Designing For Cognitive Resilience

Sustaining Attention, Memory, And Reasoning In Everyday Digital Interaction

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Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Doctor of Philosophy is entirely my own work, and that I have exercised reasonable care to ensure that the work is original and have conformed to the regulations on the use and declaration of Generative AI, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Tools. Generative AI tools were used as reading and editing aids during the preparation of this thesis. ChatGPT and Google Gemini was used between September 2024 and 23 May 2026. Claude was used between February 2026 and 23 May 2026. The tools were accessed through their standard user interfaces, using the latest model/version available to the author at the time of use; exact model/version names were not consistently recorded across the full period of use.

Outputs. The tools were used in three limited ways. First, during 2024-2025, after the main literature review had already been substantially developed, they were used to clarify unfamiliar terminology and to check the meaning, context, or background of concepts encountered during additional reading. Second, they were used to generate initial summaries or explanations of additional academic sources and research-related materials to support reading and comprehension. All sources cited in the thesis were read and checked by the author. Third, during 2025–2026, the tools were used to support editing of the thesis text, including suggesting alternative phrasings, improving readability, and checking grammar. Tool outputs were treated as reading and editing aids only; the author selected, revised, verified, and integrated content as appropriate.

Prompts. Prompts were short and task-specific. Examples include:

- “Explain [concept] in plain language.”
- “Is [term] commonly used in Human–Computer Interaction literature?”
- “Summarise the research goal and findings of this article.”
- “What method does this paper use?”
- “Suggest a clearer phrasing for this expression.”
- “How could this sentence read more naturally?”
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- “Is this sentence appropriate for academic writing?”

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List of Publications

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List of Abbreviations

Abbreviation	Expansion
ADHD	Attention Deficit Hyperactivity Disorder
AI	Artificial Intelligence
ANOVA	Analysis of Variance
BFI-2	Big Five Inventory-2
BH	Benjamini–Hochberg
CRSM	Cognitive Resilience Support Mechanism
CT	Critical Thinking
DMN	Default Mode Network
EF	Executive Functions
GDPR	General Data Protection Regulation
GSR	Galvanic Skin Response
GUI	Graphical User Interface
HCI	Human–Computer Interaction
ITS	Intelligent Tutoring Systems
LLM	Large Language Model
NASA-TLX	NASA Task Load Index
REC	Research Ethics Committee
RtD	Research through Design
SART	Sustained Attention to Response Task
SD	Standard Deviation
SPANE	Scale of Positive and Negative Experience
SUS	System Usability Scale
UI	User Interface
UX	User Experience

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Designing For Cognitive Resilience: Sustaining Attention, Memory and Reasoning in Everyday Digital Interaction

Naile Burcu Hacioglu

Abstract

Everyday digital technologies are designed to maximise speed, ease of use, and continuous engagement. While these qualities support traditional usability goals, they can also undermine the cognitive capacities they were designed to support. This thesis introduces *cognitive resilience* as a complementary HCI design construct: the capacity to maintain core cognitive functions under the immediate and cumulative demands of digital interaction.

Grounded in a review of the literature on digital technology's impact on cognitive functions, three design studies were conducted across distinct interaction contexts. *Attention Mode* introduces a cross-platform distraction-reducing feature, returning user control over attention during everyday media consumption. *SmartPause* adds breakpoints into digital reading, combining structured pauses with brief note-taking prompts; a between-subjects study (N = 51) and a within-subjects study (N = 14) showed gains primarily in memory retention. *ReasonScape* proposes a redesign of AI chat to guide reflection, reduce premature acceptance of AI outputs, and support reasoning in AI-assisted judgement tasks. Together, the studies follow a Research-through-Design methodology combined with mixed methods.

Synthesis across the three studies produced a working definition of cognitive resilience for HCI, alongside design artefacts and a set of principles and guidelines. Together, these offer practical guidance for designers seeking to sustain users' cognitive engagement. By extending existing usability and UX discussions, this research argues that digital systems should be evaluated not only by how easily they enable task completion, but by how well they sustain users' attention, memory, and reasoning during and after the interaction.

