'm urged to reflect on my revisitation while I'm not looking at my phone." (P5).* One participant went as far as saying that this would simply not have worked without an external, tangible display and that there would be a vicious cycle created in that case: *"This wouldn't have worked as well with an app. Because, firstly, the subject of matter is your phone so adding feedback point to your phone makes it into a viscous cycle. So, you get feedback about your phone, but you have to look at your phone for the feedback." (P7).*

In addition to the display's likeability in general, its **abstract and simple way of encoding information was particularly perceived as likeable.** One participant commented on how fast it could be interpreted, *"It is feedback that is quite quick to understand which is quite nice." (P4).* Another participant found it likeable to have such a significant amount of information be encoded in an abstract way which was better than a typical bar chart visualization, *"It's impressive how much info you portray using the arrangement of LEDs and their brightness and color…impressive to see an entire bar chat, which would be boring, to be displayed this way." (P6).* This participant went on explaining, *"I like the way it doesn't just give you a number or a full bar. It's quite an abstract representation of phone usage. I quite enjoyed that…I enjoyed interpreting it." (P6).*

This shows that part of the likeability was in the abstract nature of feedback that was different from mere numbers or graphs, and that trying to untangle the meaning behind the feedback was in itself perceived as something enjoyable. Another participant seemed to echo a similar sentiment, *"I also like data visualization. I like seeing graphs and easy explanation of a larger concepts…but this really is more interesting." (P7).* Another participant liked how encoding information in this visual LED-driven manner made it easier to recall that information, *"Before the display I found it very hard to know how I was doing…before I had to think hard…I couldn't exactly remember it. The visual states of the display were much easier to remember." (P5).*

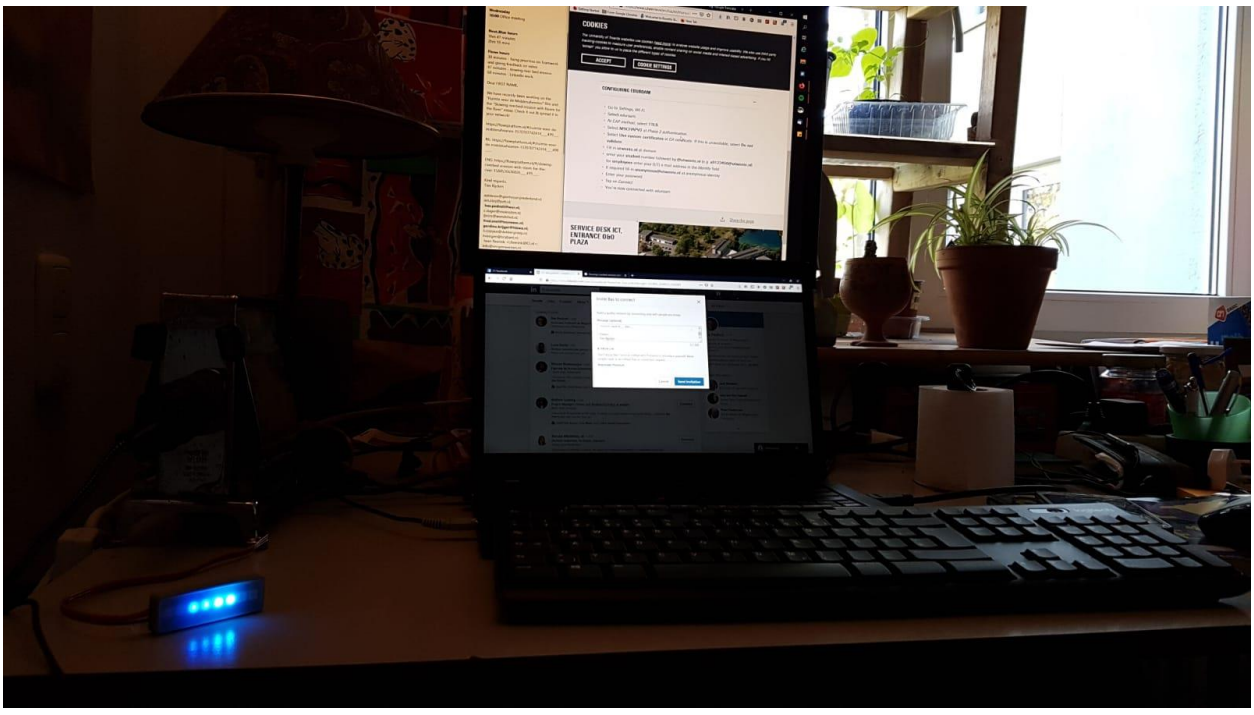
Besides participants liking individual, specific characteristics of the display's feedback, they also thought that **it was an attractive concept overall.** One participant was really fond of the overall Revisitation Reflector concept itself, *"The concept is extremely cool." (P5).* Another participant said the same when talking about the overall package, *"It's cool. It's really neat." (P6).* Another participant liked the style, but also how such a technological artifact showed him his revisitation, *"I like all this interesting technology and what it can show me about my phone revisitation...I like it a lot, I showed it to my friends and explained it to them...it's stylish I like it." (P7).*

Desire for customizations of or additions to the display

There was often some aspect of the display that the participants directly or indirectly expressed a desire to customize or add to. Such desires ranged from the very physical and aesthetic related aspects to much more fundamental ones like what dimension to give feedback on in the first place. Starting with the physical side, there was often a **desire to customize the physical design aspects** of the display. This usually had to do with the chosen colors or casing. For example, one participant said regarding the color palette used by the LEDs, *"If it was up to me, I would change the colors to something else just to personalize it a little bit." (P1).*

Another participant wanted a more enhanced case for the LED stick, *"I feel like there could be a frame around the display that kind of really refers to your phone usage. For example, a frame that looks like your phone or so. So, when you see it, you know this shows something about my phone usage." (P3).* Another participant wanted the case to be modifiable and personalizable, *"Maybe I would like personalizing it...If I purchase something like this, I would be more in favor of it if it would look how I want it... if I could personalize it...because it doesn't do that much, it has one specific aim. So, it would be nice if it could be modified." (P1).*

Other times participants expressed a desire to **customize revisitation or add some extra information to it.** One participant, for instance, wanted a number to show the number of revisitations besides the LEDs showing the relative revisitations' distribution, *"It would be nice to next to the display have a number showing how many times you revisited your phone." (P3).* Another participant also expressed such desire to know the frequency as well, "*it's a revisitation pattern and not the frequency or quantity...I don't know if that's really what one needs." (P3)*. Another participant wanted to be able to adjust the bins used for calculating revisitation, *"Maybe with a*



different scale it would be more useful...perhaps also the scale is a bit difficult to interpret....since I only look at what it kind of looks like right now, this difference isn't very clearly conveyed." (P5).

So, the participant was keen on having a scale or way of encoding revisitation that focused more on differences from time to time. There were also desires expressed to be able to change the hour interval across which the revisitation feedback was given. E.g. *"[The interval] was only an hour. But maybe it's only me because I don't use my phone much within an hour...maybe the timespan should change per person. If you're an infrequent phone user, it spans two hours and for frequent user one hour. Because, otherwise, it doesn't give much information and that gets boring." (P3).* So, this participant wanted an interval that would dynamically change across different users. Similarly, another participant wanted this interval to be longer, *"Perhaps I would like if it says more about like how my revisitation has changed over a day rather than just assessments of one hour." (P5).*

There was also a want for **seeing trends of revisitation over time.** Besides the real-time feedback, a participant wanted, *"A summary of how it [revisitation] fluctuated throughout the day. Now it's very ad hoc, but I can't change it on a day-to-day basis..." (P5).* There were several comments about wanted to see trends and changes over longer periods than a few hours: *"I want to see trends over time..." (P2); "Something like a graph on revisitation so I can change the daily behavior more than just the hourly behavior..." (P5);* and *"Perhaps it would be interesting to see what it says about like how my revisitation changed over a day rather than just assessments of one hour. Some kind of summary of the revisitation and how it changed throughout the day." (P6).*

Other comments went even more fundamental. They were about being able to **have different intervention approaches altogether**. There was a diversity of comments here regarding altering the approach itself. For example, one participant wanted more gamification or rewards and punishments: *"To do something with it, I'd need gamification...there are some apps where you get rewarded for not spending time on your phone. That would be good for me, I'd respond well to gamification..." (P4).* Another participant wanted the display to have a bit of a personality, *"I think a winking feature is what I'd go for. Where it winks at you in the morning. Some fun little features that give it more personality." (P6).*

Another participant wanted an approach where he could set the definition of revisitation himself, *"Sometimes I just open my phone and someone starts talking to me and I close it and open it right after. So, I'm not sure if I'd call it revisitation, or a single visitation with an interruption in between....So it didn't always align with my definition of revisitation....and maybe I would have liked if I could change that." (P5).* Along similar lines, another participant wanted to be able to set his own goals, *"It doesn't tell you something related to what you want to achieve. I want to be able to use this for setting goals regarding what I want." (P6).*

COVID-19 in relation to the study and digital wellbeing

As was already mentioned, this field study coincided with the lockdown and other restrictions/regulations that were enforced due to the COVID-19 situation. This had an impact on a lot of aspects of the study: the way the study was carried out, the naturality of participants' behaviors and contexts, recruitment of participants etc. An implication of this could be that not all the findings of the study would translate to COVID-19-free times. Because of this reason, COVID-19 was also addressed at the end of the participant interviews, to get an impression of the participants' own reflection on the situation and its impact on them. Many themes emerged related to the situation.

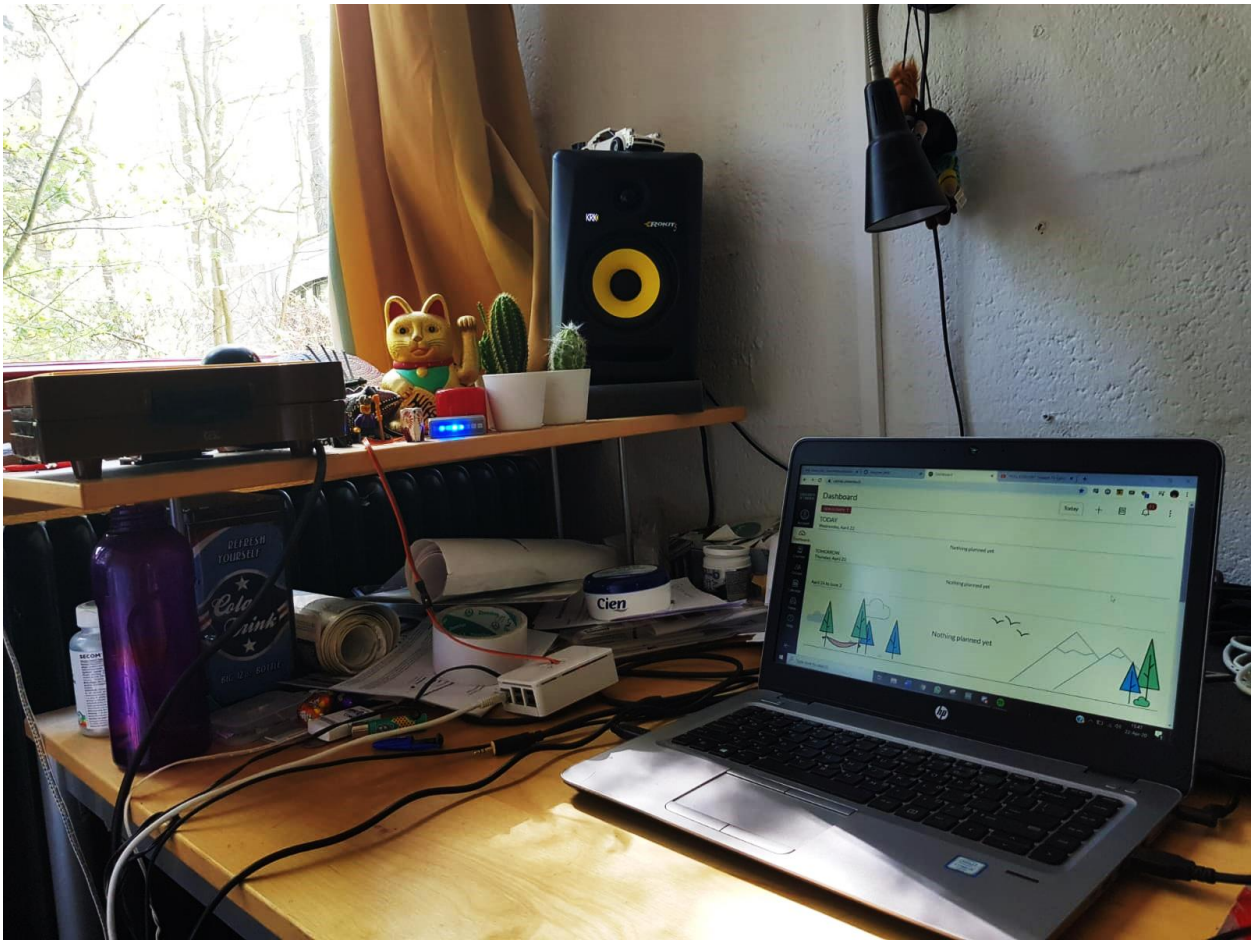
A theme that stood out regarding digital wellbeing was that almost all participants reported **atypically long laptop screen times (both absolute and relative to phones)**. For instance, one participant said how he is more on his laptop in comparison to his phone, *"Now I have the whole time to be on my laptop, and much less on my phone." (P1).* For another participant, all her phone applications had laptop alternatives, and since she was

anyways mostly home, she was using her laptop to reach all those applications: *"When I am not home, I am certain I am using my phone much more. Now I can just use my laptop instead of my phone. I can do WhatsApp, Facebook messenger, all on my laptop. So, I am definitely using my phone much less." (P1).* Along similar lines, another person basically discussed how his laptop had substituted his phone, *"I'm so much on my laptop as I'm home anyways, that I constantly have my laptop open and I don't really need my phone that much." (P3).* Another participant mentioned the laptop being the household's center now, "*My laptop has become the center of my house. So, I wake up and turn on my laptop." (P7).* Yet another participant expressed almost always being on the laptop, *"I'm on my laptop for most of the day." (P2).*

Whilst phone usage varied, for almost all participants **phone usage was reported to be atypical and unrepresentative of pre-COVID times**. As was already mentioned above, one participant expressed a decline in phone usage, *"When I am not home, I am certain I am using my phone much more." (P1).* Another participant confirmed, *"I don't really use my phone that much." (P3).* Another participant used his phone less because of lack of more practical tasks, *"Also, I don't use my phone for things that I would often use it for, for example, train route planner. There are many things I don't do anymore. I don't need my phone for a lot of practical things that I'm not doing anymore in my life." (P5).* For others, though, smartphone usage didn't change, *"Smartphone usage was also similar, because I was mostly on my laptop before the situation as well." (P2).*

For some it even increased, *"Both smartphone and laptop usage has increased." (P7).* This increase could be due to increased communication activities, *"Not seeing people that I'd normally see on a day-to-day basis. So, now I use my phone for communication purposes with those people. Before those chats would be on campus, but now it has to be on the phone. So, I have to revisit it." (P5).* Or, it could also be due to relaxation purposes, *"I use my phone more because it's now the main form of also relaxing. You don't have your hobbies anymore and you can't hang out with people anymore. So, a major part of relaxing during the day is on your phone." (P4).* In all these diverse use changes, what is common is that phone usage had changed compared to pre-COVID times, and that it may not have been as representative anymore.

Another reported aspect of atypical phone usage was **atypically reduced revisitation behaviors.** One participant said regarding this, *"So, my phone usage has not gone up, and I really think my revisitation has gone down. Because first I would use it for, for example, 'Oh, now I'm at school. What lecture do I have? Oh, what calendar slot is it in?' So, I would use it in 'small moments' a lot." (P3).* Another participant said that if this study would have been done before COVID-19 times, *"I would also have more revisitation, so it [Revisitation Reflector display] would already tell me more information and be more meaningful." (P4).* Yet another participant expressed that if it was not for the COVID situation, his revisitation would be much more, *"My revisitation would be a lot higher if I was still working and travelling." (P6).*



Perhaps what stood out the most regarding comments on reduced revisitation was that they were often attributing it to spending longer, continuous periods on the phone. For example, for someone it was long calls that reduced revisitations, *"My revisitation is quite down because I'm having long calls with people." (P7).* For someone it was very long continuous periods on the phone, *"At the moment, I can sit and look at my phone for hours on end. Whereas, when I'm travelling and doing more live things, it's more on and off and more revisitation." (P6).* For yet another participant it was long periods of entertainment, *"A long period of browsing reddit or some kind of entertainment...watch a lot for long periods, without much revisitations." (P5).* What was clear was that revisitation had reportedly been reduced for almost all participants as a consequence of the COVID-19 situation.

Something related to the participants' contexts is that they reported to be **spending atypically long amounts of time in their houses or rooms**. As noted by a participant, *"I've been staying in one room a lot more. Usually I don't spend this much time in one place." (P2).* There were many comments like the following responses when asked what has changed due to the COVID-19 situation: *"Being at home a lot..." (P4); "I now stay at home all the time except for doing groceries." (P7); "I'm spending all of my time at home" (P6).* So, participants reported spending almost all their time in the houses. This was not typical: *"Usually I'm not home that much. Only in the evenings and that too I come to my room for very few hours." (P2).* For some this went beyond just being confined to a house or a room, *"I guess I am at home a lot more than before. Living in a small room in a student room meant that I spend most of my day in the same spot which is this chair here." (P7).*

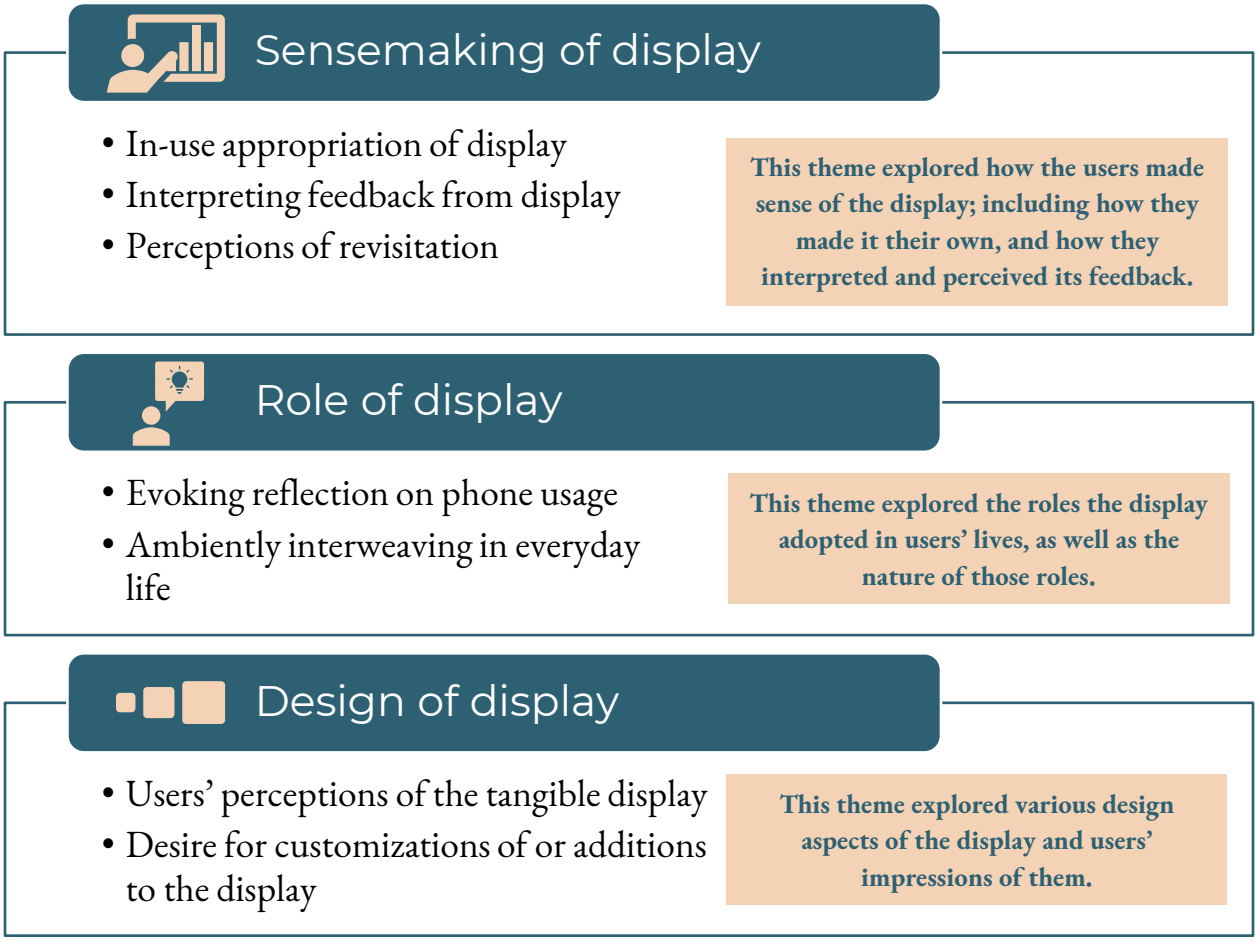
Tied to this theme of participants' context being fixed to their house or room, it was clear that the **display's portability was having an unrepresentatively low impact on its usage.** As a participant reported that if he was not restricted to his house, he would not have seen it as much, *"I would've also seen it less because I would've*

been out and not next to it most of the times." (P7). The same participant summarized this sentiment quite explicitly, *"The thing is what I haven't taken into account was the fact that with the virus I'm always at my desk. Had I not been home that much, I wouldn't have seen it as much as I did. No matter how much time you have, you would never, otherwise, be at a single place and won't see it as much."*. So, the COVID-19 situation really did create an unrepresentative scenario for this participant, where he was able to be more exposed to the display than would otherwise be the case.

Another participant used to spend time in another city to where his house was, and if it was not for not being able to go back, he would not have seen it for multiple days, *"I would not have seen the display for four days of the week I would not be here. So, I wouldn't have had any feedback on my usage." (P6).* For another participant, most of the time was spent at a university campus, and not at his house or room, *"I would not see the display most of the day. Because I have lectures and all this stuff and I'm at the university all day and I can't carry it around." (P5).* Similarly, another participant needed it to be portable for being able to take it to university, *"I would be moving around more. So, it would need to be portable or something I could also use at school." (P3)*. Therefore, display's portability could have had greater consequences if stay-at-home regulations were not in place.

OVERVIEW OF THE QUALITATIVE FINDINGS

The figure below presents an overview of the qualitative findings that have been discussed above. The next two chapters will provide further **syntheses and conclusions** of these findings. Chapter 6 will do so in relation to the Revisitation Reflector case study (summary), and chapter 7 will do so in relation to this project's five opportunistic design principles (summary). These two chapters will also further contextualize the findings by connecting them back to related **literature**.