PART I

FRAMING

Chapter 1

Introduction

1.1 Motivation: Cognitive Costs of Everyday Digital Technology

In the contemporary digital landscape, individuals are increasingly immersed in environments optimised for speed, convenience, and continuous connectivity. Smartphones, tablets, laptops, and wearable devices dominate not only professional workflows but also social and recreational life. While these affordances have transformed access to information and can expedite certain tasks, they also present challenges to sustained focus and depth of engagement, prompting concerns about their broader impact on productivity and cognitive performance. At the same time, they have introduced significant trade-offs, particularly in relation to the efficiency and effectiveness of core cognitive processes.

Empirical studies in cognitive psychology and human–computer interaction (HCI) increasingly indicate that sustained use of digital technologies can adversely affect fundamental cognitive processes such as attention, memory, and reasoning (H.-P. Lee et al., 2025; Small et al., 2020; Sparrow et al., 2011). For instance, digital media multitasking has been shown to impair executive control and working memory (Ophir et al., 2009), while persistent smartphone notifications fragment attention and diminish task engagement (Ward et al., 2017). Moreover, interactions with digital devices have encouraged widespread cognitive offloading—the delegation of information storage and retrieval to external systems. Although such offloading can enhance efficiency, overreliance may progressively undermine internal cognitive capacities (Risko & Gilbert, 2016), potentially weakening learning, critical reflection, and decision-making (Carr, 2015). Furthermore, design strategies that shape user behaviour without fostering deliberation may not strengthen and may even erode reflective judgement over time (Hertwig & Grüne-Yanoff, 2017).

Recent neuroscience findings add depth to these concerns. Greicius et al. (2003) demonstrated that the brain's default mode network (DMN) plays a central role in memory consolidation and self-referential thought. As the DMN is most active during undisturbed, internally focused states, persistent screen exposure may limit its activation and reduce opportunities for reflection, autobiographical thought, and memory integration. Complementary evidence from cognitive neuroscience indicates that habitual multitasking can alter functional connectivity and impair attentional filtering mechanisms (Uncapher & Wagner, 2018). Together, these changes carry significant implications for sustained learning, nuanced decision-making, and emotional regulation, suggesting that constant digital interaction may not only fragment attention in the short term but also reshape underlying neural processes that support long-term cognitive well-being. Yet these risks remain largely invisible outside academic and specialist circles, and public or industry awareness of the cognitive toll of everyday digital interactions is still limited (Hacioglu & Lee, 2026). Conversations around digital well-being tend to focus on screen time or digital detox strategies, rather than the more nuanced cognitive implications embedded in everyday interface design. This limited awareness contributes to a reactive, rather than preventative, stance on user cognition.

These shifts call for an urgent re-examination of how we design interactive technologies. If the goal of user experience (UX) design is not only to optimise ease and efficiency but also to support users' well-being, then cognitive well-being must be considered a key design outcome. Social and behavioural studies further underscore this need, showing how reliance on digital systems—often optimised to minimise friction—can inadvertently remove necessary cognitive thresholds that anchor knowledge and encourage deliberation (Norman, 2013). Moreover, the proliferation of multitasking behaviours—enabled and often encouraged by notifications, tabbed browsing, and rapid app-switching—has contributed to a form of cognitive fragmentation. This fragmentation not only lowers productivity (Wickens et al., 2013), but also disrupts the ability to maintain coherent thought, producing cumulative cognitive fatigue and lowering resistance to distraction (Risko & Gilbert, 2016). This thesis advances the concept of *cognitive resilience* defined here as the capacity to preserve core cognitive functions such as attention, memory, and when facing both immediate challenges and prolonged demands, particularly in the context of persistent digital interaction. Rather than focusing on recovery after cognitive disruption, this thesis is concerned with preventing degradation by designing environments that resist cognitive erosion in the first place.

At present, few solutions directly target this design-based cognitive erosion. Most interventions centre on restricting access—through parental controls, app timers, or digital detox applications—rather than fundamentally redesigning interaction patterns. This framing implicitly positions the user as the problem, overlooking how system architecture and interface design shape cognitive outcomes.

The social implications of this oversight are becoming increasingly visible. Digital platform architectures and interfaces that reinforce short attention spans can hinder public discourse, policy deliberation, and collective reasoning. Political polarisation and information bubbles are, in part, exacerbated by algorithmically mediated platforms that encourage impulsive reactions over reflective thinking (Tufekci, 2015). By privileging immediacy over deliberation, such interfaces risk eroding the depth of civic engagement and undermining informed decision-making.

In educational settings, there is growing concern that the design of digital learning environments often fails to support sustained attention and deep processing. Students report struggling to maintain focus during reading tasks, frequently being drawn toward other tabs, apps, or notifications. The introduction of digital textbooks and learning management systems has in many cases not led to improved engagement or comprehension, but has instead been associated with poorer comprehension and increased cognitive load, likely linked to multitasking and frequent shifts in attention (Goldstein, 2019; Jian, 2022).

Professionals, too, are impacted. Knowledge workers face an avalanche of information from emails, chats, dashboards, and notifications—each competing for limited cognitive bandwidth. Rather than enhancing productivity, this information deluge often leads to heightened stress, mental fatigue, and reduced job satisfaction (Mark, Iqbal, Czerwinski, Johns, Sano, & Lutchyn, 2016). In such contexts, the challenge is not simply to make systems easier to use, but to design for sustained cognitive engagement amidst high cognitive demands.

Designers have long focused on making systems intuitive and efficient—reducing the time and effort required to complete tasks (Norman, 2013; Sharp et al., 2023). While these goals remain important, they are insufficient in an era where users interact with systems not occasionally, but persistently and habitually (Harper et al., 2008). Interfaces that once served as tools now function more like environments, shaping daily rhythms of thought, attention, and decision-making (Bødker, 2006). As such, the cognitive side-effects of interface design must be brought into sharper focus.

Designing for *cognitive resilience* offers a constructive way forward. This approach recognises that digital systems are not neutral artefacts; they actively participate in cognitive processes by scaffolding, shaping, or, at times, undermining them. In this thesis, cognitive resilience refers to the capacity to maintain attention, engage in active information processing**,** retain and retrieve memory, exercise executive control, and demonstrate reflective, well-reasoned engagement. Such an interface, therefore, is one that minimises unnecessary attentional fragmentation, supports these core functions, and resists designs that foster impulsive reaction over deliberate thought.

The present work embraces the notion that interaction design can be a force not only for usability but also for cognitive empowerment. By identifying patterns in interface design that either hinder or support mental resilience, it seeks to offer both critique and constructive direction. It bridges empirical insights from cognitive psychology and neuroscience with practical strategies from UX design, aiming to enrich both fields and elevate the role of cognition in interaction design discourse.

While the long-term cognitive effects of these interventions remain beyond the scope of this thesis, this work addresses cognitive resilience through a range of complementary empirical approaches suited to each design context: controlled experiments measuring attentional control and memory retention in SmartPause, usability evaluation across devices and platforms in Attention Mode, and structured expert assessment of reasoning support design in ReasonScape. Together, these studies establish both a set of design principles and an evaluative foundation from which future longitudinal research can assess sustained cognitive impact.

1.2 Research Problem and Gaps

The pervasive adoption of digital technologies has transformed human interaction, information access, learning, and work. Yet, amid this transformation, cognitive costs have become increasingly evident. Much of contemporary UX design remains grounded in traditional usability paradigms such efficiency, learnability, satisfaction (Nielsen, 1993), but these frameworks overlook how digital interactions shape and stress cognitive resources over time.

The dominant design logic continues to prize immediacy, frictionlessness, and behavioural automation, often at the expense of deeper cognitive engagement (Carr, 2015; Norman, 2013). Usability heuristics, while valuable, can obscure the cumulative cognitive impact of interface use. As tools for interaction increasingly function as

environments—habitually used, pervasive, and immersive—their influence on users' cognitive capacities grows more profound.

Current design guidelines offer minimal support for addressing phenomena such as attentional depletion, memory offloading, or the suppression of critical thinking. While design frameworks exist for emotional design (Norman, 2004), persuasive technology (Fogg, 2003), and even digital well-being (Vanden Abeele, 2021), there are no widely adopted strategies within HCI for safeguarding baseline cognitive functioning. Moreover, the idea that interaction design could proactively foster cognitive strength, rather than merely mitigate harm, remains underexplored in both HCI research and practice.