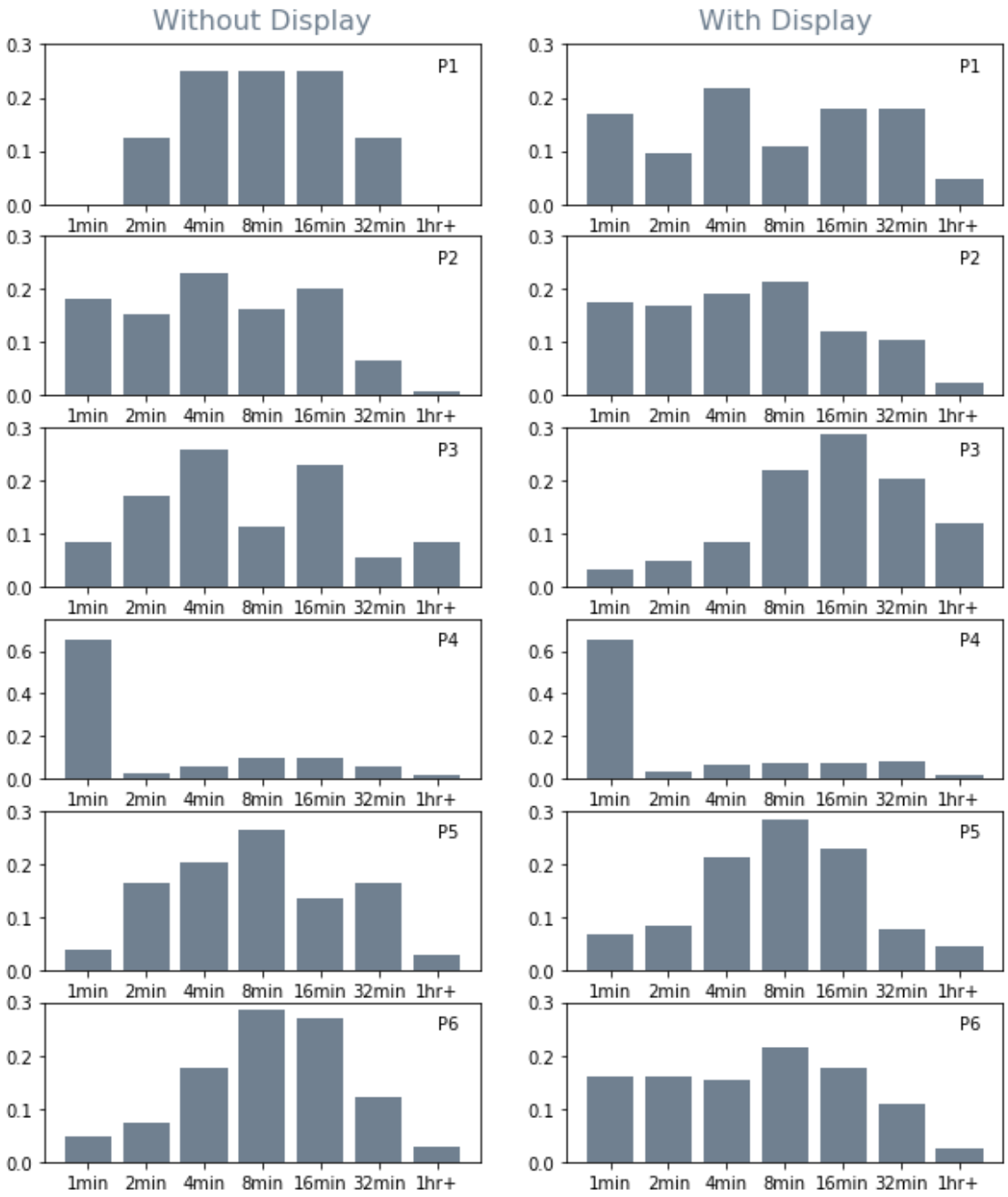


QUANTITATIVE FINDINGS

As was already discussed, the field study's main focus was on qualitative results. Whilst there were a few quantitative data sources that were part of the study, they did not form the main focus due to the limited sample size and limited duration of the study (which is also why inferences were not made). Nonetheless, here the results from the quantitative parts of the field study are going to be visually presented–without drawing any definitive general inferences. The first quantitative part has to do with the revisitation-related data collected from participants' phones by the AWARE app. The second quantitative part is about the responses to the daily ESM probe with participants' self-reported degree of control over smartphone revisitation. Despite these being quantitative results, the qualitative insights from participants do provide potential explanations for them, which will also be discussed below.

Relative revisitation patterns (average over hourly intervals)

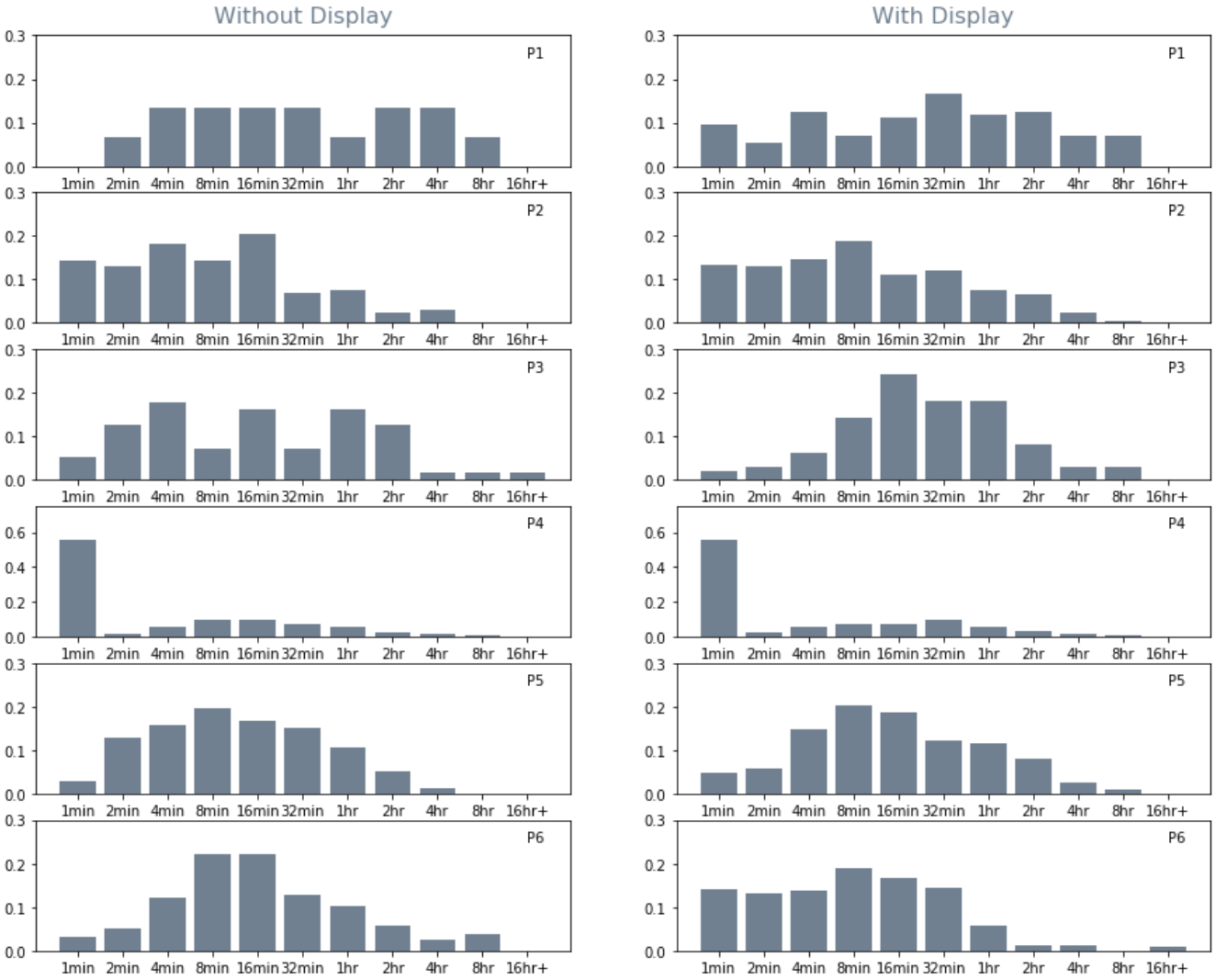
The set of graphs below depict revisitation likelihoods (and, therefore, revisitation patterns) of the participants both without having the Revisitation Reflector display and whilst having it. It depicts these revisitation patterns with respect to **hourly intervals** (to show how the hourly revisitation data might have changed). Just based on the visualizations, it seems that in some cases there is a slight shift in the distribution from fast, short-term revisitation to slower, longer-term revisitation (e.g. P2 and P3). But, overall, it appears that there is not a lot of change between the with and the without display scenarios.



Y-axis *shows relative revisitation likelihoods and* ***x-axis*** *shows the respective revisitation bins for hourly data (one participant's phone usage was not correctly recorded into the database and is, therefore, omitted).*

Relative revisitation patterns (average over daily intervals)

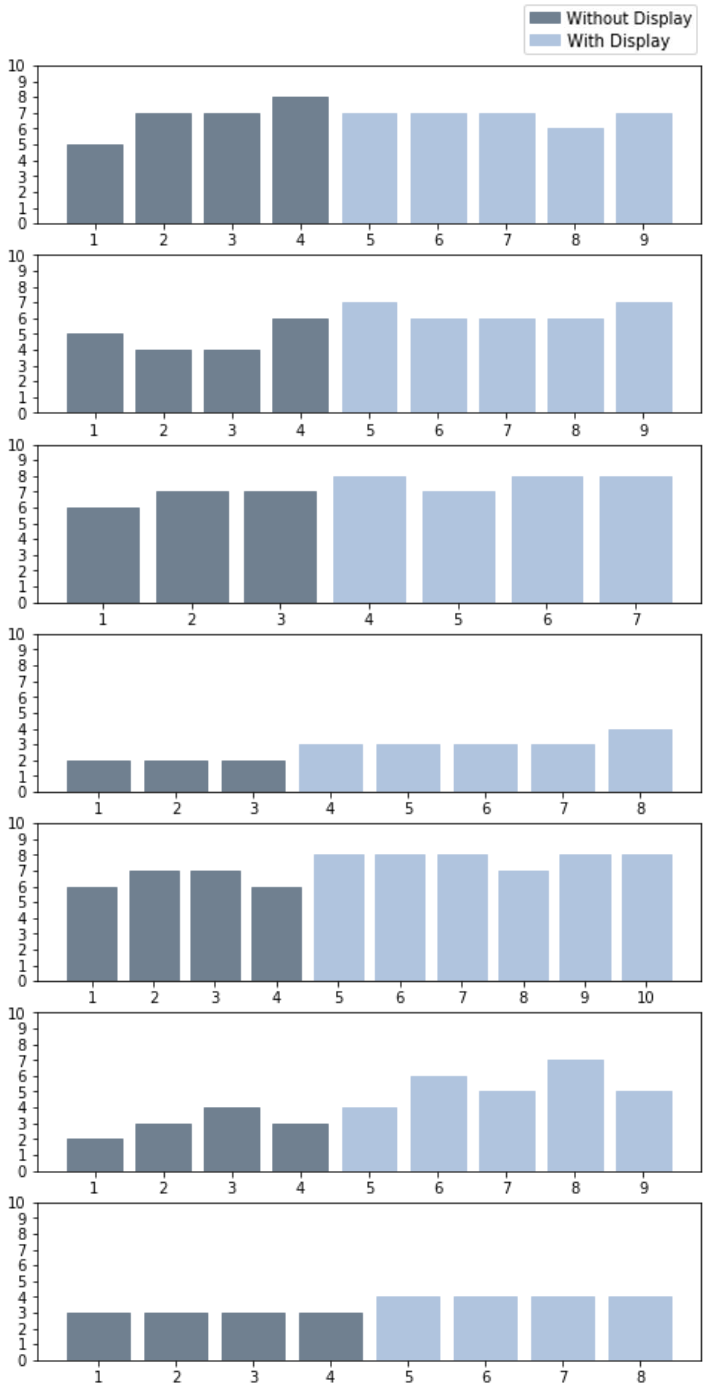
The set of graphs below depict revisitation likelihoods (and, therefore, revisitation patterns) of the participants both without having the Revisitation Reflector display and whilst having it. It depicts these revisitation patterns with respect to **daily intervals** (to show how the daily revisitation data might have changed). Overall, it seems just from the visualizations that not a lot changes between without and with display scenarios. This, however, is to be expected as the Revisitation Reflector was *not* relying on or displaying revisitation feedback for over a whole day–rather only over hourly intervals. As a result, it cannot be expected to necessarily have an influence on revisitation distributions over full days.



***Y-axis** shows relative revisitation likelihoods and **x-axis** shows the respective revisitation bins for hourly data (one participant's phone usage was not correctly recorded into the database and is, therefore, omitted).*

Daily ESM responses

The graphs below depict responses to the daily ESM probe with the participants' self-reported degree of control over smartphone revisitation. In all cases except the first one, there appears to be some increase in the self-reported degree of control when going from the 'without display' phase to the 'with display' phase. Purely based on the visualizations, it seems that the increase is not always a lot but seems to be present in most cases.



Y-axis *shows a participant's self-reported feeling of control over revisitations and* ***x-axis*** *shows the study day for the participant (unlike the revisitation graphs, here all seven participants' results are present because the ESM data was collected separately from the revisitation data and was correctly retrievable).*

Potential qualitative explanations of the quantitative results

It is apparent from the quantitative results that not much changed in terms of actual revisitation behaviors of participants. This is not surprising, due to the limited sample size and, more importantly, due to the very limited duration of the study. Nonetheless, the results from the participant interviews can provide possible explanations for why this could have been the case. They can also give insights on what types of changes were

Whilst causing actual behavior change was not the aim of the artifact, it was indeed a limitation reported by users as can also been seen in the revisitation graphs, as well as the daily ESM graphs above. From the interviews, there were some comments **reporting limited behavior change**, and confirming what can be seen in the quantitative data. For instance, a comment explicitly addressing this was as follows, *"It made me think regarding how much time I spent on my phone and how. It didn't make me change my behavior." (P4).* Another comment pointed to something similar about the display not making her do something, *"I got excited when I saw interesting changes, but it just made me aware of it not really do something about it." (P7).* Yet again, it was discussed, *"It makes me think about how I would like to use my phone…but not very actively in terms of how I'm going to change my behavior…" (P5).*

Although, it should be said that in many cases a confounding reason was reported as a hurdle towards such limited behavior change. For example, one participant simply was not an avid phone user in the first place, *"But maybe it would not make me use my phone less…because I am not a big phone user anyways. For example, at this time my phone has been in my jacket's pocket for hours and I haven't touched it." (P1).* Similarly, the participant also said, *"It was good it didn't influence me in the way that I wanted to decrease the usage of my phone, as I did not…but it was just that I was more aware and mindful that I was using it." (P1).* For another participant, it was good enough to just realize that he should change such behaviors, *"So, it got me thinking about my habits and it got me thinking about it more and that I should change them." (P4).*

Despite all this, there were also reports implying some form of behavior change. For example, for someone it helped reduce short-term revisitation, *"Yes, I wanted to understand the feedback and I tried to especially make sure especially on short revisitation feedback, I tried not to revisit my phone." (P4).* For someone else it helped control continuous on offs, *"I realized I do a lot of turning my phone on and off continuously and repeatedly out of boredom. So maybe for those behaviors it did do something." (P2).* For yet another one it was about reducing overall phone usage, *"I was consciously trying not to open my phone that much…if I saw it was off, then I wouldn't open my phone to keep the lights off sometimes." (P6).*

There were some comments that also implied that it was a limitation that the display **needed (intrinsic) motivation on behalf of the users** if it were to contribute to making changes. One participant said, *"I do think that this would work really only if you are trying to change the behavior… I'd have to actively work on it." (P6).* Another participant said that the display didn't really provide such motivation, *"Beyond this feeling of, 'this is a cool gadget that shows me data on what I am doing', I didn't feel like I got the motivation to improve my revisitation habits." (P7).* A participant also expressed that she would want motivation in order to really make this a part of her everyday life, *"I think I would like to have a little bit more motivation to take up into my routine." (P4).*

One of the participants specifically addressed the intrinsic part of motivation, *"It's cool if you have the intrinsic motivation to change. In my case I only had extrinsic motivation in terms of the lights." (P7).* The participant also explained, *"For me, I don't think so. Because again I don't have the intrinsic motivation. It's useful because it does make me aware because phone revisitation is a thing and I do it and maybe I should think about how I do it. But it doesn't motivate me to do it. The motivation has to come from within…" (P7).* It seemed though that this 'from

within motivation' was not necessarily considered as a limitation; perhaps, more as an observation, *"I thought the system was meant to make you aware of your revisitation habits and to help you in changing your revisitation habits. But I think that also has to come from the participant, not just the study." (P6).*

A very significant limitation the possible **fading of interest over time.** This could happen over the course of the day, *"Except I wouldn't pay much attention as the [work]day would end." (P5)*, or, *"In the beginning I thought it was interesting. I used it. I thought about what the feedback meant. But towards the end of my days, I would see the display but would not try to interpret the feedback. Being tired and being almost done for the day, it was extra sometimes to pay attention to it. Same goes for my study though." (P4)*. So, it could be that the fading of attention during the course of the day was a consequence of fatigue.

However, such fading of interest was in a few cases also reported during the course of the study. For instance, *"I do feel like I was paying more attention to it in the beginning of the study, rather than at the end. I became so accustomed to it that I wouldn't really focus on it. It was just there...so, I wasn't looking much at it consciously. It was in my vision but I wasn't processing the position or brightness of lights towards the end of the study. In the beginning I would consciously look at it and see this is how it looks now..." (P5).* Therefore, there could have been a novelty effect towards the start which faded over time. Another participant wanted to try it for longer-term to find this out, *"I don't know if I'm no longer intrigued by it and if it's just become a light on my desk. I want to see for a longer term if it still makes me stop and think." (P6).*

All in all, then, there could be many possible explanations for why a quantitative change did not actually occur in participants' phone usage or self-reported feeling of control. Based on participants' own comments, these explanations could have to do with possible confounding variables, the need for or lack of intrinsic motivation or the fading of interest over time (as each day passed and as the study progressed). Whatever the explanation may be, the theme of apparent lack (but also presence) of behavior change, did come up in participants' comments.

Part III: Implications, guidelines & future opportunities

This part takes a step back and looks at the project from a zoomed-out perspective. It looks at what general insights and guidelines can be derived from the project, as well as the limitations and future opportunities at hand. This is done, firstly, by using the field study's findings from the previous part as a lens for having a reflective discussion on the artifact and the study. This discussion helps answer **GQ3.1 ("What do the findings mean when using them to reflect on the artifact and on the field study?").** Subsequently, the findings are used as a lens to reflect on the five chosen design principles and on designing for digital wellbeing in general, through which **GQ3.2 ("What do they mean when reflecting on the chosen design principles and on designing for digital wellbeing in general?")** is addressed.

Overall, this part considers the themes of:

- Reflective discussion on the case study
- Reflective discussion on the prioritized principles for designing for digital wellbeing

6

Reflective Discussion on the Case Study

The project started with the aim of answering the **main research question**: "*What effect does giving users ambient, tangible and reflective revisitation feedback have on them and their smartphone usage?*". This question is mainly answered through the findings outlined in the previous part regarding the sensemaking, role and design of the Revisitation Reflector. These three themes show the impression of the artifact on its users, as well as the effect it had on their smartphone usage habits and experiences. These themes and the findings therein can be used as a lens for having a reflective discussion on the Revisitation Reflector artifact and the field study itself. That is what the chapter is going to delve into. The various themes of the findings will be reconsidered, but this time with a more reflective stance. For brevity, here only a few participant quotes and brief connections to existing work will be mentioned. For the full set of participant quotes, see qualitative findings of the field study and for detailed connections of the Revisitation Reflector to literature, see how and why the five design principles and prioritized values were embedded in the artifact.

REVISITATION REFLECTOR'S SENSEMAKING

Sensemaking of the Revisitation Reflector's feedback was one of the main themes being investigated regarding which several findings were uncovered. Starting with the dimension it was named after, **revisitation** was perceived as novel, expectation challenging and useful. Participants frequently mentioned that revisitation was something that they were completely oblivious of before using the display *("I never thought of revisitation rate before. I always thought of quantity of looking at your phone throughout the day should be reduced. Impulsiveness of revisitation is very interesting which is something I have been doing a lot, but now I have a name for that.")*. They also mentioned that it went beyond the typical screen time related metrics. Often revisitation feedback was seen to explicate participants' self-judgements about their revisitation habits and, thereafter, to challenge them. It was often the case that they thought they revisited in a particular way, but their actual behaviors contradicted that *("I would have expected that I would look at my phone more continuously, so that the state of the display wouldn't change constantly throughout the day. But now it fluctuated a lot.")*.

All in all, however, it was almost always considered to be useful to be exposed to such an atypical metric concerning phone usage. What stood out regarding revisitation perceptions was that **impulsive, fast revisitation** instances were usually considered as problematic *("...frequent, impulsive revisitation would be an issue...").* This perhaps shows that short-term revisitation, in specific, could be a priority option for revisitation-focused interventions. Indeed, this aligns with the frequent emergent goal of participants wanting to reduce fast, short-term revisitations. Short-term smartphone checking also frequently appears as a key problematic habit in literature [27,52,81], so it is interesting that it aligns with the participants' prioritized problematic aspect of revisitation. Whilst this could have been expected, it now has some empirical backing.

Regarding interpreting or assimilating the display's feedback, it was often the case that the number of **lit LEDs** (including none of them being on) and their **state changes** stood out the most**.** With the prevalence of these two aspects, it is clear that they are closely related to how glanceable or easily interpretable such a display is. It also shows that it could be the case that the number of lit lights and changes in them have more sticky connotations than e.g. their positions or colors *("Amount of lights is more impressive than color of lights...").* Which might be a reason to focus on them more when deciding how to encode user data in ambient feedback. This is not unexpected. Counting is such an innate human activity and encoding information in quantities is widespread in media, devices, apps, progress bars etc. It is standard in usual informational interfaces.

What is more interesting is that this perhaps implicitly also exposed the **nature of information** that participants expected: quantities instead of distributions. So, bars of quantity, rather than distribution patterns (which the Revisitation Reflector provided), might be what is the common expectation based on prior experience with any sort of personal informatics applications ("*...it's a revisitation pattern and not the frequency or quantity...I don't know if that's really what one needs.").* This propensity for wanting or expecting more than mere distributions was, perhaps, also evident from participants wanting additional information to revisitation patterns, like the number of revisitations or the total time spent on device. The Revisitation Reflector was based on showing relative distributions for thoroughly considered reasons, as can be read in detail in implementation decisions and seen visualized in figure 2. It turns out, however, that there is still a need to somehow balance that way of information encoding with more conventional ones that might be more natural and expected for users.

When it came to sensemaking, however, most of the insights had to do with **in-use appropriation** of the display's feedback: **patterns, morality and sensemaking practices.** Participants were seen to truly appropriate and define their own **patterns of meaning** regarding the display's feedback**.** They would start associating a certain ambient pattern with a certain way of smartphone usage, context, time of day, productivity levels, activity type etc. *("I would see the display go more to the left, it would feel to me as an indicator of me not doing good regarding revisitation.").* The field study's findings show that the Revisitation Reflector was able to be incorporated in different activities, times, contexts etc. just like it was intended to–based on the recommendations from [86]. Additionally, the findings show that a combination of incorporating ambiguous informational feedback based on [73], inquiry-driven reflection based on [9] and integration with lived experience based on [87] leads to completely user-driven sensemaking practices, some of which are quite unique and unexpected. This can reach the extent where users might end up contradicting intended goals and intentions of the system, as will soon be discussed. They would also reserve the act of stopping and properly reflecting for certain specific, self-identified patterns *("The white light did make think and reflect on my activity...").*

Not only were the patterns appropriated in these ways, but so was the **morality** regarding the feedback. Participants completely by themselves identified what they thought was desirable and normative and what they thought was undesirable regarding the feedback *("I think this was more about awareness rather than judgement.*

It leaves the judgment up to yourself…"; "I liked it just being a trigger…So, not give me good or bad results…yeah, so I would have to think what is good or bad for me…"). This is quite interesting and unexpected, as allowing the emergence of user-defined morality was not one of the original intentions behind the system. Although, looking back at philosophical perspectives on designing for reflection does reveal something about morality. Designing for reflection can inherently result in "reflective judgement" which can lead to users indeed define their own 'universals' and normativity [9]. This was vibrant in the findings. This perhaps highlights that when an artifact is intended to be designed for reflection, a side effect can also be the emergence of practices concerning user-defined morality (although, this depends on the exact artifact and its implementation and design).

Even the sensemaking practices regarding figuring out the way the Revisitation Reflector system worked in the first place were quite appropriated by different users to themselves. They had their own unique ways of **tinkering** and experimenting with it to figure out how it worked, and to see how their smartphone usage was reflected back in the display *("I was trying to experiment with the display, so I unlocked my phone more. So that I could see a result.")*. Even more, some participants actively started faking certain behaviors to manipulate the display into giving certain types of feedback *("I thought either don't revisit or don't turn off [lock] my phone. So, I sometimes I found myself simply not locking and turning off my phone and just leaving it on the side, to keep the lights off.")*. This experimental, tinkering driven sensemaking is very relevant to appear in the field study's findings because it quite exactly provides evidence for a process of hypothesis setting, testing and refining; which is exactly how reflection through inquiry is meant to be [16] and was intended to be incorporated.

The **appropriation and interpretation** were truly bottom-up and **user-driven**. To the extent that different users' sensemaking contradicted with that of other users *("If I would see the display go more to the left, it would feel to me as an indicator of me not doing well regarding revisitation"; "Now that there is the possibility of white light on the left occurring…I want to lower that as much as possible.")*; as well as with what 'should' be the case from a system-driven digital wellbeing perspective. It shows that when designing an interface that is intentionally designed to trigger inquiry by employing, amongst others, abstraction (and implicitly ambiguity), it is imminent that completely user-owned forms and patterns of meaning will emerge.

These **user-owned sensemaking aspects** might contradict the intended purpose of the system, even if the user has been explicitly told (and even understands) what the intended purpose is**.** This was evident from, for instance, a participant who was choosing to ignore the distribution or pattern of revisitation (which was explicitly communicated as the display's purpose to the participant); and was instead focusing on how many LEDs would be on, rather than what their distribution was, explicitly knowing herself that this was not the system's intention *("So, yeah, indirectly the amount of lights says more about behavior than the place of the lights, even though I know that is not true.")*. This aligns with [86], where it is shown that users do not necessarily act as rational data collectors, and that their personal data's sensemaking is done over their everyday, subjective and lived experiences.

Designing digital wellbeing interfaces in this **user-driven** manner can lead to devices where users define the **purpose and aim** of the device themselves, and where they define the degree and nature of **sensemaking and engagement** with it *("…that what is necessary for me to see should be decided by me.")*. This might not be the most 'productive' in terms of leading to objective change, but it shows a different way to design digital wellbeing interventions. There could be value in not necessarily focusing exclusively on causing change in some **quantitative, objective metric**. But instead opening up the digital wellbeing space to designs where the main focus is becoming a part of a **user's subjective experience** and e.g. the **reflection and curiosity** therein.

Clearly, from the findings resulted, for some users this role was perceived to be something completely sufficient (e.g. *"It was sufficient that it was just there to help me think..."*). This could even empower users to take control of their smartphone usage themselves. For instance, there were many instances where users blamed themselves instead of blaming the system: *"I wasn't motivated"; "I could've put it next to my bed"; "I could've put lines on it for my goals"*. Such a direction of designing for **open-ended reflection** also aligns with [9], who call for judging in what ways an artifact enabled reflection and what impact it had in terms of altering the "nature of reflective thought"–instead of just asking, "Did it work?", which limits the potential impact of such technologies.

REVISITATION REFLECTOR'S ROLE

The next theme being investigated concerned the role of the display. Here the first few findings revolved around the idea that: whilst the Revisitation Reflector was mainly a **trigger** for awareness and inquiry, it did hold the potential to impart a **mindset** for sustaining controlled phone usage. Indeed, much of the display's role as reported by the participants had to do with it being a trigger for awareness and reflective inquiry *("I liked it just being a trigger for me to think about my phone usage and reflect on it...to give an idea throughout the day on when and how I use my phone...")*. This trigger role was based on [73], and its focus on fostering inquiry was based on [9]–this was presented earlier in full detail.

Not only was such a role considered to be **sufficient** enough for the purposes that the participants appropriated the display for, but it even served as an ambient accountability partner *("Every time I was on my phone, I was like, 'Oh now this is going to be on the display!'"*) . In that capacity, it gave participants persistent feedback on their revisitation that, in many cases, facilitated an internalized mindset for self-monitoring of impulsive phone usage *("But now it gave me a mindset to control my usage such that even without the display I'm aware of when I use my phone."*). This shows that whilst at surface level a trigger role might seem too minimal and insufficient, in practice it can go a long a way, even in terms of imparting more permanent ways of thinking about smartphone usage. This indeed shows the effectiveness of the proposed 'trigger' strategies of [73], which are quite feasible to develop.

Besides the nature of the role, something else that stood out was also how the display was really interwoven in **everyday life** and everyday, **subjective experiences** of the participants [87] *("It was just there and when I wanted to look at it, I was looking at it. Sometimes I would just briefly glance at it to see what it shows.")***.** It was perceived as very ambient and unobtrusive *("I liked that it is was not very big and that it was not very obtrusive."),* yet intuitive. It had elements of ambiguity, which sometimes made it appropriable to a myriad of situations, interests and contexts. Whilst these elements of ambiguity were incorporated based on [73] with the core intention of enabling triggering and inquiry, they ended up having this positive side effect of helping with blending into users' lived experiences. The Revisitation Reflector was also physically localizable in different contexts, which also made it possible for it to be integrated into various aspects of everyday lives; as recommended by the work in [86]. This shows that having an artifact that can at least physically integrate with various contexts also goes a significant way towards helping it integrate with users' lived experiences.

A significant part of the experience with the display were spontaneous instances of **sensemaking, reflection and inquiry** *("I enjoyed interpreting it. Seeing how my behavior was reflected in the results I was getting. So, thinking about how it happened.")*. These instances helped the display interweave in participants' everyday lives and activities. It stayed in the background and let users continue on with their lived experience [38], whilst **coming to the foreground** when deemed as needed *("It slipped into background and only really came to the*

foreground if I saw something I deemed bad…I want it to be in the foreground only when there is something necessary for me to see.").

REVISITATION REFLECTOR'S DESIGN

When it came to the design of the display, there was a clear consensus that the **tangible medium** was preferred over digital alternatives. It was perceived as more useful than digital alternatives due to its **physicality**, which enabled persistent feedback that was **decoupled** from the phone *("I like it. I like to have something tangible. Makes you think as it's there in your face.")*. Such decoupling enabled users to reflect on their phone usage in the moments even when they were not on their phones, based on the recommendation from [98]; and it prevented the need for them having to go back to their phones to check how they were using and revisiting their phones themselves *("You must not have to visit an app on your phone to check your revisitation data about the phone itself.")*. In this way, it also, in certain cases, helped 'pull' the participants out of the virtual world of their phones and back into the real world. This had the added benefit of avoiding phone revisitations be gateways to other apps and to greater phone usage overall *("If I check Facebook, I'll end up checking many other apps…")*–as discussed in [81].

The tangible medium was also perceived as **novel** and more **engaging** than digital alternatives *("It's definitely better to also have the display rather than just have an app on your phone. It also makes your goal more tangible when you have something physical related to it.")*, as predicted by theory in [107]. It was also perceived as more accessible and intuitive than digital alternatives, as claimed by [83]. Furthermore, talking about the display's design, **overall concept and implementation**, they were all perceived as quite likeable *("The concept is extremely cool."; "It's impressive how much info you portray using the arrangement of LEDs and their brightness and color…impressive to see an entire bar chat, which would be boring, to be displayed this way.")*.

Whilst such likeability was usual in general, there were clear desires to **personalize or customize** the system's intervention approach, physical design aspects or revisitation-related characteristics. This shows the expected significance of personalization of tangible interfaces *("Maybe I would like personalizing it…If I purchase something like this, I would be more in favor of it if it would look how I want it… if I could personalize it…")*. This confirms the hypothesis by [107] that there is an inherent need for the possibility of (digital) wellbeing treatments to be individually tailorable to users. But, more surprisingly, users also had preferences to customize the system in more fundamental ways in terms of its intervention approach, e.g. through gamification elements *("To do something with it, I'd need gamification… I'd respond well to gamification…")*.

Interestingly, it also shows that a metric like **revisitation** (which the system was based on), could also be designed to be more **appropriable** in itself; e.g. through enabling the choosing of: different scales, different numbers of revisitation bins, different focus of revisitation, a few qualitative revisitation categories rather than several quantitative bins etc. *("Maybe with a different scale it would be more useful…"; "…maybe the timespan should change per person…")*. This desire for personalization at the level of presented data is also to be expected. The work in [30] shows that personalization is highly relevant because different users value different cuts of their personal data; and that there is dramatic variance in the data cuts that users find valuable [30], which also aligns with the great variance in the user comments in the case study's findings. It should be mentioned, though, that simply customizing does not always have to be the answer. Whilst customization can satisfy users by helping them configure a system's functionalities, modalities and form to themselves, it might lead to devices that are no longer simple enough (which was an essential quality of the Revisitation Reflector) [68]. So, the degree of customization possibilities embedded in a digital wellbeing artifact should be handled carefully.

There was also something deeper that was revealed especially by participants' desires regarding additional information to or customizations of revisitation patterns. When looking at such perceived needs for customizations, it was often visible that there might have been a deeper **expectation** amongst users for just knowing **numeric** values *("It would be nice to next to the display have a number showing how many times you revisited your phone.")*. This is perhaps due to the problem space of smartphone usage, due to existing expectations or due to an image of how smartphone usage related information is meant to be. In any case, it was clear that sometimes participant just wanted 'a number'.

FUTURE OUTLOOK ON THE REVISITATION REFLECTOR AND ITS ASSOCIATED FIELD STUDY

What has been and will be discussed in all the sections of this chapter has already been, implicitly and explicitly, pointing towards future possibilities. Thus, this section is *not* just the only one here where a future outlook is presented. However, what is specifically presented in this section is what has so far not been discussed in the rest of the chapter; as well as a future outlook whilst focusing specifically on the Revisitation Reflector artifact itself and its associated field study.

When thinking about future possibilities, one of the biggest limitations of the current implementation of the Revisitation Reflector was that it only collected, processed and gave feedback on **smartphone data**. It is obvious that for many users a lot of their digital activities take place on their laptops or computers, besides their phone *("I'm on my laptop for most of the day.")*. Furthermore, as was already discussed, much of the identified revisitation habits are attributed to the apps and services contained in the phone or on the web–rather than to the phone itself [52]. So, if as recommended by [52], the focus for countering revisitation is placed on apps rather than the medium (smartphones or computers) they are contained in, then it is crucial to indeed monitor the use of apps both on a user's phone and their **computer**. Which means that a follow-up artifact should be designed to be multi-platform and monitor data from both these sources, and to perhaps give feedback related to both these sources as well.

As has already been discussed at several points in the dissertation, there are many calls from digital wellbeing literature to focus more on **habit formation** e.g. [58,74,85,98]. Whilst it was just discussed why this might difficult from a feasibility perspective, it does not mean that it should not be done a bit more than at present; even if the habit formation capabilities cannot be developed to their ideal level of nuance. For this, three main recommendations from [98] are: supporting trigger events combined with action intentions (I will do 'X', after 'Y' happens); using reminders are reinforcers of such action intentions (so reminding a user to do 'X' before 'Y' actually happens, so that when 'Y' happens, they are ready to do 'X'); and trying to not have features that build dependence on technology (and instead building associations between contextual cues and intended actions).

Besides habit formation, app-level focus was also discussed earlier; where metrics at the level of **individual apps** are considered, besides metrics at the macro, phone-level. For instance, [74] show that digital wellbeing apps could be more targeted at the "app-level" rather than at "phone-level". However, in practice, based on the Revisitation Reflector's case study, it was already discussed how trying to go more at the app-level might disturb a delicate balance with user adoption due to privacy preferences. Nonetheless, it does present an opportunity to make digital wellbeing artifacts more nuanced, insightful and actionable. Furthermore, more **metrics** could be tested (through the same medium) besides revisitation; to see which one attracts the most engagement, which one is perceived as most useful and which one has the greatest impact on phone usage.

To this end, there were desires expressed also by users to be able to indeed have **additional information** to revisitation, **personalize** the physical design of the artifact or to customize the fundamental approach used by the **intervention**; to fulfill such desires, an interesting future opportunity could be to create a participatory methodology, together with technological building blocks, that would enable users to design their own digital wellbeing artifacts. The implementation side of this could e.g. build upon the current Revisitation Reflector prototype by using the AWARE app as a generic data collection framework and using the LED display as a generic ambient display. This combination of sensing through AWARE and ambient feedback output through an LED display can be used to create a **'generic personal data encoder'**. This can help map sensed smartphone usage metrics that a user finds interesting (frequency, duration, revisitation etc.) to any output modality (pattern, color, brightness etc.) on the display; thereby, the current prototype could form the technological starting point to a future project on enabling users to design their own digital wellbeing artifacts or partners.

When it comes to the testing side of things, the biggest current limitation was that there was no data collected on the exact moments that participants **looked at the display**. Without that data, there is no quantitative indication of how users objectively engaged with the artifact. So, a future addition to the testing could be the addition of e.g. an eye tracker. Such an eye tracker could be integrated with the existing Raspberry Pi setup, such that the eye tracking data could be collected on the same device as the LED display; and the data collected could be seamlessly integrated with the rest of the sensing and output related data being logged by the device. An added bonus of eye tracking could also be that it would allow investigating how the display's feedback could be altered based on when a user looks at it. For example, if a user has not looked at the display for the past three hours, should it not show feedback for the entirety of that duration instead of just one hour? So, addition of eye tracking would allow the testing of using glancing and engagement data to update feedback characteristics like the time interval over which it is based.

Continuing along on similar lines of testing different variations, studies could be carried out trying to **investigate parameters** like: the moment to update feedback, the scale used for encoding revisitation, handling long usage sessions without any revisitations, time interval on which revisitation is based etc. A wide array of design decisions was made based on theory, pilot testing or logic, however, there is room to set up studies to investigate and verify the best forms and combinations of those decisions.

Another aspect to incorporate in field testing in a follow-up project could be regarding **sampling** of participants. A limitation of the current case study was that it did not screen users based on whether they even cared about revisitation or whether they even objectively exhibited such behaviors. Therefore, in a follow-up, purposive sampling [10] could be incorporated where participants would be selected based on either or both of these factors (whether revisitation matters to a user and whether they exhibit it). This would avoid testing on those parts of the population who would not even be a potential target group for the artifact. Moreover, it should also be said that the field study needs to be repeated with a bigger, more objectively representative **sample**. It should also be done over a **duration** that is significantly longer than the current one of a week, to ensure that the long-term effect of and engagement with the artifact can be investigated. Finally, the study should be repeated in conditions that are more representative of **COVID-19**-free times, to see how well the findings would translate if the COVID-19 regulations were not present.

CONCLUSIONS/SUMMARY REGARDING THE CASE STUDY

The reflective discussion in this chapter covered the guidelines, opportunities and limitations that have emerged from the three main themes of insights from the Revisitation Reflector's case study. It also presented a future

outlook regarding the field study and the artifact in general. Here a summary of conclusions from the reflective discussion is presented.

Reflecting on the theme of the artifact's **sensemaking** revealed several insights–most of which had to do with the artifact being highly user-driven. The participants in a truly bottom-up fashion defined what feedback from the artifact mattered to them, what feedback aspects deserved their reflection, and what feedback was normative for them. They also gave idiosyncratic meanings to various feedback patterns and defined their own unique ways to experiment and tinker with the artifact to try and make sense of how it worked in the first place. Whilst such an approach might put a greater burden on the user, the study showed that is not necessarily a negative thing and that it can even lead to a fresh direction for designing digital wellbeing artifacts that are really open-ended; where users appropriate it to themselves, and give it meaning as they use it and curiously engage in reflection through it [9]. The outcomes of users' sensemaking of the artifact also showed that revisitation really is a useful and novel metric to include in digital wellbeing interventions; and that it is impulsive revisitations, in particular, that are perceived as problematic by users (like in [27,52,81]).

Reflecting on the theme of Revisitation Reflector's **role** also led to interesting points. The artifact was meant to be and turned out to be a trigger [73] for inquiry and awareness [9]. At first glance that might seem like too minimal of a role. However, it became highlighted by the study that not only can a trigger role be perceived as quite sufficient by users, but it can even have deeper influences on users' mindsets and thinking regarding their digital wellbeing. The nature of the artifact as being ambient and unobtrusive helped it blend in and become a part of the everyday, subjective experiences of the participants [87]. The artifact being able to be localizable in different contexts helped with this, and so did its somewhat ambiguous feedback (from [73]) that helped it to fit in various purposes, interests and situations. It was apparent that the artifact's inquiry fostering role indeed made brief moments and longer periods of reflection a significant, desirable part of users' experiences.

The reflective discussion on the theme of the artifact's **design** also unveiled several insights. The first bunch of insights were centered around the tangibility or physicality of the artifact. Its physicality enabled decoupled feedback from smartphones [98] and avoided the need to rely on phones for feedback on the phones themselves. The tangibility also made the artifact engaging, accessible, intuitive and likeable. Besides tangibility, the other insights that stood out were about participants' desires to customize physical design aspects of the display, or to customize the more fundamental aspects of the approach or the revisitation feedback it was based on. Sometimes, participants also wanted to have additional information or feedback beyond what was already given by the display. These insights showed the need to potentially enable users to make modifications or personalizations, where feasible, to enable them to make their digital wellbeing artifacts really their own [107]–also in a more literal sense.

Besides reflecting on the findings related to the sensemaking, role and display of the artifact, reflecting on the **artifact** and the **field study** as a whole also led to pointers for future directions. Perhaps the most crucial feature to improve in the artifact's next iteration would be to make it multi-platform, i.e. also enable it to monitor and give feedback on laptops or personal computers. Moreover, a greater focus could be placed on habit formation through contextual cues and intention setting [98]. Further alternative metrics (besides revisitation) and their effects on users could be tested and more 'app-level' approaches could also be investigated. A significant limitation of the current field study was lack of data on how and when participants looked at the display. Overcoming this limitation through e.g. eye-tracking could make the field study's data a lot richer in a follow-up project based on a similar medium. Finally, purposive sampling [10] could be done, the study duration could be increased, and it could be repeated in more usual, COVID-free times.

7

Reflective Discussion on the Five Principles for Designing for Digital Wellbeing

The previous chapter had a reflective discussion on the findings from the main themes case study that helped address the main research question ("What effect does giving users ambient, tangible and reflective revisitation feedback have on them and their smartphone usage?"). As the research question highlights, this project employed the untapped, pertinent metric of revisitation; which demands a different design material that has not yet been widely adopted for the digital wellbeing domain. One that is reflective, ambient and tangible and that is focused on the lived experience of smartphone users. Together this **untapped metric and underexplored medium** were geared towards helping smartphone users feel and be more in control over their smartphone usage. This chapter will take a zoomed-out, reflective look at the principles for designing for digital wellbeing that were related to this metric and medium: the principles that the Revisitation Reflector was based on.

DESIGNING FOR BEING TANGIBLE

Revisitation Reflector was designed as a tangible artifact that gives physically persistent feedback on personal revisitation data. It is literally external to a user's phone and it visualizes data in a way which is novel within the typical digital wellbeing interventions. By being **decoupled** from a user's phone, it enables the human to stay available in the real world rather than the virtual one. However, something which became apparent to the case study was that when designing for tangibility or physicality, you are inherently designing something which could be poised to be an extrinsic motivator. Not that smartphone-based feedback is not extrinsic, but perhaps having a device with is not situated on or held by your body makes it even more **'extrinsic'**. The theoretical consequence of this might be that

the device leads to temporary habit changes, which would revert to original state once the external motivator would disappear–same as what happens in smartphone-based interventions [85].

However, the results from the case study also showed a different point of view. They showed that the Revisitation Reflector had the potential to be **provocative** enough to highlight to users that the motivation had to be intrinsic and that in the end technology was not really what was going to enable longer-term change. This, in itself, does not completely overrule the effectiveness of the such a tangible display's role: it might create temporary habit changes, but it might also alert users to them having to take control of their digital wellbeing themselves. This was facilitated, in part, by the artifact being an externalized display that is decoupled from the smartphone. As that meant the feedback was persistent and was able to remind participants of its extrinsic nature, even or especially when they were not on their phones.

In any case, the case study showed that **empowering** users to realize the need to and a way to take control of smartphone usage, could in itself be a **reasonable objective** for digital wellbeing interventions. Interestingly, this provocative approach towards empowering users themselves aligns quite strongly with approaches driven by critical thinking to help form a better relationship between technological tools and human practices [9]. Such fostering of critical thinking through provocativeness can create reflection moments that can lead to deeper change from within users [9]. They can start realizing that there is a need for change and that change has to come from them, as was the case in the case study: *"I wasn't motivated...the display could definitely have helped if I wanted to change...but now I know of this habit and have a name for it"*.

Another aspect of tangibility that was preferred by participants was how such a display being is its own discrete device was completely decoupled from the user's phone, and does not require the user to interact with or visit their phone in order to get their current **revisitation feedback status**. For someone this preference was linked to how the externalized display avoids opening the door towards other apps, *"This is better than an app. Because an app would make me go back to my phone and if I check this app, it might make me visit Facebook as well and it would increase my time on the phone."* This entirely aligns with the findings in [81], that show how smartphone checking is indeed a "gateway" towards other apps and does indeed increase overall phone usage.

This was not the only way in which theoretical principles upon which the tangible display was made were reflected back in the findings. Another foundational principle was not **relying on a smartphone** to give user feedback on its own usage. Such an approach is quite prevalent in current purely digital interventions ([67,74]), but was expected to create a perpetual cycle: One is relying on having to come back to one's smartphone in order to track and get feedback on how one is using it. Interestingly, this was quite specifically reflected back in the findings, *"This wouldn't have worked as well with an app. Because, firstly, the subject of matter is your phone so adding feedback point to your phone makes it into a viscous cycle. So, you get feedback about your phone, but you have to look at your phone for the feedback."*. This, thus, warrants the utility of such a design principle, and shows how tangibility can be a way to implement this principle.

Continuing on with this theme of decoupling from the phone, was the ability of such **decouplings** to bring users to the real world, out of their phones' **virtual worlds**. The external physicality of the display enabled one participant to pay attention to something novel that she would not at all notice without such an externalized artifact: *"I was aware that, 'hey I am using my phone.'. Without it, using my phone would not be something that I would pay attention to. I would not pay attention to doing this activity. When I am sporting, I know I am sporting, but when I'm on my phone I don't feel like I am on my phone. It feels like it's part of every activity and that it's not separate. With the device it felt a bit more separate."*. Whilst the way decoupling was created based on the

current Revisitation Reflector might not have enabled the most translation to action or change, it clearly did enable users to distinguish between moments of being in the real world versus being in the virtual one.