The gap widens further when considering methodological limitations. Evaluations of user interfaces often prioritise short-term usability metrics or observable behavioural outcomes such as task completion rates or error counts. These approaches rarely address how sustained interaction with a system affects core cognitive faculties (Risko & Gilbert, 2016). There is also limited research exploring how cognitive load varies with interface affordances or how design features may subtly promote or inhibit mental stamina.

Another under-addressed issue is the tension between usability and cognitive resilience. Many canonical usability principles—from minimising cognitive load to reducing decision points—may inadvertently disincentivise users from engaging deeply with content or choices. This paradox suggests the need to refine or reframe design principles to account for cognitive outcomes beyond task completion. From an empirical perspective, scalable evaluation methods that capture cognitive impact in naturalistic, real-world contexts remain scarce. Without such tools, designers lack robust evidence to inform decisions aimed at fostering long-term cognitive health.

This thesis responds to these gaps by proposing a cognitively-resilient design approach: a framework and set of design criteria that explicitly aim to support cognitive processes such as sustained attention, memory, and critical thinking. This includes identifying common interface patterns that either impair or enhance cognition, translating cognitive science into actionable design knowledge, and conducting targeted evaluations to validate cognitive outcomes.

Crucially, while this research explores short-term usability and cognitive indicators through empirical and exploratory studies, it acknowledges the limitation that long-term effects of design interventions remain difficult to capture within the scope of a single thesis. Future longitudinal research will be required to assess the durability of cognitive support strategies in real-world settings.

The research problem, therefore, can be stated as follows: The design of everyday digital systems continues to prioritise usability and efficiency while overlooking their cognitive costs, leaving cognitive resilience unaddressed at the interaction design level.

1.3 Hypothesis and Research Questions

This research is grounded in the premise that digital interaction design not only affects immediate task performance but also cumulative effects on users' cognitive functioning both in the moments following interaction and over extended periods of use. While traditional design paradigms have prioritised ease, speed, and efficiency, this thesis posits that it is possible, and increasingly necessary to reorient these paradigms toward fostering preservation of baseline cognitive functions**,** particularly attention, memory, and reasoning. The hypothesis guiding this study is:

- **Hypothesis**. ***It is possible to design the interactions of everyday applications in such a way as to reduce or minimise negative consequences to users' cognitive abilities, including attention, memory, and reasoning, by preserving baseline cognitive functioning during both short-term and habitual interaction contexts***.

This hypothesis is underpinned by interdisciplinary findings from cognitive psychology, neuroscience, and HCI, which demonstrate that environmental and interactional factors significantly influence cognitive resource allocation, decision-making strategies, and information retention.

To investigate this hypothesis, the study is structured around three research questions:

- **RQ1.** ***Which interaction contexts in everyday applications undermine core cognitive processes such as attention, memory, executive functions, and reasoning, when engaged with in the short term, on a repeated basis, or during continuous use?***

This question seeks to identify interaction patterns or design affordances that contribute to cognitive decline, including attentional fragmentation, overreliance on cognitive offloading, and diminished critical engagement. It is informed by insights from existing empirical literature and initial exploratory studies.

- **RQ2.** ***How can these interaction contexts be redesigned to mitigate negative cognitive effects while maintaining usability and engagement, without relying on device, platform or application-level restrictions?***

Here, the focus shifts to design intervention. Using a research-through-design approach, this study explores ways to modify, counterbalance, or reconceptualise interaction elements to enhance users' cognitive endurance. Particular attention is paid to

mechanisms such as interface friction, reflection prompts, memory supports, and purposeful ambiguity as strategies, while avoiding full device, platform, or application restrictions.

- **RQ3.** ***What are the implications for existing design knowledge (principles, guidelines, and heuristics), and how can these be extended to support cognitive resilience in interaction design?***

Finally, this question examines how adopting a cognitive-resilience lens could influence both the theoretical and practical foundations of UX and HCI. The aim is to propose extensions to existing heuristics and design principles so they explicitly account for cognitive impacts, enabling their potential integration into mainstream design practice.