Along this line, specifically for the digital wellbeing domain, decouplings from smartphones through **externalized tangibility** can be an impactful strategy to help people come back to the real world. This perfectly aligns with the idea of tangible interfaces being "supporting interaction technologies which make the human available" in the real (as opposed to the virtual) world [80]. This project gives additional empirical evidence to support this claim.

DESIGNING FOR BEING REFLECTIVE

As was discussed several times earlier, the Revisitation Reflector was designed to facilitate a specific kind of reflection: inquiry. Amongst other things, as recommended by related work [16], the Revisitation Reflector tried to stimulate a process of creating, testing and refining **hypotheses** regarding one's revisitation patterns. It did this by having abstract feedback that would constantly update, so one could try something and try to explore its effect on the feedback outcome. It also enabled this by following the theoretical recommendation of letting users review and reflect on past experiences through past personal data (by giving them continuously updating feedback on past data) [9]. It was also designed without many pre-conceived notions of how users should make sense of their data and what would be the most important cues and insights for them [30]. Embedding of these theoretical principles in the designed artifact really did lead to what the aforementioned theory predicted it would: Inquiry-driven reflection.

All in all, the intention was to embed affordances for sparking **inquiry (hypothesis setting, testing and refining).** This intention was clearly embedded in the artifact and it came back in the results. There were a lot of inquiry-style activities going on that were facilitated by the artifact. Consequently, what the results also did convey was that embedding cues for inquiry (e.g. abstract feedback [37], ambiguous feedback [73], or continuously updating feedback [9]) in an artifact inherently also affords tinkering behaviors. It was quite apparent from the results that **inquiry and tinkering** go hand in hand. Participants would want to deliberately exhibit specific smartphone usage patterns to see how that would affect the display, and they would want to deliberately manipulate it *("I was trying to experiment with the display, so I unlocked my phone more. So that I could see a result.")*.

Another design principle that the reflection was based on was that of giving the Revisitation Reflector primarily a **trigger role.** As recommended by theory [73], the artifact was designed to be a trigger by presenting abstract data cues; whilst leaving room for bottom-up emergence of what type of feedback, reflection and behavior change would be relevant to individual users. On first glance, this might seem to be a minimal role, without much 'active' intervention that might be visible in some other digital wellbeing applications.

However, what the results of this project made clear was that merely being a trigger, without any sophisticated **intelligence or system-driven** sensemaking or morality can be sufficient for certain users. A participant, for instance, said, *"I liked it just being a trigger for me to think about my phone usage and reflect on it. So, not give me good or bad results, these many hours, these many times a day...but being a trigger was enough."*. This also shows

that perhaps we do not need to make all the devices geared towards enabling wellbeing too easy to use. Indeed, difficulty of usage might become a valuable part of the (reflective) experience, and it might be perceived as interesting and likeable by some users. Indeed, this lack of straightforwardness in terms of usage is somewhat related to the "breakdown" approach of [9], where uneasiness of usage, and confusing, conflicting or surprising cues are intentionally used to foster reflection. Such reflective processes emerging from such cues showed that trying to interpret, think about and **make sense** of the display's feedback was in itself a significant part of the experience for participants–that led to triggering inquiry and deep thinking.

DESIGNING FOR BEING AMBIENT

The Revisitation Reflector display a completely ambient display that was designed to be glanceable. It was designed to be non-obtrusive and be in the periphery by virtue of its size, minimal design and minimal LED feedback. By choosing an LED stick to give visual cues through LED colors and positions, feedback was designed to be ambient. Since this feedback mechanism was also quite minimal and did not demand explicit attention, it was more likely to be ambient [38]. Indeed, it was unanimously perceived as such *("I liked that it is was not very big and that it was not very obtrusive.").* All participants found it to be **unobtrusive and ubiquitous**, yet effective. At the same time, they found this characteristic to be **engaging and likeable**.

However, it was also clear from the results that the **ubiquity or unobtrusiveness** of such a display could be too little of a call to action; perhaps showing you that you can have too much ubiquity. Sometimes, for some participants, the display drifted too much into the background to even be properly noticeable or spur some thought or action. Whilst, this was not very common, it does show that embedding ubiquity in such a display should be balanced with the degree of active engagement that is expected [53]. For the Revisitation Reflector, such active engagement or behavior change was not the direct purpose, so it did not have negative implications; but the results do indicate the need to be mindful of the potential compromise between a display being ambient and it leading to active engagement and actions.

Another way in which **glanceability** was embedded in the display was through using minimal, abstract LED feedback. It was based on the theoretical recommendations of using a data abstraction of revisitation patterns, to turn them into simple feedback that is quick to process and is not meant to require much conscious thought or attention [37]. By being in an **everyday, domestic context**, the Revisitation Reflector would also be poised to be gazed at relatively frequently–which was another theoretical recommendation for glanceability [37]. The glanceability and ubiquity of the artifact were evident from quotes like, *"It didn't interfere with my activities, but it did catch my attention.".*

Based on these theoretical recommendations, employing both **data abstraction and integration with activities** indeed turned out to be the most important aspects for enabling glanceability. Regarding the specific forms for encoding data for abstraction, the number of lit LEDs and the changes in the states of the LED feedback were the affordances that stood out the most for participants. From the findings of the Revisitation Reflector case study, it was also clear that **simplicity and compactness** seem to have a strong correlation with glanceability and ambient feedback *("I like how it's simple. It's not a big ugly device that you have to put on your desk...it doesn't interfere with you...").* This is not unexpected; however, it is important to point out because just

employing abstraction might not have been sufficient if the form and design did not complement the abstraction with simplicity and an obtrusive size.

DESIGNING FOR LIVED EXPERIENCE

This principle was strongly related to designing for being ambient; it is somewhat of a subset of designing for ambience. This principle was also clearly reflected back in the results, showing that it had indeed been embedded in the designed artifact. It was clear that for most participants the artifact really blended into everyday lives and activities, and became part of **subjective, 'lived experiences'**. The way this was done was by making sure that the artifact was appropriable by users for whatever purposes, needs and contexts they would be interested in [86].

The Revisitation Reflector along these lines was designed as a generic, ubiquitous artifact that can be placed wherever a user wants, can be appropriated to be a part of whatever digital activity a user is partaking in or can be suited to whatever needs a user has. For instance, a participant said, *"It was pretty much just like one of my cacti that I have on my desk. It's just sitting there. I am aware of it. It evokes thoughts or feelings..."*. By designing an artifact in this way, the Revisitation Reflector's case study really does show how these principles had a noticeable impact on how well the artifact integrated with its users' lived experiences.

The design intention was to allow users to be able to make sense of it however they wanted to, they could draw whatever **conclusions** they think would be there *("If I didn't like a result, then I would stop and ask why..."*) and they could set it up in whatever **space or context** they would want *("It fit quite easily into my workplace."*). To allow it to be interwoven into whatever its user would doing during the day, it did not demand explicit attention or obstruction of daily activities [87].

As recommended also by [87], it also did not assume that users just wanted to do **rational data collection** and only reflect on it after it had been thoroughly analyzed. All of this was mostly embedded in the artifact through ambience-related ethos. In a way designing for ambience, at least the way it was done in the case of Revisitation Reflector, inherently meant designing for interweaving in everyday lives and for being a part of users' subjective experiences. This goes to show that the principle of "designing for lived experience" is actually practically just a subset of the principle of "designing for being ambient".

DESIGNING FOR REVISITATION FEEDBACK

The Revisitation Reflector was fundamentally based on revisitation and giving users awareness of their revisitation habits. It incorporated revisitation as a metric to give users feedback on, as well as a metric that the artifact's purpose was based on. The main emergent finding regarding user-defined normativity associated with revisitation was that **impulsive, short-term revisitation** was considered as the most undesirable revisitation habit, confirming theoretical notions like in [27,52,81]. Other than that, there were also desires expressed to be able to **customize** various aspects of revisitation feedback: the scale used, the encoding or sensemaking mechanism, the revisitation bins, exclusively focusing on impulsive

behaviors etc. So, making such customizations possible and giving users agency over them could be a valuable future opportunity.

What should be acknowledged as well is that revisitation is not unique to smartphones, as the same habit is exhibited on the web by users for similar purposes [52]. Therefore, as shown by Jones et al., there is a substantial chance that revisitation habits are actually "driven by the type of service or information that the user gets – irrespective of technology." [52]. They attribute much of the identified revisitation habits to the **apps and services** contained in the phone or on the web–where evidence shows that the phone is simply a vessel or medium holding these services. They call on to "consider smartphones not as hardware devices, but as sets of functionalities and services (i.e. apps)." [52]. They also, therefore, stress the need for not associating smartphone revisitation to the fact that phones are mobile and available etc., but to the apps contained in them. As at a macro-level, very similar revisitation patterns are exhibited on web-based desktop services [52].

This was reflected in the findings as well, where multiple participants explicitly mentioned using their laptops over their phones for the same services, especially when they were home. For one participant, indeed, all the phone applications of interest had laptop alternatives, and since she was anyways mostly home, she was using her laptop to reach all those applications: *"Now I can just use my laptop instead of my phone. I can do WhatsApp, Facebook messenger, all on my laptop. So, I am definitely using my phone much less."*. This project, thus, verifies the theoretical perspective that it is the services within a phone or a laptop that trigger and characterize revisitation habits [52]. It also shows the need to also include other **digital platforms**, besides phones, in digital wellbeing artifacts.

Another aspect that was missing was active consideration of **context** by the artifact. Yes, the artifact was embedded in diverse contexts by participants themselves, but it was not actively sensing or reacting to contextual cues. At the same time, however, participants reported their self-perceived revisitations (before they had the Revisitation Reflector around) were highly variable, situational and dependent on various contextual factors. For instance, for one participant revisitation depended on his location, *"It really depends on the setting I'm in. That's why at the moment it's different to what it was when I was working in Amsterdam than when I am now in Enschede."*. Another participant associated his typical revisitation to the time of the year and to task requirements, *"It depends on the situation, time of year, holidays or not, do I have something to do..."*.

This is related to perspectives from revisitation-related theory. There, it is concluded that habitual revisitations are consistently tied to particular, triggering contextual cues. Just like [52], however, this project used screen status (screen unlocks and locks) and inter-visit times as habitual behavior trigger gauges, without explicit regard for contextual cues. Therefore, incorporating and investigating **contextual cues** and their effect specifically on **smartphone revisitation** presents another valuable future opportunity regarding the revisitation metric. Whilst this need for incorporating contextual cues might already have been obvious from literature [58,74,85,98], feasibility constraints of the project did not allow this approach to be fully present in the current proof-of-concept.

MISCELLANEOUS INSIGHTS RELATED TO THE PRINCIPLES FOR DESIGNING FOR DIGITAL WELLBEING

Besides reflecting on how the Revisitation Reflector case study relates back to the prioritized design principles, it is important to address some more general insights related to designing for digital wellbeing that also emerged from the study. To start with, the greatest bottleneck when designing for digital wellbeing is the sensing of relevant data. Whilst AWARE was a good choice for sensing required data for conducting an academic study,

its full sensing functionality would almost be impossible to be embedded in an app that could actually be permitted to release on e.g. the Android play store. Other significant limitations when designing for digital wellbeing include: privacy considerations; operating system restrictions; user aversion to granting data access and monitoring permissions to apps; and the sheer heterogeneity of situations and parameters to be sensed. So, when thinking of implementing digital wellbeing interventions, it basically just comes down to **feasibility**; as was the case with the choice for building the Revisitation Reflector. Feasibility, amongst others, was a key factor in converging to that concept.

These aforementioned feasibility-related constraints might also be strong reasons for why there are not many digital wellbeing interventions that e.g. enable **non-trivial habit formation**. Explicit routine support, selecting and detecting meaningful cues to action and forming and detecting implementation intentions [98], are pointed out as crucial features to enable habit formation. What the experiences with concept development of this case study convey is that doing such habit formation in a non-trivial manner would require significantly richer data and a lot more intelligence in sensing, processing and output. That can be practically difficult to achieve due to all the feasibility constraints listed the paragraph above.

On the other hand, **habit formation** can be enabled by embedding an artifact like the Revisitation Reflector in a user-chosen context and leaving association building and implementation intentions to the user, with the hope that **visual cues** are meaningful enough to lead to **reflection and/or action**. Regardless, there has been lots of focus in literature on calling for habit formation e.g. [58,74,85,98]. If this is to be something beyond a task list with reminders, much more sophisticated sensing and contextual capabilities are needed. But those might not always be possible to implement due to the aforementioned limitations regarding privacy, operating systems, development constraints, sensing limitations etc. There is a reason why not many (deployed) interventions have been able to do this despite recurring calls in literature for such in-depth habit formation.

When thinking about designing for digital wellbeing, something which has been quite prominently and pervasively addressed in literature is the need to move beyond merely using screen time [62]. As was just discussed in the previous few paragraphs, feasibility constraints might not even allow going beyond screen time in a sophisticated enough manner. But besides such pragmatic constraints, it was evident from the study's results and participant expectations that **screen time** might be unavoidable. Even when participants were explicitly told that the Revisitation Reflector was about revisitation (and, therefore, not about screen time), they would still try to reverse engineer screen time from it *("I was seeing whether there were more lights, because that for me meant I spent more time on my phone...even though I know that was not necessarily true...")*. Perhaps also showing how screen time might not just be the expectation, but also of higher personal relevance or significance. It is no wonder, therefore, why screen time is still such a prevalent metric in various studies, e.g. [60, 48, 59, 58, 13, 16, 32].

Speaking about trying to make digital wellbeing interventions more sophisticated, another oft-repeated recommendation in literature is calling for going beyond 'phone-level' and more towards 'app-level' metrics [74]. So, e.g. instead of considering amount of time spent on the phone as a whole, considering the amount of time spent on specific apps. Whilst these calls for **app-level approaches** seem logical and attractive on paper, it must be stressed that such approaches might be difficult for users to easily accept. At least based on the experiences from the case study, if users would be similar to the study participants, app-level would be difficult to get user adoption for. In the case study, this was privacy reasons. The first thing that participants would inquire about and/or be skeptical about was the data collection being done from their phones by AWARE. Specifically, they would want to know whether the apps they were using, or the activities therein would be

tracked *("At first it was strange. I was wondering whether you could monitor what I was doing it my phone's apps...")*. Thus, going into app-level interventions might not be necessarily be well-perceived in terms of privacy.

CONCLUSIONS/SUMMARY REGARDING THE FIVE PRINCIPLES

The reflective discussion in this chapter looked at the general implications, opportunities and limitations that emerged from the five principles that this project was based on. This section will present a summary of the conclusions made from this reflective discussion.

Reflecting on findings within the principle of **designing for being tangible** revealed several themes most of which had to with this medium being externalized, tangible and decoupled from a user's phone. The study showed that having such a tangible, decoupled artifact is particularly useful for the digital wellbeing domain because it keeps users available in the real world [80] and helps them be pulled out of the virtual worlds. Tangibility also prevents the need to visit a phone itself to get digital wellbeing feedback. What stood out was how such a medium gives an artifact the potential to be provocative enough to show users that change might be needed and that has to come from within them, rather than from such an extrinsic source. It, thus, shows that empowering users to realize the need to and a way to take control of smartphone usage, could in itself be a reasonable objective for digital wellbeing interventions.

Besides tangibility, the approach the Revisitation Reflector was also based on the principle of **designing for being reflective**. When discussing findings related to this principle, the theme of inquiry-driven reflection stood out. By having abstract, constantly updating feedback on past revisitation behaviors, a digital wellbeing artifact can be well-poised to enable the reflective, inquiry process from [16] of setting, testing and refining hypotheses regarding given feedback. An artifact of such inquiry-fostering nature also inherently encourages users to tinker and experiment with it to figure it out and make sense of its feedback. Perhaps the most surprising theme here was that despite only having a trigger role from [73] with sensemaking left to the users (without any system-driven intelligence), the artifact was perceived as having sufficient capabilities, and its 'non-intelligent' nature was actually considered as a significant positive feature. It allowed users to reflect and create meaning by themselves–the processes surrounding which they found meaningful.

The discussion on findings regarding the principle of **designing for being ambient**, firstly, revealed that the display was indeed perceived as unobtrusive, as intended. It was also visible that such a characteristic can significantly contribute to a digital wellbeing artifact's likeability and engagement, although, if overdone it could also serve as too minimal of a call to action. Nonetheless, this study did make it apparent that being ambient [38] and glanceable [37] (through simplicity, data abstraction, compactness etc.) truly goes hand in hand with being able to blend into users' everyday experiences.

This shows how strong of a relationship there is between the principle of designing for being ambient and the principle of designing for lived experiences; the latter principle seems to be a subset of the former. Reflecting on the principle of **designing for lived experience** did indeed reveal that designing an artifact for glanceability, for being ambient and for providing abstract feedback all help it blend in with users' lived experiences (and the various needs, contexts and interests therein). The user practices that emerged from this lived experience principle also confirmed the theoretical idea that users are not rational data collectors, but instead their interaction with data happens in a situated, subjective manner as part of their lived experiences [87].

Discussing the principle of **designing for revisitation feedback**, firstly, confirmed some theoretical notions. It was confirmed that short-term revisitation is considered as problematic in particular, and that it is probably indeed the apps and services within a phone that lead to revisitations (the phone is just a "conduit") [52]. The

study also highlighted that some users want to be able to really customize aspects of the revisitation feedback they get. Furthermore, thinking of the findings within this principle in conjunction with revisitation-related theory [52] showed that incorporating further digital platforms besides phones, and actively incorporating contextual cues in such a revisitation-centric digital wellbeing artifact can all enhance its effectiveness and engagement.

There were also **miscellaneous** insights that emerged from the reflective discussion on the five principles. The primary one had to do with how feasibility-related constraints are the main bottleneck regarding developing digital wellbeing interventions. Feasibility constraints regarding sensing, user privacy, heterogeneous parameters, operating system restrictions etc. can all be an issue when trying to develop more intelligent interventions. This is especially evident through the paucity of highly sophisticated habit formation and contextual cues related features in digital wellbeing interventions–despite there being long-standing calls in literature for them [58,74,85,98]. Nonetheless, this project did show that having an artifact which relies on its users, to e.g. set habit intentions and do context-habit association building, can actually to desirable reflection and actions. Other literature insights that this project unlocked new perspectives on had to do with screen time and app-level approaches. Despite there being widespread consensus in literature on going beyond screen time [62], many participants still expected it and tended to reverse engineer it–even if it was not present or communicated as a metric, as was the case with the Revisitation Reflector. Similarly, despite literature calling for more app-level approaches [74], this project highlighted how, pragmatically speaking, that might make user adoption more challenging due to users' privacy concerns.

Part IV: Supplementary material – Additional literature reviews, appendices and references

This part reconsiders the digital wellbeing literature, based on all that has been discovered in the project until now. It does that with a specific focus on uncovering additional future opportunities regarding digital wellbeing based on two prominent themes that arose from the rest of the project. This part, therefore, helps answer **GQ3.3 ("Could additional opportunities for designing for digital wellbeing be derived from literature?").** The two themes it focuses on are agency and human-data interaction. It aims to relook at the literature to uncover further future opportunities within these themes because these two themes formed a significant part of the foundations and findings of the project, as will be discussed.

Overall, this part considers the themes of:

- Literature review on future opportunities regarding agency
- Literature review on future opportunities regarding human-data interaction

This part also includes the appendices, acknowledgements and references.

8

Literature Review on Future Opportunities Regarding Agency

This chapter aims to relook at literature to uncover further future opportunities within the theme of agency because it formed a significant part of the foundations and findings of the project. It was part of the project's foundations and findings because agency is inherently tied to control over device usage–which was the fundamental premise behind the entire project's problem space. So, not was the Revisitation Reflector artifact tied to agency, but so were the field study's results and the general lessons learned. The insights on how users made sense of the display were often tied to agency-related aspects like user-driven appropriation, user-defined morality or user-driven interpretation and bottom-up patterns of meaning. It was sensible to, therefore, reconsider existing work related to agency, and see if reviewing it could lead to further future opportunities. Here the most promising or prominent results of the literature review on agency are going to be covered.

User agency involves putting the control of goals, features, intelligence, customization, morality etc. of personal informatics (PI) systems back in the hands of users. This chapter is going to address few specific aspects of that agency pertaining to PI systems. These aspects were chosen based on their prevalence in related work, their novelty and their alignment with the rest of the themes discussed in the project so far. This chapter is going to start with discussing aspects of PI systems related to personal goals, as those aspects inform the underlying purpose of such systems. **Since digital wellbeing interventions are basically a subset of PI systems, here the broader PI perspective is adopted to allow learning points from other related domains to also emerge.** Goal setting, therefore, presents a fundamental future opportunity regarding giving users agency. After goals, this chapter moves towards discussing aspects of personalization of PI systems. Personalization can again hold potential regarding giving users agency by enabling them to tailor their PI systems to themselves. Finally, this chapter is going to address user agency in relation to intelligent, automated systems. It is going to address aspects of giving users sufficient control over the intelligent parts of a PI system. Together these perspectives on user agency can serve as potential opportunities for future projects.

GOALS AND PERSONAL INFORMATICS SYSTEMS

A substantial number of PI systems are meant to enable users to achieve their wellbeing-related goals; whether those goals are explicitly or implicitly (by system design) defined. Goal-setting presents a fundamental aspect of such systems that can be used to give users greater agency, as it can give users control of what a system should help them achieve (and possibly be mindful of why). Regarding goals-related user involvement with PI systems, there are a few major design issues based on most of the typical PI systems.

To start with, there can be a mismatch between a user's goals and their system's goals [38]. Typical PI systems can support different goal types and possibly their combinations. These goal types are most frequently either reflective/documentary goals or achievement-based goals [38]. Reflective goals are driven by a user's desire to learn more about their habits and personal data patterns, without necessarily exercising any behavior change [87]. Whilst achievement-based goals are driven by a user's motivation to achieve a certain thing like walking a particular number of steps each day [38]. PI systems can support one of the two types of goals, or a combination of the two–with the two being present to different degrees. However, it is not always the case that the goal possibilities a typical PI system offers or is capable of align with what a user wants as their goals [38].

Furthermore, what a user wants as their goal(s) can change over time during the course of use of a system [93], as e.g. a person could discover that a particular goal they initially thought they wanted to go for is far more ambitious than they can manage. Regarding this change of personal goals over time, PI systems do not typically enable a user to reframe or reconsider their goals so that they better reflect the user's lived experience during system use over time [38]. Another design concern has to do with when a user has achieved their goal. When that happens, a user may just stop using a system; whilst, it might have been more beneficial for them to just recalibrate their goals [38]. Current systems, however, do not sufficiently support this process of goal shifting depending on present use state [38]. It could also be the case that a system does not match with certain aspects of its user's identity in a more fundamental sense; a system might not fulfill the needs that motivate its user to use it in the first place, and it also might not enhance a user's understanding of their personal values (which could be seen as e.g. their higher-order goals) [38].

Going back to the initial point this section was started with, goal-setting can play a crucial role as a mechanism for a PI system's user to effectively stick to a goal in the long-term [100]. In simple terms, a goal-setting process involves an individual examining their current state, framing their desired future state and creating a strategy to reach that state [38]. Two of the principal factors (amongst others) that affect an individual's ability and inclination to actually reach a goal are efficacy and commitment [38]. Efficacy reflects an individual's self-belief that they can actually achieve a goal and commitment reflects how strongly they are driven to work for that goal [23]. Another crucial factor that influences the likelihood of an individual reaching their goal is how reasonable and personally aligned with themselves they consider their goal to be [61]. Therefore, goals need to be set at a reasonable level of difficultly, as well as sufficient personal alignment in terms of their specificity.