Together, these questions structure a programme of inquiry encompassing theoretical development, iterative prototyping, and mixed-method evaluation. The goal is not to enhance cognitive capacity per se, but to stabilise and protect core cognitive functions from degradation during digital interaction. This approach treats cognition as something that can be sustained through design—not merely supported in isolated moments, but preserved over time through the creation of enduring user environments.

1.4 Research Objectives: Creating Design Strategies for Cognitive Resilience

The overarching aim of this research is to contribute a cognitively resilient perspective to the design of everyday digital interactions—one that prioritises the preservation of a broad set of cognitive functions, including but not limited to attention, memory, executive control, and critical reasoning, across both short- and long-term engagements with digital systems. This involves reconceptualising existing usability goals to consider not just user satisfaction or performance efficiency, but also the preservation of users' cognitive functions. To achieve this, the research pursues several interrelated objectives:

1. **Diagnose the Cognitive Effects of Everyday Interaction Patterns.** In response to RQ1, the first line of inquiry focuses on identifying which prevalent design features—such as constant notifications, infinite scroll, autoplay media, and frictionless navigation—most negatively impact users' cognitive functioning, and which specific faculties, such as attention, memory, or executive control, are most susceptible to these effects. These features are often justified on the basis of engagement and user retention, yet they may contribute to fragmented cognitive states and reduced metacognitive awareness. A review of prior studies indicates that such patterns occur across a wide range of digital activities and affect users of different age groups. While the state-of-the-art research employs diverse

methodologies—from surveys and experiments to observational studies—the reported cognitive effects are predominantly negative, particularly for executive functions.

2. **Design and Explore Interventions for Cognitive Resilience.** To address the challenge outlined in RQ2, this objective seeks not only to critique harmful digital interaction patterns but to propose and prototype alternative designs that better support users' cognitive needs. These prototypes will serve as exploratory artefacts to investigate how design might protect core cognitive skills like attention and memory. While not all interventions will be evaluated, a selected set will be studied in greater depth to explore how they can foster more resilient patterns of digital interaction.
3. **Formulate Cognitive-Resilient Design Knowledge.** As part of RQ3, this part of research focuses on synthesising both exploratory and empirical insights from the prototyping process into a coherent body of actionable design knowledge, comprising principles, and guidelines. This set of knowledge is intended to be domain-agnostic, supporting application across diverse digital contexts—from social media and productivity tools to educational platforms. The resulting design knowledge will offer practical guidance for UX professionals seeking to create cognitively aligned and resilient digital environments.
4. **Situate the Proposed Design Principles within the Broader Field of HCI and UX.** As a continuation of RQ3, this involves not only comparing the proposed cognitive-resilient strategies with established usability heuristics; such as those developed by (Nielsen, 1993; Norman, 2013; Shneiderman et al., 2018); but also critically examining the assumptions underpinning these frameworks. By foregrounding cognitive resilience as a core design value, this research challenges the prevailing efficiency- and usability-driven paradigm in UX. It calls for a more comprehensive conception of usability, one that accounts for both immediate cognitive engagement and the preservation of cognitive functions across repeated and prolonged digital interaction. This reframing also brings into focus the tension between instant usability and sustained cognitive well-being, raising important questions about how design values are prioritised in contemporary HCI practice.
5. **Propose a Methodological Model for Evaluating Cognitive Dimensions of UX.** Traditional usability metrics often focus on task performance, satisfaction, or errors, which may overlook subtler cognitive implications. In parallel with

addressing the core research questions, this thesis explores how cognitive dimensions might be assessed through lightweight, complementary methods. Several methods will be trialled in selected design studies to explore how cognitive indicators can inform UX evaluation beyond surface-level usability. The aim is to support a more nuanced understanding of user experience in cognitively demanding contexts, while providing a foundation for more robust evaluation frameworks in future work.