Many of these issues related to goal-setting (especially the ones related to insufficient support for goal-setting) can be achieved by adopting a reflective stance on goal-setting when designing PI systems [38]. Such an approach can involve either enabling users to set PI system goals that are more strongly aligned with their personal, broader goals, or enabling users to ponder upon the challenges they might have to deal with when working towards their goals [38]. So, rather than having pre-determined system goals, or merely asking users to select or input their goal, systems can trigger reflection in users by asking them about the motivation behind their decision to choose a goal [38]. This would also help a user in the goal choosing itself. Another way to enable reflection is to prompt users to think more consciously and deeply about their specific, lower-level goals

in combination with their higher-level, broader motivations behind those specific goals [59]. Once such information is distilled from the user, it can be used in giving useful feedback to them–especially when there are deteriorations or hindrances in their progress towards their goals [38]. This distilled information could also be used for providing users with a deeper understanding of what goal variations might be most reasonable for them, and what the best preparation could be that they could undertake to overcome the challenges that might arise in their goal-achievement journey [38].

There is a clear gap in related literature on PI systems regarding incorporating reflection in the process that such systems use to enable users to set their goals; even though, in one of the studies that did incorporate such reflection, the result was an increase in the users' goal achievement [59]. Such inclusion of reflective goal-setting or at least user-driven goal setting can also help users set better goals and be more mindful of their own motivations [38]. The information distilled from a user during the reflective goal-setting process can be quite useful in personalizing the feedback a user gets from a system during course of use [38]. This can also positively impact the process of a user's expectation management. Reflection at the start of the process, when goals are being set, can help "reinforce the idea that reflection can play an instrumental role in achieving long-term benefits" [38].

Besides solving the typical issue of inadequate goal-setting support through adopting a reflective stance on goal-setting, there is another goals-related issue that was already just introduced above: a mismatch between user and system goals [38]. Pragmatically, the solution to this lies in directions that enable reframing, refinement or adjustment of initially set goals [38]. There can be personal challenges a user can face about this; it is difficult to get a user engaged in higher-level thinking about their goals and how to reach them, and there can be negative associations with having to change an original goal [38]. The key is to, of course, ensure a system does not make a user feel as if they have failed, and instead frame it like something completely positive and encouraged [38]. Another problem mentioned above was that caused by lack of opportunities to enable users to refine their long-term goals when they have reached a short-term one [38]. Goal adjustment strategies in system design can help mitigate this issue, as well as enable users to have greater agency by enabling them to re-evaluate to what degree their initial goals align with their higher-level ambitions [38]. Based on that users can be enabled to adjust their goals and work towards new ones [38].

These issues regarding mismatch between user and system goals can once again by solved by incorporating reflection in PI system design [38]. This time, however, the reflection is more about periodic reflections (on initially set goals) later on in the process, rather than at the start when defining the initial goals themselves [38]. This is another gap in existing systems: They do not have intermediate, periodic reflection opportunities for users within their structures [38]. It can be relevant to fulfill this gap, as shown by related work; when users are asked about the reasons for engaging in a particular activity, they are triggered to (re)consider and become conscious of their underlying higher-level motivations and goals [103]. Creating periodic prompts also leads to a more effective result for user behavior [35]. So, with such an approach there is not only opportunity to help match a user's goals with that of the system, but also to increase PI systems' usefulness and engagement [38].

There are some recommendations regarding the way such periodic reflection opportunities can be designed in PI systems. Systems should provide such opportunities to allow users to periodically reflect on their goals so that they can gauge their own progress and possibly think about other resources that can help them in their journey [38]. Such periodic reflection features can also enable users to themselves evaluate how much value they harness from a system versus the amount of effort they have to put into using it [38]. There are parameters that need to be considered when designing such features though. It is, for instance, very important to consider the moment(s) when reflection will occur [38]. If the reflection moments' timings are personalized (through a

user's interaction history, through estimated user effort required or through usage patterns), the chance of engaging users in ways they perceive to be unmeaningful is reduced [38].

All in all, regarding goal-setting issues in PI systems, such systems can become much more user-centric by enabling users to set their own goals and to reflect on the underlying motivations behind those goals. Such information can then be used by a system to further personalize the feedback it provides to a user during course of use. Moreover, creating periodic reflection moments over goals can help users continuously gauge how they are progressing towards their goals, and can help PI systems engage them in much more meaningful ways.

PERSONALIZATION

Besides a user-driven approach to goal setting and habit formation, personalization is another direction that can be used to enhance the user agency of PI systems. The reason this matters is because enabling users to personalize their goals for PI systems can enhance the effectiveness and likability of such systems [45]. Furthermore, a crucial gap in existing (digital) wellbeing treatments and strategies is that they cannot be individually tailored to users [107]. Such personalization of features, feedback, sensing etc. can have a significant positive impact on users, it can lead to more accurate assessments of users' inner states and it can also enhance the chance of success of wellbeing-related interventions [107]. Personalized feedback can also enhance the behavior change capacity of PI systems and aligns with the heterogeneity in PI regarding what works for which user, when and why [54]. Furthermore, personalization is relevant because different users value different cuts of their personal informatics data [30]. There is dramatic variance in the data cuts that users find valuable, which shows clear significance of personalizing PI systems' output to users [30]. This ethos of different users valuing different portions or perspectives of their personal informatics data signifies the need to enhance personalization of PI systems to give their users greater agency.

A common theme in a set of articles geared towards integrating personal informatics in everyday experiences is that of "respecting agency and supporting individual needs" [25]. This can be done by having systems that stimulate agency rather than suppress it by creating a rift between a user's lived experience and utilitarian, computation-driven personal informatics. Thus, there is a need to create a balance between "computational support and individual empowerment" or automation versus agency–especially because there is substantial paucity on this aspect in existing personal informatics work [25]. A possibly impactful approach towards doing this is creating possibilities in systems for enabling users to personalize the what, how and why of tracking. Especially because different users who share the same goal might have completely different ideas and needs regarding what they want to track and why [25]. So, it can quite fruitful and relevant to explore designs where representations of, interactions with and analysis of personal data is mediated through tools that can be personalized to individual users, goals and contexts [25]. The subjective, personal experience of individual users has the potential to be a quality that is leveraged rather than one which is unaccounted for.

Personalization involves using choices made by users regarding their interactions with systems in order to affect the content they engage with in the future [38]. The approach to personalization can also be more explicit, where it can simply involve giving users the ability to select the features they want to use, so that the users' interactions with a system can be customized [38]. Based on reviewing several works, [38] show that such personalization can be quite beneficial for users, as it can reduce their cognitive load, help them with their workflow, and overall offer them more satisfying and persuasive interactions. Regarding the approaches to personalization, [38] define two categories: system-driven personalization and user-driven personalization. The system-driven approach involves drawing inferences regarding a user through a computational model of them. This approach is naturally underused and underexplored due to implementation difficulties of such features

and due to the chance of negative implications [38]. Nonetheless, such an approach can be quite useful to allow systems to accommodate the needs of different user types (e.g. serious athletes versus first-time user of self-tracking); and it can help meet the different preferences that different user types have regarding the feedback types they find most motivating [38].

The personalization approach can also be user driven. In that case, it is about letting users choose by themselves from various possible features or alternatives so that they can adapt their system to themselves [38]. The pros here are that tailor-made experiences can help reduce users' cognitive overload, can make interactions more engaging and can offer customized support for goal-reaching. But the cons are that the 'custom' choice possibilities that users are presented with can feel like "formulaic customization" [50], and the users can be overwhelmed by the difficulty of the task of making lots of choices [96]. Nonetheless, PI systems can benefit significantly by being more responsive to user-driven strategies (e.g. letting a user set their own goal) and by giving recommendations to users regarding how they could personalize their PI systems (e.g. suggesting a possible goal to a user based on their performance from last few weeks) [38].

There is a "lived informatics model of personal informatics" from [31] that helps structure this approach. That model consists of a cyclic process of five stages: *deciding, selecting, tracking and acting, lapsing and resuming* [31]. The process starts with a user *deciding* to track personal data pertaining to some part of their life. Different users can make this decision based on different underlying motivations (curiosity, rewards, social sharing etc.); and different users can come to tracking with different levels of prior experience with it [31]. After making the decision, it is down to *selecting* a tool with which to tracks some personal data. This can happen in conjunction with the previous step. It can be quite speedy, or it can be more extensive and involve comparisons of tools [31]. The final selection of a tool can depend on features, aesthetics, convenience, prices, existing technology in possession of a user etc. [31]. After a selection is made, it comes down to *tracking and acting,* where a user tracks their data and tries to act on the insights distilled from it. Within this stage there are actually three sub-stages that can and frequently do occur simultaneously [31]. These sub-stages are of *collecting* personal data using a tracking tool, *integrating* collected data to make sense of it and *reflecting* on and reviewing the collected data and possible insights generated from it [31].

After tracking and acting, next is *lapsing* which can occur when a user stops actively using a self-tracking tool due to hurdles regarding one of the previous steps [31]. It can happen due to a user forgetting to user their tools; due to maintenance or upkeeping demands of a tool; due to a user skipping some data logging by deciding they do not need to or want to log everything they track; or due to a user suspending their tracking for a particular time period. [31] A lapse can be a temporary break in tracking, or it can be permanent if a user loses the intention to come back to tracking again [31]. If the lapse is indeed more of a break, then it is followed by *resuming,* where the user continues the tracking process [31]. Resuming can follow on from a short-term lapse (e.g. over a weekend), where a user quickly resumes tracking without revisiting the earlier phases of deciding to track and selecting a tool [31]. Resuming can also follow on from a longer-term lapse (e.g. lapsing for months), where there is a chance that a user may not quickly resume the collection of even more data; but might first try to resume the integrating and reflecting stages of already collected data–and only later deciding whether to resume collecting even more data [31].

All in all, personalization of PI systems is crucial for their user satisfaction, impact and effectiveness. Personalization can be user-driven or system-driven, but in both cases can enhance the engagement of PI systems. The discussed lived informatics model of personal informatics brings a structure for conceptualizing possible applications in this area.

HUMAN AGENCY VERSUS AUTOMATION

Enabling users to personalize their personal informatics systems and enabling them to set and reflect on their own goals are only two parts of giving users agency. Another more literal, agency-related part is about keeping them in the loop or in control when it comes to automated or intelligent systems [101]. A 'smart-everything' paradigm can take too much agency away from users in three specific ways. Firstly, the inability or error-prone behavior of an AI-driven system is manifested in, amongst others, the strong dependence of supervised machine learning on having high quality, unbiased and sufficient training data [73, 26]. So, whilst the expectation of users could be that such a system will lead to the same "right answer" with different data input and constraints, it could practically lead to really different predictions that contain too much errors [48]. Secondly, the rigidity of an automated system poses another issue; minor deviations from a standard routine or process can lead to a system being unable to function well [101]. Recommendations of such systems can also become too stale or repetitive [101]. Thirdly, lack of transparency, comprehension and traceability of decisions or outcomes of automated systems can also suppress user agency. It can lead to problems regarding reproducibility, liability, as well as lack of user awareness regarding what led to particular decisions, recommendations or outcomes [101].

Because the consequences of shifting too much agency towards automation can have quite some ethical, welfare and fairness implications even, there is a need for "people-empowering smartness" instead of mere "smart-everything" [101]. In such a paradigm, people should not only possess sufficient control over autonomy, but they should own how that control is exercised [101]. In order to enable people to make informed decisions, whilst still not overwhelming them with further processes and choices, at the very least users should be able to control the degree of system automation, and the degree to which humans can intervene and make decisions [101]. This also means that when automated informatics systems are designed, there is a need to fundamentally reflect on the incorporation of such an objective in them [101]. That is, keeping options for customizable automation to enable users to stay in the loop should be a design objective in itself.

There is further motivation to involve human agents in the loop also from health informatics literature. Humans can still outperform machine learning systems (or help those systems learn better) in some specific areas where e.g. a human agent's instinctive or instantaneous interpretation of complex patterns can be more efficient and effective [80]. In such scenarios (and possibly these scenarios could exist also in personal informatics for wellbeing), an "expert-in-the-loop" approach can be quite helpful [80]. Here, an expert's high-level knowledge can be incorporated in the intelligent agent's decision-making processes by distilling the expert's relevant judgements regarding preliminary results and using them to influence the retrieval process [80]. It could be argued that the user of a personal informatics system is such an "expert" who in the end (besides e.g. a system's recommendations) knows what is best for him/her regarding tracking their lived experience(s) and the analysis and presentation of tracked data [80]. And if such a framing is adopted, then we also need to acknowledge that a human agent should be able to teach and adjust the behavior of a personal informatics system [80]. This is going to be considered in the following few paragraphs.

There are further aspects and design recommendations to be considered when thinking about enhancing user agency when it comes to intelligence in personal informatics. One source of such recommendations is the model of action orchestration which aims to go beyond the typical master-slave personal informatics systems where one agent (human or system) is expected to blindly obey the instructions of the other [80]. The model aims to do this through emphasizing the need to design a conscious take towards human-computing cooperation, where cooperation can be driven by both a system and its user [80]. In this model each of the different actions has an "initiating party" and an "executing party"; and a system can have one of the two roles with its user having the other. So, cooperation could be human-driven, where based on their current context and thoughts a

user is able to take an action that results in a computing system being instructed or engaged with to revise its behavior or initiate a reactive action [80]. On the other hand, cooperation could also be system-driven, where according to its sensor inputs and monitored states, the system can request the human to take some action or in a more subtle way provide information to indirectly revise the human's behavior [80].

Of course, this all depends on the system's capabilities, the user interface(s), the interaction channels and, most importantly, expression of intentions or instructions in a form that is mutually understandable by the human and the user. This is meant to be an ongoing process where e.g. the human agent directs the computing system to adjust its behavior, and its revised behavior in turn affects future human behavior and interaction with the system [80]; or where e.g. the same process happens but is then system-driven where the system affects human behavior which in turn affects it back [80]. In the case of this report (and possibly the follow-up project), the focus will be on human-driven cooperation side–simply because that is most aligned with the ethos of empowering informatics systems' users with agency, and because compared to its counterpart (system-driven actions) it is significantly more absent in current applications.

And regarding the human-driven cooperation side of the cooperation action orchestration model, there are many design considerations that are crucial for developing intelligent personal informatics systems. Firstly, there is a substantial need to explore alternative framings of personal informatics systems where they are based on cooperation between a human agent and a computing agent [80]. So, instead of having goals that are perceived merely as a human agent's business, where the computing agent's task is to simply monitor them, it is important to explore directions where goals are an mutual concern for both agents; and there is room to establish rules regarding which agent should do what [80]. Secondly, behavior change should not be left to the human agent alone, but instead should be framed as a joint human-system effort in designs of personal informatics systems [80]. Hence, user interfaces should indicate a system's contributions in such a way that the insights gained from tracked data can be used to update future behavior of the personal informatics system [80]. Thirdly, the impact of intelligent capabilities and contributions of the personal informatics system should be explicated particularly when it comes to user engagement and motivation [80]. Finally, there needs to be an evaluation (possibly over course of use) regarding the relationship between the personal informatics system and its user; such evaluation should be used to assess at what times and how the computing system should work with the user, as well as assess what sort of interaction approaches should be utilized [80].

9

Literature Review on Future Opportunities Regarding Human-Data Interaction

The previous chapter addressed the various aspects of giving users agency when it comes to personal informatics (PI); it also looked at the relevance of those aspects. Giving users agency back is important, but so is carefully considering how such users can potentially interact with their personal data in novel and interesting ways that move towards enabling users to experience, rather than merely visually see, their data. The theme of human-data interaction is as important as agency within the context of this project. To this end, this chapter aims to relook at related literature to uncover further future opportunities within the theme of human-data interaction because it formed a significant part of the foundations and findings of the project.

This theme was part of the project's foundations and findings because it is inherently linked to creating artifacts that enable users to experience their tracked personal data on smartphone usage (which was the premise behind the project's solution space). The field study's results were also related to this theme. The insights on the role and design of the display were tied to human-data interaction aspects like: how users perceived the tangible, ambient medium of the artifact; how it interweaved in their everyday lives; how it evoked reflection; or how it uncovered desires for personalization. It was sensible to, therefore, reconsider existing work related to human-data interaction, and see if reviewing it could lead to further future opportunities. Here, prominent results of the literature review on human-data interaction will be presented.

This chapter is going consider how users can make sense of their data in much more experiential ways. These ways can serve as creative directions to develop interesting concepts that users can use to interact with their personal data, in ways that go beyond what has already been done in this project. These experiential ways of human-data interaction can be a very impactful transition for typical PI systems. To reiterate, just like in the previous chapter, here again **the broader PI perspective is adopted to allow learning points from other**

related domains to also emerge, since digital wellbeing interventions are basically a subset of PI systems.

FROM VISUALIZING TOWARDS EXPERIENCING PERSONAL DATA

When considering various approaches that can be used to deliver data to users or enable them to interact with it, some new perspectives on what it means to learn from, and experience personal data come to light. Deborah Lupton brings forth interesting thoughts in this direction. She calls for going beyond conventional data representations towards ones that enable users to get an intuitive, embodied feeling for their data [65]. Typical "data literacy" concerns the way individuals learn from data and the way they learn how to learn from data [65]. The limitation here is that such an approach is focused almost exclusively on user cognition–assuming and implying that learning is a disembodied process [65].

However, perspectives like those of Merleau-Ponty show that learning and cognition is not disembodied, and that humans are embodied beings and that they experience the world through their bodies and their senses [71,72]. His work shows that "being-in-the-world" is crucial to the human experience and that it is intersubjective. Human bodies are an essential part of the way humans perceive the world. Bodies and their contexts (e.g. other bodies, artefacts, spaces) shape the emotions and sensations humans feel, and in turn these sensations mediate how humans experience the world [71,72]. In the world of digital technologies, embodiment is often mediated through technology. Digital devices can incorporate human body or human movements (for interaction or for placement), and this has turned bodies and their contexts digital as well.

In this space, the perspective of Haraway is useful to consider: There exist "post-cyborg entities" that are "assemblages" of human and non-human agents and entities that co-live and co-evolve [42]. Part of these assemblages is a human's personal data. These personal data assemblages are generated on a continuous basis and they and are "heterogeneous and dynamic" such that they evolve as their data points change (are added or removed) [65]. Human interactions with digital (PI) technologies and with lived experience data leads to personal data assemblages; again, these assemblages are not merely a static "data double" of an individual, but rather constantly changing "intertwinings" of them and their data that update as new data forms are generated [65]. These dynamic assemblages not only include human-data entanglements, but also the contexts, devices, agents and artefacts beyond them.

Going back to digital technologies, our digital data assemblages and our digital devices co-habit with us. [42] And as we co-habit with them, we co-evolve with them [42]. Humans co-evolve with their personal data assemblages and their personal data is based on their experiences and bodies. Humans impact the data they generated, and that in turn can evolve how they perceive themselves and their lived experiences [65]. Hence, humans, their devices and their personal data are all part of an assemblage, where these components are interlinked, interembodied and intersubjective [65].

Based on these perspectives of embodied experience, embodied learning, data assemblages and the sheer importance of human sensations in data-related sense-making, Lupton calls for a new, broader paradigm encapsulating the embodied ways in which users generate, make sense of and respond to their personal data: "data sense". Here embodiment is included in the process of learning from and responding to personal data; it considers human senses as an essential part of how users respond to data [65]. It also incorporates sensors into that picture, in a way where there exist "entanglements of human senses and digital sensors with sense-making" [65].

This is in contrast to the typical data visualization approaches in HCI research (and consequently conferences like CHI), where data is manifested visually in order to enable people to understand and engage with the information enclosed in that data. Typical data visualization approaches have to do with encoding information in visual formats like shape, size, color etc., such that the generated visual objects map information onto visual objects that convey the meaning of the information they encode [65]. When it comes to the pragmatics of exposing users to visualizations of their personal data, users face the struggle of interpreting such visualizations relative to the alternative information about their bodies that they perceive from their bodily sensations [65].

Past empirical research provides evidence that many users perceive data visualizations generated from their personal data as being more "real" to them than what their bodily sensations convey to them [63,64]. So, users only seem to know how their bodies respond to e.g. physical activity once they see the numbers and the data they trust regarding their physical activity [65]. Users are more likely to view such digital data visualizations as more accurate than their embodied sensations and bodily feedback [65]. Nevertheless, users who track personal data do still delve into data sensemaking that is more embodied by relying: on past experiences of activities, or on sensory feedback of their bodily feelings during activities or on their sensory memories of e.g. the weather and spatial conditions where the activities were situated [65].

Thus, the challenge still stands of how individuals interpret, judge and incorporate in their lives information about their own bodily sensations fed to them by digital sensors. The challenge specifically has to do with the negotiations users have to encounter between the information fed to them through visualizations and the information fed to them through their own embodied sensations [65]. Such challenges and negotiations are scarce in current literature [65], which is why there is a substantial opportunity present to bring more of embodiment and sensory aspects when it comes to designing artifacts for engaging users in data sense-making.

There are suggestions regarding how such negotiations between system output and bodily output could be mediated in ways that adopt a more multisensory approach towards representing and learning from data. An emerging approach is that of using haptic sensations that provide notifications or information in an intimate manner and one that is a reminiscence of human touch [65]. In this direction, visual displays tend to be viewed as less effective for information communication than the approach of directly tapping a wearer [65]. Examples here are about haptic interfaces the enable tactile feedback through vibrations and motion. Another common method of data communication, "data physicalizations", involves embedding data in physical, three-dimensional artifacts. The literature around this method ([2,51,102]) provides evidence that multisensory approaches to data rendering lead to richer and more effective understandings than the typical, two-dimensional visual approaches that are prevalent in HCI and PI.

They do this by enabling access to types of knowledge regarding the data that would not otherwise be available, such as mappings of the data to haptic sensations like texture, temperature, weight etc. [2,51,102]. The main modalities used to represent data in multisensory data representations are visual, haptic and sound [46]. [46] create a design space for multisensory data representations along three dimensions (or design choices): (1) "Use of modalities", (2) "representation intent" and (3) "human-data relations". (1) constitutes the number of modalities used and whether the modalities are cross-modal. It also includes the materials that are used, as well as the way data insights are generated through experiences. (2) is about whether the intention behind the representation is casual or utilitarian. It is also about the profoundness of the insight (little or large) uncovered by the representation. (3) is about whether the representation is static, non-interactive or whether it is dynamic, interactive. It is also about whether it is 'live' based on active data or whether it is passive based on archived data. These three dimensions can serve as guidelines or a source of interesting questions to ask when trying to come up with data representations that are more sensorial and embodied, and that go beyond the mere 2D

approaches. Still, there is potential to go even beyond these aforementioned most frequently used modalities of visual, haptic and sound [46] and create genuinely holistic sensorial experiences with data.

Besides data physicalization approaches, and approaches like 'data sculptures' that bring artistic qualities to physical data visualizations, there in another set of approaches that also aim to similarly include haptic sensations [65]. Embodied interfaces and tangible user interfaces (both of which will be discussed later on in the section) try to bring the embodied richness and physicality associated with the manipulation of physical objects into data visualization paradigms–such that they can go beyond the mere 2D focus which is deprived of such richness [65]. Embodied interfaces by do it through embodied forms of interaction e.g. interacting by tilting, rotations etc., whilst tangible user interfaces do it through manipulatable, physical objects that control digital representations [65]. In these directions, there is potential for a novel approach to data representations that involves encoding of data in the affordances and experiences enabled by the representation [46]. Here data insight is facilitated through a human's natural abilities to sense the way something feels or is experienced. Such experiential data representations can leverage humans' natural interactive instincts and thereby allow researchers to enable data insight in a more natural and intuitive manner [46].

This section started off by laying out the concept of 'data sense' to facilitate users to develop intuitive feelings corresponding to their personal data. 'Data sense' uncovers thinking of data communication and interaction in terms of the entanglements of humans' bodily sensations, human senses, digital sensors, software, context and the digital data generated through these entanglements. 'Feeling of data' through such approaches involves both the sensations arisen from e.g. interactions with 3D data phsyicalizations, as well the cognitive responses that are generated from such sensory relationships with data [65]. Thus, in this 'data sense' paradigm, humans, interaction technologies and digital (personal) data work together in various dynamic and complex ways. Artefacts and technologies that enable such 'data sense' to emerge can fulfill a gap–in existing research–regarding how such artefacts can stimulate embodied and sensory responses to personal data in users [65]. They can be used to investigate how users might be able to engage with and learn from their data in a sensory, embodied way as part of the other sensory routines of everyday life [65].

Haptic data interaction approaches can enable users to also get a feel for when, where and how their data stops 'feeling right' for them [65]. These approaches can arouse frictions or discomforts, and consequently, make users sensitive to situations where digital data by itself might not work well [65]. Breakdown or confrontation in such approaches can help experientially remind users that the data might be skewed in one direction [24[1]]. So, it might even be interesting to explore how loss of the "seamless nature" of typical PI approaches (that rely on 2D data visualizations) might make users much more conscious of their own bodily sensations and over time enable them to learn what certain forms of their data 'feel' like [65]. Finally, overall, there is an opportunity to investigate what role bodies can play in HCI related to personal data [65].

Research can also investigate potentially effective "multisensory materializations" of personal data. Such questions reflect back on the concept that were introduced at the beginning of this section. As we could more broadly question, "What can digital data assemblages (which include bodies) do?"; and going back to Merleau-Ponty we can think about, "How are data physicalizations and the haptic and other sensations they incite part of 'being-in-the-world' experiences?" [65]. Here it is about researching ways in which human senses can work in partnership or even in conflict when humans are involved in sense-making as a response to their digital data assemblages. So, Lupton's "data sense" ethos brings together all these diverse concepts that can help design a

[1] based on the authors' personal communication with Peter Shenai (2015)

new generation of PI systems that really enable users to "feel" or experience rather than merely visually "see" their personal data.

DESIGNING FOR BEHAVIOR TRANSFORMATION THROUGH "INTERACTIVE MATERIALITY"

Stienstra et al. [99] present yet another unique perspective that aligns with the paradigm of embodied, "data sense" type interfaces; and can present a distinctive approach for designing interfaces specifically for behavior transformation. They call for designing for behavior transformation through embodied interfaces in such a way that the systems designed go beyond merely cognitive approaches to persuasion; and that they instead also incorporate embodied aspects of the human experience that lead to respecting of all human skills [99].

This approach towards shaping interaction technologies strongly aligns with the "designing for embodied 'being-in-the-world'" framework from [28]. Here the ethos that is really stressed is that of ensuring that embodied activities or inherently embodied tools (like a hammer) do not end up merely as physical carriers for digital applications. But instead, adding technology or interactivity to embodied activities or tools should really go beyond "hammers or traditional computer applications" [28]; and should enable substantial flexibility by continuously adapting their behaviors and responses–whilst keeping users properly situated and embodied in the real world [28]. In the paradigm of digital wellbeing, perhaps, incorporating such an ethos would require a new, creative reframing of the paradigm's problem space. That is because the digital paradigm is quite inherently disembodied and virtual. Nonetheless, a fresh reframing of this space can indeed open it up for truly (more) embodied applications for changing user behaviors.

The work in [99] proposes a three-step process for designing for such an embodied approach to behavior transformation, where the process is fundamentally about (re-)designing or (re-)shaping action-perception loops of users [99]. The first stage of their process of behavior transformation through embodied materiality is that of "affirming and appreciating the current behavior" [99]. This is about understanding and analyzing the essential parameters of the current behavior and the context it is in [99]. It is about gaining insights, at a skills-level, regarding the current behavior that is intended to be transformed–so it is about what behavioral aspects address physical perceptual-motor skills, which ones address emotional skills and which ones address cognitive skills [99]. The overall purpose of the first stage is to identify the essential aspects of the current behavior, and especially the repetitive patterns and multimodal sensations regarding those aspects. Particular attention can be paid to the embodied, bodily aspects of the current behavior [99].

After understanding the current behavior, the next step is to "design mapping for transformation of behavior" in order to actually transform the behavior [99]. This second step is about designing continuous action-perception loops that influence the behavior towards the desired new direction [99]. This is done by creating mappings between input(s) and output(s) of the activities in interaction, where the mappings can be used to "color" certain activities [99]. 'Coloring' is about inviting or inhibiting an activity through amplifying or suppressing the feedback of the user's embodied movements or other bodily states and actions. 'Coloring' or mapping can be timing related i.e. consist of delays and anticipations. Delays are about having delayed feedback to a continuously inputted action to push back the action [99]. Anticipations concern making an action faster by 'anticipating' an ongoing behavior to cause a "pull-ahead" of the action. 'Coloring' can also be scale related [99]. Here it is about having inversions, scalings, amplifications or reductions of inputs towards their outputs.

Once desired and new action-perception loops have been created, the final step is about "fine-tuning the sensitivities in the interactive materiality" [99]. This step is about ensuring that the action-perception loops or

input-output mappings designed in the previous step are kept as "ready-to-hand" as possible to maximize their behavior transformation potential [99]. This is done by playing around with and fine-tuning the sensitivity and subtle nuances of the designed mappings [99]. It is also done by ensuring the designed mappings are unobtrusive and subminimal, and that they consider the uniqueness of users (regarding their skills, capabilities and perceptual-motor sensitivities) [99]. Finally, this stage is about ensuring the designed mappings are validated in context [99]. Together these three stages provide a unique way to design embodied interfaces that rely on bodily sensations and actions to influence the behavior of humans.

10

Appendices

APPENDIX A: WHAT ELSE COULD WORK TO EMPOWER DIGITAL WELLBEING?

Facilitating disconnection

A research project adopted an ethnographic study with the aim to explore a similar area on understanding the nature of excessive smartphone usage and the experience surrounding smartphone disconnection [5]. Their findings led to three sets of recommendations that can facilitate the building of healthy and pleasurable digital technology usage habits: *"facilitate disconnection, reduce temptation to re-engage, and allow for partial disconnection"* [5]. *Facilitate disconnection* comprises three phases to support smartphone users with disconnecting: reflection, finding support, and practice [5]. Reflection is about getting a user aware of their online behaviors, reminding them to disconnect and increasing general awareness of technology overuse [5]. Support is about tools that can enable users to gather support partners for holding them accountable or for having a productive social influence on them [5]. The practice phase enables pinning down of new habits through e.g. restricted usage times, app usage time windows or social circles to facilitate habit formation [5]. There are many examples of apps given by [5] to illustrate the ones that facilitate all these three phases: "Moment, Space, Thrive, Offtime, Forest, Flipd, AppDetox, ...".

Reduce temptation to re-engage is about providing tools that not only enable users to disconnect from smartphones, but to also stay away from returning to back to them [5]. This need arises from the lack of an external repellent pushing users away from re-engaging with smartphones once they have disconnected; as external or internal triggers can make the re-engagement process too easy to fall into [5]. Strategies to enable such prevention of re-engagement would have to do with adding an obstacle (e.g. a temporary lockout) that deters from re-engagement or creates a moment of behavior reconsideration, whilst still allowing a user to feel in control [5]. *Allow for partial disconnection* is an approach that acknowledges the useful functionalities of smartphones [5]. It acknowledges how their importance in everyday life make it hard to disconnect from them, and can lead to stress and frustration [13, 24]. Hence, a more partial approach can preserve the essential functionalities (like camera, calendar, clock, calling etc.), but restrict other apps and functions for a predetermined time period. Such an approach could increase the frequency of disconnections from smartphones by still preserving the crucial functions that a user needs [5].

There is still a fundamentally different evaluation paradigm that needs to be put in place to really enable the current technology industry to facilitate healthier digital habits, and that is a paradigm where companies do not evaluate app success merely through typical user engagement metrics [5]; as such a focus incentivizes companies to capture a greater duration and frequency of user attention. User attention becomes a product sold to advertisers and app users' attention ends up being a commodity to businesses [26]. Instead, there needs to be an evaluation paradigm that also takes into account alternative success metrics that gauge users' satisfaction and quality of digital time spent [5]; where typical engagement metrics are not taken as a proxy for user satisfaction [3].

Positive psychology

This theme of inducing user-centric satisfaction into digital technology is reflected also in another approach [56] which claims that Gaggioli et al.'s [36] positive technology framework approach could influence users' personal experience to involve more digital wellbeing practices in it. This approach would involve organizing personal experience through goals and feedback, using multisensory and multimodal experiences to augment personal experience and having alternate realities to replace personal experience [36]. This would have to be done with a focus on emotional quality, on social connectedness (with e.g. collective intentions) and on engagement [35, 18]. Such a positive technology approach can play a strong role in stimulating self-transcendence in users. This self-transcendence can take the shape of mindfulness, flow, awe, peak experiences etc. [109], where all these positive self-transcendent emotions can be opportunities for future technologies to create applications that improve personal experiences through digital wellbeing enabled in a positive, affective manner [56].

As such positive psychology can uplift people's daily lives through an understanding of what they feel positive about and through crafting interventions that support such positive experiences [88]. Such interventions can be about for instance, amongst others, enabling individuals to celebrate their own good deeds through an app or recognize those of others [88]; or facilitating individuals to experience joyful practices (e.g. "stopping to smell the roses") [88]; or helping users achieve a positive outlook over the digital traces they leave [88]. Such prospective app ideas for enabling digital wellbeing through positive psychology adopt an ironic perspective, as they utilize the already ubiquitous and prevalent smartphones themselves to outshine their own negative effects [88]. These ideas consider smartphones rather as a ubiquitous opportunity to persistently enable users to experience positive experiences so that over time users can get used to enhancing positive moods themselves [88].

Balancing user resources

There is also another framework on digital wellbeing that considers four sets of user resources when trying to define or create what features an intervention should include. These resources include: Time, trust, social skills and health [91]. Time is considered as the main target of present applications to enable users to keep their time expenditure in check. A useful next step beyond current time-focused features (e.g. time visualizations, limiting access times for certain apps or features, break recommendations) would be to help users critique which features are really worth their time [91]. Trust is crucial in an intervention's functionality as well as in the information provided to a user–especially due to automation, transparency and data privacy concerns; for balancing this resource, interventions should help users identify for themselves the sources, contexts, divergent cues etc. that the information presented is based on [91]. For social skills, visualizing how technology influences a user's social behavior can be helpful [91]. It could also involve adding an emotional layer to digital communication or nudging towards more social forms of communication (like in-person meetings or video calls) if indirectness of communication is detected [91]. For health, the obvious thing is helping users monitor and manage their

health-related signals (e.g. activity tracking), with personalized interactions that have a custom motivation-paternalism balance for various users [91].

Tracking screen time

As was already discussed at the start of this part of the paper (in subsection: defining digital wellbeing), related literature strongly highlights the need to move digital wellbeing interventions beyond mere screen time. However, since screen time is still one of the most common approaches to tracking digital activity (for instance, [60, 48, 59, 58, 13, 16, 32]), it is sensible here to include what can be learnt regarding its tracking (besides the already overwhelmingly prevalent idea of moving beyond screen time). A project in this exact space that developed and tested an application for personal tracking of screen time concluded with a rich set of lessons for tracking screen time [86].

To start with, tracking screen time is done by users to support a myriad of different purposes (e.g. productivity, lifelogging), possibly with varying usage periods (short-term or long-term) [86]. When designing interventions, trackers can be designed such that they are focused towards one such purpose or such that they are meant to be appropriated by users for whichever purpose they find interesting. Next, the authors justify that there is no such thing as "raw" data when presenting screen time data to users [86]. Representation of screen time data involves several deign choices that influence user perception (How should data be segmented? When should users be presented with data?) and is a matter of balancing representation with practice [86].

Another learning point is that users' everyday life and routines are reflected in their screen time data (or even in the absence of such data) [86]. This relation of screen time data with everyday lived experience can be positively leveraged by designers, but it should be carefully considered regarding user privacy–as it could reveal too much information about an individual's life [86]. The paper also shows that another crucial design point is that depth of screen time data is more important than its breadth [86]. Users are less interested in a high-level, overall figure on how much time they have spent on their device(s), and more interested in using specifics of the data in particular ways to draw insights to e.g. better organize their usage of different digital devices [86]. Finally, when it comes to devices shared between multiple users, screen time tracking becomes less meaningful; because data collected from such devices is impersonal and consequently less valued by specific individuals [86].

APPENDIX B: IMPLEMENTATION DECISIONS AND THEIR JUSTIFICATIONS

Implementation decision	Justification
Revisitation pattern of the past one hour is shown.	An interval of one hour is long enough to have a significant pattern likely to show up, but short enough to enable a user to rely on their memory to gauge how their revisitation has progressed or changed; so that reflection can be triggered by being able to see past behavior. Based on preliminary testing with the researcher and with one pilot test participant, for similar reasons one hour was also decided as the most suitable interval over which to base the feedback.
Revisitation pattern updates every twenty minutes.	When deciding how frequently to update the revisitation feedback, the aim was to enable gradual fading out of previous hour's feedback and fading in of next hour's feedback. This would be more indicative of one's progress than suddenly disappearing one hour's feedback at the end of an hour time period and having the next hour's feedback appear.

	Moreover, based on pilot testing, twenty minutes was found to be real-time enough to see short-term changes, but infrequent enough to not be too obtrusive. This also aligned with the experiences from [37] of setting up a glanceable display that also displayed feedback of the past hour but updated every minute; and that was perceived by users to be too frequent. So, twenty minutes was less frequent than that, but more frequent than just once or twice an hour (which would anyways also make seeing one's revisitation progress difficult).
Screen state data collected by the AWARE app on a user's smartphone is synced every five minutes with the remote database.	This frequency was chosen based on syncing constraints of typical smartphones and of the server; as well as based on the need to not use up too much battery or processing power, and not over query the server.
The color palette shown in figure 2 was used to encode the relative revisitation percentages. The color palette was applied to the LEDs in combination with gamma correction.	The chosen palette is especially designed for accessibility, having enough colors and having colors that are clearly distinguishable. It is geared towards data visualizations and has a wide range in both hue and brightness–which maximizes accessibility and ease of differentiation between different parts of the palette. It is designed to follow natural patterns of color; particularly those that signify being brighter, fuller and more intense on the one end, and dimmer, darker and less intense on the other end (so being able to encode a higher and a lower quantity as naturally as possible). This palette was also thoroughly tested in various pilot tests and was found to be the best option amongst alternatives. Another plus point of it was that it did not imply any morality, as it did not feature colors that commonly have positive or negative connotations. Since these colors were operationalized as LED lights, gamma correction was applied. This was due to the need for "LED colors to appear more 'true'...", as well as, "to better match the response curve of our eyes [17]. Without it, mid-range levels appear unreasonably bright (50% brightness appears to our eyes more like 80%)" [17].
Revisitation was used as the metric to track and give feedback on.	For a multitude of reasons regarding its prevalence, relevance and underutilization, see revisitation section in chapter 2.
A vector of relative revisitation percentages was used to define the feedback output of the display.	Having relative revisitation avoided the need to have 'global' thresholds of when revisitation is really short-term, mildly short-term, medium-term, long-term, hybrid of all etc. Such thresholds would be difficult to define across all participants and would be very difficult even within a participant; as for even the same participant this such a threshold would continuously change. What is highly short-term revisitation at one moment in time might not be the same as what it counts as in another moment in time. Not only that but trying to define absolute revisitation scales would inherently induce system-driven normativity; what revisitation is short, medium or long, how easily that revisitation is triggered and also implicitly what might turn out to be perceived as

	'good' or 'bad'. This did not align with the design principles of the artifact (as will be discussed below). Furthermore, a relative approach lets a user see changes more easily across different time stamps by not relying on absolute values but more on how the distribution of those values varies; and this was also evident from pilot testing. Relative revisitation is also more glanceable, as it relies on having more of an abstract idea of how revisitation roughly looked like, rather than something absolutely accurate. It also enables easier comparisons of feedback interpretations and results across participants and within different time periods of the same participant–as it does not depend on some arbitrary, different revisitation thresholds.
The feedback displayed is based on a 'revisitation vector' for the past hour. This vector is simply a vector of eight revisitation bins with inter-visit times of: 1, 2, 4, 8, 15, 30, 45, and 60+ minutes. It shows the relative percentage of the number of times a user revisits their phone within 1, 2, 4 ,8, 15, 30, 45 or 60+ minutes following a previous phone use.	This choice of bins was chosen because as recommended by [1] and [52], exponential spacing of bins is a very effective way to encode revisitation habits and patterns. Although, when appropriated to the Revisitation Reflector, this choice stops being properly exponential at and after the 15-minute bin. This is because the revisitation distribution displayed was always hourly. As such, after the first short-term, exponentially spaced intervals (1, 2, 4, 8 minutes), the rest were spaced as quarters of an hour because that was necessary to have enough bins for a full pattern for the LED stick. Much more importantly, having intervals like 16 and 32 minutes turned out to not be easily imaginable and quickly digestible based on pilot testing. The 15, 30, 45 and 60+ minute bins are and were perceived as much more natural chunks of time.
The form with a cased Raspberry Pi and a cased, compact high-density LED stick.	The form of the display was chosen to be as minimalist and simplistic as possible. This was to keep the physical form aligned with the ethos of ambience, simplicity and unobtrusiveness. This was also done to make sure that the feedback from the LEDs would form the main point of focus for the users–rather than the casing or other physical components. A diffuser was added over the LED stick to reduce eye strain due to the very high intensity of the LEDs, to again not make them too intrusive.
Raspberry Pi with an LED stick was used as the hardware components.	This all aligned with the ethos to have an implementation made of open-source components. Furthermore, the Pi supported the required software, hardware and connectivity requirements.
AWARE was used as the smartphone app or framework to track a user's revisitation data.	Amongst all the available apps for such purposes, no other option matched AWARE's level of reliability, maturity, version updating and academic testing (it has appeared in a large number of studies like [11,12,21,33,94,108]). AWARE was also completely open source, free and came with infrastructure to handle data storage and querying. It was also designed to natively comply with GDPR regulations.

APPENDIX C: HOW AND WHY THE FIVE DESIGN PRINCIPLES WERE EMBEDDED IN THE ARTIFACT

Designing for revisitation feedback: Designing digital wellbeing interventions that utilize revisitation as their metric of purpose, tracking and feedback

The Revisitation Reflector:	Chosen ways of embedding the prioritized value and justification of choices
Is fundamentally based on revisitation and giving users awareness of their revisitation habits.	See all below.
Incorporates revisitation as a metric to give users feedback on, as well as a metric that the artifact's purpose is based on. Revisitation Reflector's purpose is to enable awareness and inquiry (reflection) on revisitation. It incorporates revisitation in the same way recommenced by the related studies: a vector of exponentially distant bins of inter-visit times. It uses revisitation at the macro-level of the phone.	• In [1] and [52], a revisitation pattern can be quantified in a vector of 15 exponentially distant bins of "inter-visit times", where each bin captures the frequency of revisitations within its respective inter-visit time. These bins can be normalized and thereafter used to plot a histogram–a smoothed out version of which forms a "revisitation curve" [52]. "A revisitation curve characterizes an app by its 15-dimensional vector, where each dimension corresponds to the frequency of revisits within the corresponding bin" [52]. • This can be done at the micro-level of apps or at the macro-level of the phone of a particular user (across all apps) [52]. • For this study the macro-level is chosen as it aligns with the exploratory nature of the study (and of the "nature of revisitation" metric) by letting users themselves appropriate the metric however they want. • Also, because it avoids having extra confounding variables that would vary across the participants, as different participants might choose different (types of) apps if app-level tracking would be an option. • It also avoids the need for having extra pre-intervention steps (to e.g. get participants' app needs and incorporate them), which would add extra development time and would be less fitting with the COVID-19 constraints. • Most importantly, not relying on app-level tracking avoids privacy issues by e.g. making users feel that an app is being too invasive. Such issues and feelings of discomfort could have turned out to be the case if users would find out their app activity was being tracked (as was clear from the pilot trials). Tracking merely of phone usage at a macro-level, so what the screen status was (on, off, locked, unlocked) was perceived to be much less intrusive in pilot trials, and so, more comfortable for potential participants.
Allows self-tracking of and feedback on revisitation without any pre-conceived	• There is not yet any established principles or clear normativity on how to design for this metric. This also means that there is no indication of whether giving users feedback on this metric will even

normativity, goals, rewards, or punishments—as prioritized.	be perceived as relevant by them and, if so, in in what ways. For the same reasons, it is also difficult to know how users would want to set revisitation goals and what those goals would be • Self-tracking can be a useful first step towards investigating a digital wellbeing artifact or intervention centered around revisitation. Since unlike e.g. rewards/punishments, goal advancement or feature blocking, self-tracking avoids normativity. It also aligns with the "nature of revisitation", making it the clear approach to focus on as a first step. • Self-tracking can enable users to become consciously aware of their relevant behavioral patterns and wellbeing-related data so that they can achieve a greater awareness of what their system 1's automatic impulses are up to [67]. Such awareness can be a first step towards changing such unwanted behaviors [7,60]. People cannot alter their motivation and actions well without paying attention to self-tracking of their relevant behavior or actions [7]. • Self-tracking of revisitation help smartphone users take a first step towards altering their motivation and actions (should they find that necessary), it can also help this project uncover what aspects of revisitation tracking and feedback do users filter out, make sense of and/or appropriate to themselves or their situations.
Tracks revisitation patterns and delivers persistent feedback on them as visual cues through an LED stick (as recommended). Again, as highlighted in related work, the tracking and feedback lets users become aware of their near past revisitation, as the feedback delivered is always about the past hour revisitation.	• This can help because past revisitation (due to its sequential and temporal nature) can be a predictor of future revisitation [52]; and, therefore, might help users become aware of what their past revisitation pattern has been like (and implicitly how it could become if they keep continuing as they have in the past). • Reflection in the form of thinking about past experiences, thoughts or insights is triggered by (visual) cues which is the first step towards more deeper reflection and behavior change [83]. • Feedback in the form of persistent visual cues based on tracked behaviors can be an effective approach for enabling habit formation [98].

Designing for lived experience: Designing digital wellbeing systems to interweave with users' everyday lives and the subjective experiences they contain

The Revisitation Reflector:	Chosen ways of embedding the prioritized value and justification of choices
Is appropriable by users for whatever purposes, needs and contexts they are interested in. Users can make sense of it however they want to, they can draw whatever conclusions	• Different users' PI systems should be designed to be appropriable to them and whatever contexts, needs and purposes they find interesting [86].

they think are there and they can set it up in whatever space or context they want.	
Is meant for being interwoven into whatever its user is doing during the day. It does not demand explicit attention or obstruction of daily activities. As recommended, it also does not assume that users just want to do rational data collection and only reflect on it after it has been thoroughly analyzed.	• Users use information and uncover its meaning in their everyday, day-to-day lives. • PI *is done over* a range of everyday lived experiences and activities. Hence it is unfeasible to make the assumption that users merely want to do rational data collection and that they want to take action only after all the data has been thoroughly analyzed [87]. • Users' everyday life and routines are reflected in their screen time data [87].
Is meant to be interwoven in everyday lives and be a part of a user's subjective experiences. Just as discussed in the above points.	See above.

Designing for being reflective: Designing digital wellbeing interfaces that act as information-driven triggers for inquiry

The Revisitation Reflector:	Chosen ways of embedding the prioritized value and justification of choices
Has a primarily trigger role. It is a trigger through presenting abstract data cues (as recommended), whilst leaving room for bottom-up emergence of what type of feedback, reflection and behavior change is relevant to individual users.	• A *trigger* role involves a trigger that nudges a user to reflect. Such a trigger can be some content (e.g. presenting data, media or even ambiguous data visualizations to provide a reflection direction) [73]. • Triggers lead to mind wandering which leads to critical analysis [83]. After such analysis, an individual gains a new perspective and learns from it. Based on the patterns that an individual uncovers regarding their personal experiences, they can learn and try to improve themselves in various ways [83]. • Nudges towards reflection can "help people collect personally relevant information for the purpose of self-reflection and gaining self-knowledge" [60]. • Reflection is an important stage in personal informatics models like [60]. Reflection phase in that PI model forms the basis for the final stage of the model that involves a user taking action for actually changing their behavior based on the insights gained from reflecting on their personal data [60]. • Trigger was, specifically, chosen because the artifact to be designed is meant to help smartphone users take a first step towards reflection and inquiry–rather than necessarily make a big change to their behavior. As that is not aligned with the previously discussed

	"nature of revisitation", as well as the feasibility of the study. A trigger approach fits will with this open-ended artifact approach, and it leaves room for bottom-up emergence of what type of reflection and behavior change is relevant to users of the to-be-designed digital wellbeing artifact.
Is designed to facilitate inquiry. Amongst other things, as recommended by related work, the Revisitation Reflector tries to stimulate a process of creating, testing and refining hypotheses regarding one's revisitation patterns. It does this by having abstract feedback that is constantly updating, so one can try something and try to explore its effect on the feedback outcome. It also enables this by following the recommendation of letting users review and reflect on past experiences through past personal data (by giving them continuously updating feedback on past data). It is also designed without many pre-conceived notions of how users should make sense of their data and what will be the most important cues and insights for them.	• Inquiry, especially when it is conscious and intentional, forms the basis of many reflection frameworks [9]. Indeed, reflection can even be conceptualized as inquiry [16]. So, facilitating inquiry and creating opportunities for it is directly tied to designing a system for stimulating reflection. • Reflection as inquiry is conceptualized in a similar way to the scientific process of creating, testing, refining and retesting hypotheses [16]. Facilitating such an iterative, curiosity-driven process of testing and refining hypotheses regarding personal informatics can be one way to design for reflection through inquiry [9]. • Inquiry can also be fostered by enabling a critical dialogue between an individual and the (normative) values underlying a design [8] or enabling an individual to investigate the origins of knowledge they are presented with. • At a basic level, designing for inquiry can mean giving users feedback on their past behaviors or actions through cues that allow or encourage inquiry [9]. Some examples in [9] discuss regarding designing for inquiry have to do with enabling users to review and reflect on past experiences through past personal data. • Inquiry was chosen because it fits entirely with the exploratory nature of the study. By enabling users to form, test and refine their own hypotheses, inquiry leaves room for emergence of whatever users find interesting and whatever way they want to make sense of the feedback presented to them. An inquiry approach enables designing an artifact without many pre-conceived notions of how users should make sense of their data and what will be the most important cues and insights for them.
Is inherently information-driven by being based on a user's revisitation data. Such data is typically invisible to a user and uncovering it aligns with information-driven ethos. Again, here, as recommended, somewhat ambiguous data representation (encoding relative revisitation into a LED color palette) is used to help with reflection encouragement.	• *Information driven reflection* is about driving reflection by presenting information or data [73]. Such an approach is particularly common for enabling pattern exploration or facilitating behavior change. • Information driven reflection can be targeted towards uncovering information which might typically be invisible to a user [73]. • It can also be aimed towards using ambiguity of data representations to encourage reflection [73]. • The project utilizes the *information-driven* approach because relies on presenting some form of revisitation data to the user.

Designing for being tangible: Designing digital wellbeing interventions as tangible artifacts

The Revisitation Reflector:	Chosen ways of embedding the prioritized value and justification of choices
Is a tangible artifact. It gives a physically persistent form to feedback on personal revisitation data and it visualizes it in a way which is novel within the typical digital wellbeing interventions. By being decoupled from a user's phone, it enables the human to stay available in the real world rather than the virtual one. It is based on one of the potentially engaging, effective and accessible modalities of visual (colored) cues.	• Being tangible can offer more effective capabilities regarding its output or feedback (e.g. more suitable personal data communication especially for accessibility by all users) [107]. That can enable "new, intuitive ways to interact with and visualize data" and can allow greater convenience [107]. • Tangible interfaces are an example of "supporting interaction technologies which make the human available" [80]. • Tangible interfaces can be used to a create "digital wellbeing agents" that that can bring a physical dimension and enhanced persuasive and restrictive mechanisms to PI systems–with the possibility to be usable in diverse use contexts [55]. • Tangible interfaces can make traditional wellbeing treatments more "accessible and user-centric" and are more engaging due to their abilities regarding encoding various wellbeing related data in tangible feedback (e.g. colored lights) [83]. • Tangible interfaces enable unique input/output capabilities that can be e.g. tactile, movement-related, haptic, sound-related, touchable or visual [107]. This can enhance their educational and behavior change potential regarding wellbeing, when compared to traditional approaches [107]. • Merely tangible, rather than truly "embodied", interfaces are considered because the tangible interfaces are more feasible to achieve, have less development constraints, less sensing requirements and require less training/learning time from participants. They also could be easier to prototype in the limited time and resources available due to the COVID-19 situation.
Is literally external to a user's phone. Revisitation Reflector is its own discrete device that is completely decoupled from the user's phone and does not require the user to interact with or visit their phone in order to get their current revisitation feedback status.	• By not creating a dependence between new, desired behavior and the presence of a smartphone, tangible interface are more likely to enable longer term engagement with digital wellbeing data, as well as more longer-term habit formation [98]. • It is difficult (perhaps not even 'designerly') to rely on a smartphone to give its user feedback on its own usage. Such an approach is quite prevalent in current purely digital interventions ([67,74]), but is paradoxical and could create a perpetual cycle: One is relying on having to come back to one's smartphone in order to track and get feedback on how one is using it.

Designing for being ambient: Designing digital wellbeing systems that are unobtrusive and glanceable

The Revisitation Reflector:	Chosen ways of embedding the prioritized value and justification of choices
Is a completely ambient display that is designed to be glanceable. It is designed to be non-obtrusive and be in the periphery by virtue of its size, minimal design and minimal LED feedback. The LED stick relies on just LED colors and positions to give feedback that is glanceable. Since this feedback mechanism is also quite minimal and does not demand explicit attention, it is inherently ambient.	• Ambient interfaces can mitigate a few significant design issues regarding PI systems: Burdensome usage of PI systems and easy accessibility of feedback [38]. • Ambient displays or ambient awareness can help improve the user experience of PI systems by requiring only minimal user attention [38]. • Overall burden of PI systems can even be diminished by through ambient interfaces which give feedback or present information to users in a manner that only requires minor attention from them [20].
Relies on using minimal, abstract light feedback. It follows the recommendation of using data abstraction of revisitation pattern, to turn it into simple feedback that is quick to process and is not meant to require much conscious thought or attention. By being in an everyday, domestic context, the Revisitation Reflector is poised to be gazed at relatively frequently.	• Displaying data abstractions (rather than raw data) to users enables them to perceive and make sense of information without requiring much conscious thought and attention [41]. This can enable rapid awareness of and reflection on one's habits and behaviors [22].
Allows itself to interweave with everyday activities.	• By being able to be flexibly situated in whatever context, physical position or location that a user finds most suitable; and by being ambient and glanceable as discussed above, the Revisitation Reflector allows itself to be interwoven with everyday activities.

APPENDIX D: FIELD STUDY'S PARTICIPANTS AND SAMPLING

In total, there were seven participants recruited through student chat groups and through personal contact in student housing. To qualify for being recruited for the study, the participants had to be at least eighteen years of age and they had to own a smartphone. They also had to be willing to install the associated AWARE app's clone, as well as be willing to participate in the study for at least seven weekdays. They were 21 to 24 years old and consisted of three females and four males. University students were chosen primarily because of accessibility, time constraints, COVID-19 regulations and this being a first exploratory study in the direction of

a revisitation-driven, tangible artifact. Indeed, convenience sampling was employed in accordance with [10]. The participant quantity of seven was chosen in accordance with Nielsen's recommendations [76], as well as due to data saturation selection suggested by [10]. A feasibility analysis also helped choose the sampling strategy and amount [10]. All the details regarding such participant-related decisions can be found in appendix B.

University students were chosen primarily because of accessibility: This study was carried out over a short timeframe and without any recruitment budget. It also needed to be in the same city (or another one which would be close by) as the researcher, as the prototype had to be handed over to and collected back from the study participants. This would also be useful in case some quick troubleshooting or repairing would be requiring. Students in close proximity had to also conveniently be chosen because of time constraints for the study, the risk of losing already available participants (due to uncertainty caused by COVID-19) and this being a first exploratory study in the direction of a revisitation-driven, tangible artifact.

Indeed, ideally, user research would be conducted with random sampling to make the results as representative of the entire population as possible. However, as [10] suggest, convenience sampling often has to be used instead– and was used in this study. Participants were recruited from a convenient sample for the population [10]: students at university. The limitation here is that the sample obtained reflects, "those who were available (or those you had access to) at a moment in time, as opposed to selecting a truly representative sample of the population". This choice was made because there has to be a balance between rigor and practicality [10]. As such, the convenience sample was still made as representative as possible [10] by having three out of seven participants be more random than others (by e.g. not being in the researcher's immediate living proximity), and by trying to have a balanced gender ratio and different ages.

Seven participants were considered sufficient for the mainly qualitative study because as Nielsen [76] indicates, for qualitative user studies "the best results come from testing no more than 5 users". Indeed, the cost-benefit analysis of user testing also shows an optimal ratio of 3 to 5 users. [10] also indicate that for qualitative field studies, four to six participants are sufficient. Furthermore, it was also a matter of data saturation; "Data saturation is the point during data collection at which no new relevant information emerges", and it is considered the ideal time to stop collecting further data [10]. Like [10] suggest, due to this study being a qualitative one, the data being collecting was undergoing implicit, preliminary analysis throughout the study. Judging from the overview of data being collected or analyzed at the time, after seven participants there was indeed no new relevant information emergence. It was evident that reasonable saturation had been reached.

Another justification for the sampling strategy and size comes from the need for doing a feasibility analysis as shown by [10]. They discuss how the time available to finish the study, availability and scheduling of participants, number of participants, number of prototypes, number of researchers etc. all need to be considered. With all this considered, together with the other recommendations discussed in this chapter, it was considered most feasible to have a convenience sampling strategy and a sample size of seven.

APPENDIX E: FIELD STUDY'S PROCEDURE AND ITS DETAILED JUSTIFICATIONS

First, the participants were onboarded into the study, which included assisting them with installing the AWARE app on their phone and introducing them to the study's overall timeline (and when to expect what). After the onboarding, the participants would start with the study. The study would last for at least seven weekdays. This duration was as long as it was possible whilst sticking to the field study's schedule. The first three weekdays would only involve running the AWARE app on the participants' smartphones. The app would

run entirely in the background and would require no interaction or additional action from the participants. The participants would use their phones as they normally would and AWARE would not have any input or interferences with that. Whilst running in the background, AWARE would log timestamped data regarding the screen status of a participant's phone (whether the screen is locked, unlocked, on or off). This would provide a baseline for the data analysis or reflection on the study later on. It would help discover how the participants' smartphone revisitation was before having the Revisitation Reflector around. Getting such a baseline is an important part of a field user study as it helps get an impression of how things are before an intervention (participants might be doing something completely different before exposure to it) and it also helps participants get used to being in a study [47].

After the first three weekdays of the study, the participants were onboarded into the Revisitation Reflector system. This involved assisting them with setting up the system. They were also introduced to the concept of revisitation and to the functionality of the system. This introduction to the system would be supplementing by–along with the Revisitation Reflector–giving participants a short one-pager outlining the current necessities for usage (e.g. keeping the system plugged in and stable Wi-Fi access), as well as some common, easily fixable error signals and how to fix or report them. This was to ensure that they could experience the system as smoothly as possible by taking care of the essential requirements for functionality, as well as knowing what the few error lights would mean so they could solve them. It should be noted that besides telling the participants what the system did and what they had to do to keep it running, they were not instructed on what they should be doing with the system and how they should be interacting with it etc. This was to allow them to do whatever they wanted to do (unlike a lab study with a demo), to enable anything interesting to naturally emerge [47].

After the participants were handed over the system and were taught how to interpret it, the next step was to let them experience it for themselves in their household environment for four weekdays. An extra day was included here to provide some padding to fix any issues arising with the prototypes or to make other alterations the prototypes if something unexpected would occur (as opposed to three days for the baseline phase with just AWARE). It was three weekdays without the prototype and four weekdays with; specifically, weekdays were counted in order to avoid an extra variable of weekends varying between participants, or even causing different behavior within a participant compared to their typical weekday phone usage.

Again, during this time, the AWARE app (that the participants installed earlier on in the process) would still be running in their phones' backgrounds. The timestamped data collection of screen status would continue. This time, in addition, the Revisitation Reflector would also be pulling that logged data and would be using it to give revisitation feedback to users. The Revisitation Reflector would also internally continuously log its relevant data. This was timestamped data on what the current revisitation pattern (if any) being displayed by the LEDs was, what the status of Raspberry Pi's Wi-Fi was, whether the database server had synced with the participant's phone, whether the participant's phone had Wi-Fi, when did the data collection and feedback giving start etc.

In addition to automatic data collection through participants' phones and through the prototypes, throughout the study (both before and after giving participants the prototype), at a random time towards the end of each day, the participants would also be sent an experience-sampling (ESM) probe. An ESM probe would allow the measuring of the ground truth regarding participants' degree of control [24] over revisitation by collecting their self-reported, subjective feedback about their current feeling of control. It allowed the addition of an extra, quantitative data source that gives more in-situ self-reports [82] of the participants' subjective level of control over revisitation. Like [82], this ESM probe was sent via the participants' smartphones and it asked them to rate their feeling of control on a Likert scale. The participants could choose a discrete value from 1 (fully disagree) to 10 (fully agree) to answer the question, "To what extent do you agree with the statement: Today I felt in control

of my revisitation?". This ESM-probe was formulated along the same lines as [82] due to the success they had with their probe on gauging smartphone users' boredom levels; except in this case the formulation was changed to probe the feeling of control over revisitation–rather than the level of boredom. A frequency of once a day was chosen to minimize the influence of ESM on the natural experiences of smartphone and Revisitation Reflector usage–whilst still gathering some in-situ, quantitative and self-reported data.

After the participants had experienced the Revisitation Reflector for at least four weekdays, a semi-structured interview was conducted with the participants to gain insights into their thoughts and impressions regarding the prototype and the study. The interview was conducted in a semi-structured style, where a set of open-ended and close-ended questions and their follow-ups were prepared [10]. But the interview was allowed to deviate appropriately in terms of the order of questions and in terms of redefining existing questions and defining and asking new ones based on the real-time insights that were being obtained during the interview [10]. This semi-structured style was chosen because an unstructured one would be too open (and a bit inefficient), as the study had some specific information requirements [10]; and a structured one would be too constraining (and would generate less rich data) by having mostly closed-ended questions [10].

This technique of semi-structured interviewing after letting participants test a digital wellbeing intervention in their natural environments was also employed by [86]. Like this project, [86] also had an "interview schedule (i.e. a list of questions)", but that list was not used to direct where the interview would go. Like [86], this project also started with the open questions of: (a) What did you think of the study? followed by (b) What did you think of the display? As the end of the interview would be approaching, the interview schedule would be checked to ensure that nothing that had to be sought out was missing [86]. The themes that the interview schedule was operationalized from included: 'problem space' of smartphone usage/habits; overall and general impressions of the prototype and the study; design and implementation of the Revisitation Reflector; the impact of the prototype on smartphone usage; and reflection on the COVID-19 situation.

Overall, the procedure was significantly linked to the procedures of the two related studies that were discussed earlier ([37] and [86]). Like both of those studies, participants were given a prototype to try in their household situations. Like those studies, there was automatic data collection during prototype usage (via the participants' phones and via the prototype itself) as well as data collection through interviews after the prototype usage. Whilst this study did not run as long, it was still longitudinal like [37] and [86], and it was done in the field. As explained, the study followed a minimum 3+4 days setup; however, the exact number of days varied due to participants' availabilities, time constraints and limited number of prototypes (but the total study duration was always at least 7 days, and therefore, aligned with the adopted procedure). In the end, the average time duration before participants had the display was 3 days 17 hours, and the average time duration whilst they had the display was 4 days 21 hours.

11

Acknowledgements and References

ACKNOWLEDGEMENTS

The author would like to thank the primary supervisors of this research (dr.ir. Edwin Dertien, dr. Rúben Gouveia and dr. Jelle van Dijk) for their insights, support and guidance throughout the project. In particular, without being surrounded by Edwin's inspiration and unwavering support, this project would not have reached this far. Without Rúben's continuous and instant support, critical feedback and pragmatic insights on the subject matter, the quality and rigor of the project would not have been as high. Without Jelle's early on reflective discussions on embodied interactions, this project would not have found its ethos. Finally, this project would not have been possible without the participants who chose to participate in it–to whom the project owes greatly.

REFERENCES

[1] Eytan Adar, Jaime Teevan, and Susan T. Dumais. 2008. Large scale analysis of web revisitation patterns. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/1357054.1357241

[2] Jason Alexander, Yvonne Jansen, Kasper Hornbæk, Johan Kildal, and Abhijit Karnik. 2015. Exploring the challenges of making data physical. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/2702613.2702659

[3] Pengcheng An, Saskia Bakker, Sara Ordanovski, Ruurd Taconis, Chris L.E. Paffen, and Berry Eggen. 2019. Unobtrusively enhancing reflection-in-action of teachers through spatially distributed ambient information. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/3290605.3300321

[4] J Anderson and L Rainie. 2018. *The future of well-being in a tech-saturated world*.

[5] Julie H. Aranda and Safia Baig. 2018. Toward "Jomo": The joy of missing out and the freedom of disconnecting. In *MobileHCI 2018 - Beyond Mobile: The Next 20 Years - 20th International Conference*

on Human-Computer Interaction with Mobile Devices and Services, Conference Proceedings. DOI:https://doi.org/10.1145/3229434.3229468

[6] Saskia Bakker, Elise van den Hoven, and Berry Eggen. 2015. Peripheral interaction: characteristics and considerations. *Pers. Ubiquitous Comput.* (2015). DOI:https://doi.org/10.1007/s00779-014-0775-2

[7] Albert Bandura. 1991. Social cognitive theory of self-regulation. *Organ. Behav. Hum. Decis. Process.* (1991). DOI:https://doi.org/10.1016/0749-5978(91)90022-L

[8] Shaowen Bardzell, Jeffrey Bardzell, Jodi Forlizzi, John Zimmerman, and John Antanitis. 2012. Critical design and critical theory: The challenge of designing for provocation. In *Proceedings of the Designing Interactive Systems Conference, DIS '12*. DOI:https://doi.org/10.1145/2317956.2318001

[9] Eric P.S. Baumer. 2015. Reflective informatics: Conceptual dimensions for designing technologies of reflection. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/2702123.2702234

[10] Kathy Baxter, Catherine Courage, and Kelly Caine. 2015. *Understanding your users: a practical guide to user research methods*. DOI:https://doi.org/10.1016/B978-0-12-800232-2.00013-4

[11] Niels Van Berkel, Denzil Ferreira, and Vassilis Kostakos. 2017. The experience sampling method on mobile devices. *ACM Comput. Surv.* (2017). DOI:https://doi.org/10.1145/3123988

[12] Niels Van Berkel, Chu Luo, Theodoros Anagnostopoulos, Denzil Ferreira, Jorge Goncalves, Simo Hosio, and Vassilis Kostakos. 2016. A systematic assessment of smartphone usage gaps. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/2858036.2858348

[13] Hugh Beyer and Karen Holtzblatt. 1998. *Contextual design: Defining customer-centered systems*.

[14] Matthias Böhmer, Brent Hecht, Johannes Schöning, Antonio Krüger, and Gernot Bauer. 2011. Falling asleep with Angry Birds, Facebook and Kindle: A large scale study on mobile application usage. In *Mobile HCI 2011 - 13th International Conference on Human-Computer Interaction with Mobile Devices and Services*. DOI:https://doi.org/10.1145/2037373.2037383

[15] D. Brockmann, L. Hufnagel, and T. Geisel. 2006. The scaling laws of human travel. *Nature* (2006). DOI:https://doi.org/10.1038/nature04292

[16] Eugene G. Bugg and John Dewey. 1934. How We Think: A Restatement of the Relation of Reflective Thinking to the Educative Process. *Am. J. Psychol.* (1934). DOI:https://doi.org/10.2307/1415632

[17] Phillip Burgess. Assigning Colors to LEDs | FancyLED Library for CircuitPython | Adafruit Learning System. Retrieved June 24, 2020 from https://learn.adafruit.com/fancyled-library-for-circuitpython/led-colors

[18] Jacob Buur and Astrid Soendergaard. 2000. Video card game: An augmented environment for user centred design discussions. In *Proceedings of DARE 2000 on Designing Augmented Reality Environments*. DOI:https://doi.org/10.1145/354666.354673

[19] Xavier Carbonell, Ursula Oberst, and Marta Beranuy. 2013. The Cell Phone in the Twenty-First Century: A Risk for Addiction or a Necessary Tool? In *Principles of Addiction*. DOI:https://doi.org/10.1016/B978-0-12-398336-7.00091-7

[20] Panagiotis Chatzitsakyris, Gonçalo Ducla-Soares, and Alejandro Zulas. 2004. IN-Visible: Perceiving invisible urban information through ambient media. In *Conference on Human Factors in Computing*

Systems - Proceedings. DOI:https://doi.org/10.1145/985921.986061

[21] Karen Church, Denzil Ferreira, Nikola Banovic, and Kent Lyons. 2015. Understanding the challenges of mobile phone usage data. In *MobileHCI 2015 - Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services*. DOI:https://doi.org/10.1145/2785830.2785891

[22] Sunny Consolvo, Predrag Klasnja, David W. McDonald, Daniel Avrahami, Jon Froehlich, Louis Legrand, Ryan Libby, Keith Mosher, and James A. Landay. 2008. Flowers or a robot army?: Encouraging awareness & activity with personal, mobile displays. In *UbiComp 2008 - Proceedings of the 10th International Conference on Ubiquitous Computing*. DOI:https://doi.org/10.1145/1409635.1409644

[23] Sunny Consolvo, Predrag Klasnja, David W. McDonald, and James A. Landay. 2009. Goal-setting considerations for persuasive technologies that encourage physical activity. In *ACM International Conference Proceeding Series*. DOI:https://doi.org/10.1145/1541948.1541960

[24] Sunny Consolvo and Miriam Walker. 2003. Using the experience sampling method to evaluate ubicomp applications. *IEEE Pervasive Comput.* (2003). DOI:https://doi.org/10.1109/MPRV.2003.1203750

[25] Dan Cosley, Elizabeth Churchill, Jodi Forlizzi, and Sean A. Munson. 2017. Introduction to This Special Issue on the Lived Experience of Personal Informatics. *Human-Computer Interact.* 32, 5–6 (2017), 197–207. DOI:https://doi.org/10.1080/07370024.2017.1324787

[26] Ann Cunliffe and Chris Coupland. 2012. From hero to villain to hero: Making experience sensible through embodied narrative sensemaking. *Hum. Relations* (2012). DOI:https://doi.org/10.1177/0018726711424321

[27] Alexander J.A.M. Van Deursen, Colin L. Bolle, Sabrina M. Hegner, and Piet A.M. Kommers. 2015. Modeling habitual and addictive smartphone behavior: The role of smartphone usage types, emotional intelligence, social stress, self-regulation, age, and gender. *Comput. Human Behav.* (2015). DOI:https://doi.org/10.1016/j.chb.2014.12.039

[28] Jelle van Dijk. 2018. Designing for embodied being-in-the-world: A critical analysis of the concept of embodiment in the design of hybrids. *Multimodal Technol. Interact.* (2018). DOI:https://doi.org/10.3390/mti2010007

[29] Jon D. Elhai, Jason C. Levine, Robert D. Dvorak, and Brian J. Hall. 2016. Fear of missing out, need for touch, anxiety and depression are related to problematic smartphone use. *Comput. Human Behav.* (2016). DOI:https://doi.org/10.1016/j.chb.2016.05.079

[30] Daniel A. Epstein, Felicia Cordeiro, Elizabeth Bales, James Fogarty, and Sean A. Munson. 2014. Taming data complexity in lifelogs: Exploring visual cuts of personal informatics data. In *Proceedings of the Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques, DIS*. DOI:https://doi.org/10.1145/2598510.2598558

[31] Daniel A. Epstein, An Ping, James Fogarty, and Sean A. Munson. 2015. A lived informatics model of personal informatics. In *UbiComp 2015 - Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. DOI:https://doi.org/10.1145/2750858.2804250

[32] Hossein Falaki, Ratul Mahajan, Srikanth Kandula, Dimitrios Lymberopoulos, Ramesh Govindan, and

Deborah Estrin. 2010. Diversity in smartphone usage. In *MobiSys'10 - Proceedings of the 8th International Conference on Mobile Systems, Applications, and Services*. DOI:https://doi.org/10.1145/1814433.1814453

[33] Denzil Ferreira, Vassilis Kostakos, Alastair R. Beresford, Janne Lindqvist, and Anind K. Dey. 2015. Securacy: An empirical investigation of android applications' network usage, privacy and security. In *Proceedings of the 8th ACM Conference on Security and Privacy in Wireless and Mobile Networks, WiSec 2015*. DOI:https://doi.org/10.1145/2766498.2766506

[34] Denzil Ferreira, Vassilis Kostakos, and Anind K. Dey. 2015. AWARE: Mobile context instrumentation framework. *Front. ICT* (2015). DOI:https://doi.org/10.3389/fict.2015.00006

[35] Jillian P. Fry and Roni A. Neff. 2009. Periodic prompts and reminders in health promotion and health behavior interventions: Systematic review. *Journal of Medical Internet Research*. DOI:https://doi.org/10.2196/jmir.1138

[36] Andrea Gaggioli, Giuseppe Riva, Dorian Peters, and Rafael A. Calvo. 2017. Positive Technology, Computing, and Design: Shaping a Future in Which Technology Promotes Psychological Well-Being. In *Emotions and Affect in Human Factors and Human-Computer Interaction*. DOI:https://doi.org/10.1016/B978-0-12-801851-4.00018-5

[37] Rúben Gouveia, Fábio Pereira, Evangelos Karapanos, Sean A. Munson, and Marc Hassenzahl. 2016. Exploring the design space of glanceable feedback for physical activity trackers. In *UbiComp 2016 - Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. DOI:https://doi.org/10.1145/2971648.2971754

[38] Rebecca Gulotta, Jodi Forlizzi, Rayoung Yang, and Mark W. Newman. 2016. Fostering engagement with Personal informatics systems. In *DIS 2016 - Proceedings of the 2016 ACM Conference on Designing Interactive Systems: Fuse*. DOI:https://doi.org/10.1145/2901790.2901803

[39] Anton Gustafsson and Magnus Gyllenswärd. 2005. The power-aware cord: Energy awareness through ambient information display. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/1056808.1056932

[40] Lars Hallnäs and Johan Redström. 2001. Slow technology - Designing for reflection. *Pers. Ubiquitous Comput.* (2001). DOI:https://doi.org/10.1007/PL00000019

[41] Jaap Ham and Cees Midden. 2010. Ambient persuasive technology needs little cognitive effort: The differential effects of cognitive load on lighting feedback versus factual feedback. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. DOI:https://doi.org/10.1007/978-3-642-13226-1_14

[42] Donna Haraway. 2000. The Companion Species Manifesto: Dogs, People, and Significant Otherness. Retrieved January 23, 2020 from https://www.youtube.com/playlist?list=PL1D9615FA85ED8B19

[43] Gunnar Harboe and Elaine M. Huang. 2015. Real-world affinity diagramming practices: Bridging the paper-digital gap. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/2702123.2702561

[44] Gunnar Harboe, Jonas Minke, Ioana Ilea, and Elaine M. Huang. 2012. Computer support for collaborative data analysis: Augmenting paper affinity diagrams. In *Proceedings of the ACM Conference on Computer Supported Cooperative Work, CSCW*. DOI:https://doi.org/10.1145/2145204.2145379

[45] Katja Herrmanny, Jürgen Ziegler, and Aysegül Dogangün. 2016. Supporting users in setting effective goals in activity tracking. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. DOI:https://doi.org/10.1007/978-3-319-31510-2_2

[46] Trevor Hogan and Eva Hornecker. 2017. Towards a design space for multisensory data representation. *Interact. Comput.* (2017). DOI:https://doi.org/10.1093/iwc/iww015

[47] Steven Hoober. 2016. Succeeding with Field Usability Testing and Lean Ethnography. Retrieved May 23, 2020 from https://www.uxmatters.com/mt/archives/2016/11/succeeding-with-field-usability-testing-and-lean-ethnography.php

[48] Matthew Hutson. 2018. Missing data hinder replication of artificial intelligence studies. *Science (80-.).* (2018). DOI:https://doi.org/10.1126/science.aat3298

[49] Hiroshi Ishii, Craig Wisneski, Scott Brave, Andrew Dahley, Matt Gorbet, Brygg Ullmer, and Paul Yarin. 1998. ambientROOM: Integrating Ambient Media with Architectural Space. *Proc. Conf. Hum. Factors Comput. Syst. Mak. Impos. Possible* (1998). DOI:https://doi.org/10.1145/286498.286652

[50] Sheena S. Iyengar and Mark R. Lepper. 2000. When choice is demotivating: Can one desire too much of a good thing? *J. Pers. Soc. Psychol.* (2000). DOI:https://doi.org/10.1037/0022-3514.79.6.995

[51] Yvonne Jansen, Pierre Dragicevic, Petra Isenberg, Jason Alexander, Abhijit Karnik, Johan Kildal, Sriram Subramanian, and Kasper Hornbæk. 2015. Opportunities and challenges for data physicalization. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/2702123.2702180

[52] Simon L. Jones, Denzil Ferreira, Simo Hosio, Jorge Goncalves, and Vassilis Kostakos. 2015. Revisitation analysis of smartphone app use. In *UbiComp 2015 - Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. DOI:https://doi.org/10.1145/2750858.2807542

[53] Wendy Ju. 2015. The Design of Implicit Interactions. *Synth. Lect. Human-Centered Informatics* (2015). DOI:https://doi.org/10.2200/s00619ed1v01y201412hci028

[54] Elisabeth T. Kersten-van Dijk, Joyce H.D.M. Westerink, Femke Beute, and Wijnand A. IJsselsteijn. 2017. Personal Informatics, Self-Insight, and Behavior Change: A Critical Review of Current Literature. *Human-Computer Interaction*. DOI:https://doi.org/10.1080/07370024.2016.1276456

[55] Jaejeung Kim and Uichin Lee. 2019. Interaction Restraint Framework for Digital Wellbeing. *ACM CHI Work. Des. Digit. Wellbeing* (May 2019).

[56] Alexandra Kitson, Bernhard Riecke, and Andrea Gaggioli. 2019. Digital Wellbeing: Considering Self-transcendence. In *Conference on Human Factors in Computing Systems – Workshop on Digital Well-being*.

[57] Daniel J. Kruger and Jaikob M. Djerf. 2016. High Ringxiety: Attachment Anxiety Predicts Experiences of Phantom Cell Phone Ringing. *Cyberpsychology, Behav. Soc. Netw.* (2016). DOI:https://doi.org/10.1089/cyber.2015.0406

[58] Phillippa Lally and Benjamin Gardner. 2013. Promoting habit formation. *Health Psychology Review*. DOI:https://doi.org/10.1080/17437199.2011.603640

[59] Min Kyung Lee, Junsung Kim, Jodi Forlizzi, and Sara Kiesler. 2015. Personalization revisited: A

reflective approach helps people better personalize health services and motivates them to increase physical activity. In *UbiComp 2015 - Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. DOI:https://doi.org/10.1145/2750858.2807552

[60] Ian Li, Anind Dey, and Jodi Forlizzi. 2010. A stage-based model of personal informatics systems. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/1753326.1753409

[61] Edwin A. Locke and Gary P. Latham. 2006. New directions in goal-setting theory. *Curr. Dir. Psychol. Sci.* (2006). DOI:https://doi.org/10.1111/j.1467-8721.2006.00449.x

[62] Kai Lukoff. 2012. Digital wellbeing is way more than just reducing screen time. Retrieved January 22, 2020 from https://uxdesign.cc/digital-wellbeing-more-than-just-reducing-screen-time-46223db9f057

[63] Deborah Lupton. 2016. Personal data practices in the age of lively data. In *Digital Sociologies*. DOI:https://doi.org/10.2307/j.ctt1t89cfr.27

[64] Deborah Lupton. 2016. The quantified self : a sociology of self-tracking. (2016).

[65] Deborah Lupton. 2017. Feeling your data: Touch and making sense of personal digital data. *New Media Soc.* (2017). DOI:https://doi.org/10.1177/1461444817717515

[66] Ulrik Lyngs. 2019. Putting Self-Control at the Centre of Digital Wellbeing. *2019 ACM CHI Conf. Hum. Factors Comput. Syst. (Position Pap.* (2019). DOI:https://doi.org/https://doi.org/10.1145/3290605. 3300361.

[67] Ulrik Lyngs, Kai Lukoff, Petr Slovak, Reuben Binns, Adam Slack, Michael Inzlicht, Max Van Kleek, and Nigel Shadbolt. 2019. Self-control in cyberspace: Applying dual systems theory to a review of digital self-control tools. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/3290605.3300361

[68] Angelika Mader, Edwin Dertien, and Dennis Reidsma. 2012. Single value devices. In *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering*. DOI:https://doi.org/10.1007/978-3-642-30214-5_5

[69] Jennifer Mankoff, Anind K. Dey, Gary Hsieh, Julie Kientz, Scott Lederer, and Morgan Ames. 2003. Heuristic evaluation of ambient displays. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/642640.642642

[70] Bess H. Marcus, Vanessa C. Selby, Raymond S. Nlaura, and Joseph S. Rossi. 1992. Self-efficacy and the stages of exercise behavior change. *Res. Q. Exerc. Sport* (1992). DOI:https://doi.org/10.1080/02701367.1992.10607557

[71] Merleau-Ponty Maurice. 1962. *Phenomenology of perception / by M. Merleau-Ponty ; translated from the French by Colin Smith*. Routledge & Kegan Paul London.

[72] Maurice Merleau-Ponty. 1968. *The visible and the invisible : followed by working notes*.

[73] Ine Mols, Elise Van Den Hoven, and Berry Eggen. 2016. Technologies for everyday life reflection: Illustrating a design space. In *TEI 2016 - Proceedings of the 10th Anniversary Conference on Tangible Embedded and Embodied Interaction*. DOI:https://doi.org/10.1145/2839462.2839466

[74] Alberto Monge Roffarello and Luigi De Russis. 2019. The race towards digital wellbeing: Issues and opportunities. In *Conference on Human Factors in Computing Systems - Proceedings*.

DOI:https://doi.org/10.1145/3290605.3300616

[75] Jennifer A. Moon. 2013. *Reflection in Learning and Professional Development*. DOI:https://doi.org/10.4324/9780203822296

[76] J Nielsen. 2000. Why you only need to test with 5 users. Retrieved from https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/

[77] Petter Nielsen and Annita Fjuk. 2010. The reality beyond the hype: Mobile internet is primarily an extension of PC-based internet. *Inf. Soc.* (2010). DOI:https://doi.org/10.1080/01972243.2010.511561

[78] Michael Nunes, Saul Greenberg, and Carman Neustaedter. 2008. Sharing digital photographs in the home through physical mementos, souvenirs, and keepsakes. In *Proceedings of the Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques, DIS*. DOI:https://doi.org/10.1145/1394445.1394472

[79] Hartmut Obendorf, Harald Weinreich, Eelco Herder, and Matthias Mayer. 2007. Web page revisitation revisited: Implications of a long-term click-stream study of browser usage. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/1240624.1240719

[80] Fredrik Ohlin and Carl Magnus Olsson. 2015. Intelligent computing in personal informatics: Key design considerations. In *International Conference on Intelligent User Interfaces, Proceedings IUI*. DOI:https://doi.org/10.1145/2678025.2701378

[81] Antti Oulasvirta, Tye Rattenbury, Lingyi Ma, and Eeva Raita. 2012. Habits make smartphone use more pervasive. *Pers. Ubiquitous Comput.* (2012). DOI:https://doi.org/10.1007/s00779-011-0412-2

[82] Martin Pielot, Tilman Dingler, Jose San Pedro, and Nuria Oliver. 2015. When attention is not scarce-detecting boredom from mobile phone usage. In *UbiComp 2015 - Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. DOI:https://doi.org/10.1145/2750858.2804252

[83] Afarin Pirzadeh, Li He, and Erik Stolterman. 2013. Personal Informatics and Reflection: A Critical Examination of the Nature of Reflection. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/2468356.2468715

[84] Qualtrics. 2016. Millennials & Technology Research & Stats. 2. Retrieved June 6, 2020 from https://www.qualtrics.com/millennials/ebooks/Millennials_And_Tech_At_Home_eBook_All_AK.pdf

[85] Ian Renfree, Daniel Harrison, Paul Marshall, Katarzyna Stawarz, and Anna Cox. 2016. Don't kick the habit: The role of dependency in habit formation apps. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/2851581.2892495

[86] John Rooksby, Parvin Asadzadeh, Mattias Rost, Alistair Morrison, and Matthew Chalmers. 2016. Personal tracking of screen time on digital devices. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/2858036.2858055

[87] John Rooksby, Mattias Rost, Alistair Morrison, and Matthew Chalmers. 2014. Personal tracking as lived informatics. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/2556288.2557039

[88] Mary Beth Rosson. Injecting a Positivity Spin into Our Everyday Digital Lives. In *Conference on*

Human Factors in Computing Systems – Workshop on Digital Well-being. Retrieved from https://digitalwellbeingworkshop.files.wordpress.com/2019/04/15-digitalwellbeingchi19-rosson.pdf

[89] Samantha Rush. 2011. Problematic Use of Smartphones in the Workplace: An Introductory Study. *Zhurnal Eksp. i Teor. Fiz.* (2011).

[90] Daniel Schiff. 2019. A New Paradigm For Autonomous and Intelligent Systems Development: Why Well-being Measurement Matters. In *Conference on Human Factors in Computing Systems – Workshop on Digital Well-being*. Retrieved January 22, 2020 from https://spp.gatech.edu/publications/pub/6057

[91] Matthias Schmidmaier. 2019. A Perspective On Digital Wellbeing. *Conf. Hum. Factors Comput. Syst. – Work. Digit. Well-being* (2019).

[92] D A Schön. 1983. *The Reflective Practitioner*. DOI:https://doi.org/10.1542/peds.2005-0209

[93] Victoria Schwanda, Steven Ibara, Lindsay Reynolds, and Dan Cosley. 2011. Side effects and "gateway" tools: Advocating a broader look at evaluating persuasive systems. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/1978942.1978991

[94] Sandra Servia-Rodríguez, Kiran K. Rachuri, Cecilia Mascolo, Peter J. Rentfrow, Neal Lathia, and Gillian M. Sandstrom. 2017. Mobile sensing at the service of mental well-being: A large-scale longitudinal study. In *26th International World Wide Web Conference, WWW 2017*. DOI:https://doi.org/10.1145/3038912.3052618

[95] Amitai Shenhav, Matthew M. Botvinick, and Jonathan D. Cohen. 2013. The expected value of control: An integrative theory of anterior cingulate cortex function. *Neuron*. DOI:https://doi.org/10.1016/j.neuron.2013.07.007

[96] Itamar Simonson. 2005. Determinants of customers' responses to customized offers: Conceptual framework and research propositions. *Journal of Marketing*. DOI:https://doi.org/10.1509/jmkg.69.1.32.55512

[97] John Stasko. 2014. Value-driven evaluation of visualizations. In *ACM International Conference Proceeding Series*. DOI:https://doi.org/10.1145/2669557.2669579

[98] Katarzyna Stawarz, Anna L. Cox, and Ann Blandford. 2015. Beyond self-tracking and reminders: Designing smartphone apps that support habit formation. In *Conference on Human Factors in Computing Systems - Proceedings*. DOI:https://doi.org/10.1145/2702123.2702230

[99] Jelle Stienstra, Miguel Bruns Alonso, Stephan Wensveen, and Stoffel Kuenen. 2012. How to design for transformation of behavior through interactive materiality. In *NordiCHI 2012: Making Sense Through Design - Proceedings of the 7th Nordic Conference on Human-Computer Interaction*. DOI:https://doi.org/10.1145/2399016.2399020

[100] Victor J. Strecher, Gerard H. Seijts, Gerjo J. Kok, Gary P. Latham, Russell Glasgow, Brenda Devellis, Ree M. Meertens, and David W. Bulger. 1995. Goal Setting as a Strategy for Health Behavior Change. *Heal. Educ. Behav.* (1995). DOI:https://doi.org/10.1177/109019819502200207

[101] Norbert Streitz, Dimitris Charitos, Maurits Kaptein, and Marc Böhlen. 2019. Grand challenges for ambient intelligence and implications for design contexts and smart societies. *J. Ambient Intell. Smart Environ.* (2019). DOI:https://doi.org/10.3233/AIS-180507

[102] Simon Stusak. 2015. Exploring the potential of physical visualizations. In *TEI 2015 - Proceedings of the 9th International Conference on Tangible, Embedded, and Embodied Interaction*. DOI:https://doi.org/10.1145/2677199.2691604

[103] Yaacov Trope and Nira Liberman. 2010. Construal-Level Theory of Psychological Distance. *Psychol. Rev.* (2010). DOI:https://doi.org/10.1037/a0018963

[104] Alexei Vazquez. 2007. Impact of memory on human dynamics. *Phys. A Stat. Mech. its Appl.* (2007). DOI:https://doi.org/10.1016/j.physa.2006.04.060

[105] Leo Sang Min Whang, Siujin Lee, and Geunyoung Chang. 2003. Internet over-users' psychological profiles: A behavior sampling analysis on Internet addiction. *Cyberpsychology Behav.* (2003). DOI:https://doi.org/10.1089/109493103321640338

[106] Julia Carrie Wong. 2017. Former Facebook executive: social media is ripping society apart | The Guardian. Retrieved June 6, 2020 from https://www.theguardian.com/technology/2017/dec/11/facebook-former-executive-ripping-society-apart

[107] Kieran Woodward, Eiman Kanjo, David Brown, T. M. McGinnity, Becky Inkster, Donald J Macintyre, and Athanasios Tsanas. 2019. Beyond Mobile Apps: A Survey of Technologies for Mental Well-being. (May 2019). Retrieved January 22, 2020 from http://arxiv.org/abs/1905.00288

[108] Haoyi Xiong, Yu Huang, Laura E. Barnes, and Matthew S. Gerber. 2016. Sensus: A cross-platform, general-purpose system for mobile crowdsensing in human-subject studies. In *UbiComp 2016 - Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. DOI:https://doi.org/10.1145/2971648.2971711

[109] David Bryce Yaden, Jonathan Haidt, Ralph W. Hood, David R. Vago, and Andrew B. Newberg. 2017. The varieties of self-transcendent experience. *Rev. Gen. Psychol.* (2017). DOI:https://doi.org/10.1037/gpr0000102

[110] Tingxin Yan, David Chu, Deepak Ganesan, Aman Kansal, and Jie Liu. 2012. Fast app launching for mobile devices using predictive user context. In *MobiSys'12 - Proceedings of the 10th International Conference on Mobile Systems, Applications, and Services*. DOI:https://doi.org/10.1145/2307636.2307648

[111] Kimberly S Young. 1999. Internet addiction: evaluation and treatment. *BMJ* (1999). DOI:https://doi.org/10.1136/sbmj.9910351

[112] RescueTime: Fully Automated Time Tracking Software. Retrieved January 23, 2020 from https://www.rescuetime.com/

[113] Digital Wellbeing through technology | Google. Retrieved January 24, 2020 from https://wellbeing.google/

[114] Focusly - Chrome Web Store. Retrieved January 23, 2020 from https://chrome.google.com/webstore/detail/focusly/jlihnplddpebplnfafhdanaiapbeikbk?hl=gb

[115] News Feed Eradicator for Facebook - Chrome Web Store. Retrieved January 23, 2020 from https://chrome.google.com/webstore/detail/news-feed-eradicator-for/fjcldmjmjhkklehbacihaiopjklihlgg?hl=gb

[116] Checkout of your phone on the App Store. Retrieved January 23, 2020 from https://apps.apple.com/gb/app/checkout-of-your-phone/id1051880452?ign-mpt=uo%3D4

[117] Todobook - Chrome Web Store. Retrieved January 23, 2020 from https://chrome.google.com/webstore/detail/todobook/ihbejplhkeifejcpijadinaicidddbde?hl=gb

[118] Time: Defeat Distraction on the App Store. Retrieved January 23, 2020 from https://apps.apple.com/gb/app/time-defeat-distraction/id1313017655?ign-mpt=uo%3D4

[119] Forest - Stay focused, be present. Retrieved January 23, 2020 from https://www.forestapp.cc/

[120] Timewaste Timer - Chrome Web Store. Retrieved January 23, 2020 from https://chrome.google.com/webstore/detail/timewaste-timer/pengblgbipcdkpigibniogojheaokckd?hl=gb

[121] Remember The Milk: Online to-do list and task management. Retrieved January 23, 2020 from https://www.rememberthemilk.com/

[122] What is Appropriation? | Interaction Design Foundation. Retrieved June 28, 2020 from https://www.interaction-design.org/literature/topics/appropriation