6. **Raise Awareness about the Cognitive Implications of Digital Interaction.** An ancillary objective of this work is to stimulate critical reflection among designers, researchers, and technology developers about the broader implications of interaction design on users' thinking, reasoning, and attentional processes. In a landscape shaped by persuasive technologies and behavioural nudges, safeguarding user cognition becomes a matter of both design responsibility and ethical imperative. This includes advocating for cognitive-centred design audits and raising public awareness of how design choices can subtly erode or support sustained cognitive agency.

Together, these objectives outline a programme of research that integrates conceptual analysis, iterative design work, and empirical evaluation. The ambition is not simply to document harm, but to articulate viable design alternatives that foster digital environments in which users can think clearly, not merely act fast. This work ultimately contributes toward a more sustainable, humane digital ecosystem—where technology augments rather than undermines the cognitive capabilities that define human agency.

1.5 Methodological Approach and Design Rationale

The methodological foundation of this thesis is grounded in Research through Design (RtD), a practice-based and iterative approach commonly employed within HCI and design research communities (Frayling, 1993; Zimmerman et al., 2010). RtD enables the development of knowledge through the process of designing, implementing, and evaluating interactive systems, with the design artefact itself serving as both an outcome and a means of inquiry. This approach is particularly suitable given the thesis's dual goals of theoretical advancement and practical design impact.

RtD is well-positioned to deal with complex, ill-structured problems—such as mitigating the cognitive costs of digital technologies—that resist reductive hypothesis testing, or purely observational research. Instead, it embraces messiness, ambiguity, and situated knowledge, making it ideal for addressing how interaction design can be used to

provoke, guide, and reshape cognitive experience. By embedding iterative cycles of design and reflection, RtD acknowledges the situated, contextual, and temporal nature of interaction, while generating insights that extend beyond any single artefact.

This study integrates RtD with a mixed-methods evaluation framework to ensure rigour and relevance. Qualitative methods including usability interviews, think-aloud protocols, contextual inquiries, and expert feedback —are used to gather rich, interpretive insights into user experiences, reflective engagement, and perceived cognitive effort. Such methods are especially valuable for revealing tacit responses and underlying mental models. They are complemented by quantitative assessments such as the System Usability Scale (SUS) (Brooke, 1996), NASA-TLX workload index (Hart & Staveland, 1988), and performance-based tasks including Stroop and memory recall tests (Stroop, 1935). The combination of interpretive and numerical data is intended to capture both usability and engagement dimensions, as well as short-term and sustained cognitive variations that may arise during or following interaction.

Three core design artefacts serve as primary empirical cases. Each was produced as an interactive prototype or design concept rather than a deployed application:

(1) Attention Mode: An interface designed to support sustained attention by suppressing non-essential notifications, eliminating task-irrelevant interface elements, and reducing opportunities for multitasking on the device (Hacioglu et al., 2023b, 2023a).

(2) SmartPause: An intervention targeting memory retention by introducing strategic pauses into digital reading (Hacioglu, Leva, Kim, et al., 2025; Hacioglu, Leva, & Lee, 2025a).

(3) ReasonScape: A conceptual AI chatbot prototype for stimulating critical thinking via reasoning progress visualisation and reflective questioning (Hacioglu et al., 2026; Hacioglu, Leva, & Lee, 2025b).

Each artefact represents a distinct cognitive dimension, allowing for comparative insights across attention, memory, and reasoning. These cases were selected not only for their conceptual alignment with the hypothesis but also for their methodological diversity. Evaluation strategies include user testing, in-situ feedback collection, simulation-based experimentation, and expert critique. This triangulation enables a nuanced analysis of usability, cognitive performance, and perceived value. Rather than seeking generalisability in the statistical sense, the thesis aims for transferability—offering patterns, insights, and principles that can inform future HCI practice concerned with

cognitive resilience across domains such as productivity tools, social media and digital leisure environments.

The methodological structure builds on this RtD foundation through iterative cycles within each design artefact. The three artefacts are independent of one another, and each was refined through prototyping, targeted feedback, and reflection in response to its own design context and cognitive focus. Although findings from one artefact occasionally informed subsequent designs, they more commonly contributed in parallel to a broader investigation of cognitive resilience in digital interaction. Despite differing in form, context, and evaluation approach, the three designs are united by a shared focus on cognitive resilience and draw equally on experiential, empirical, and theoretical insights. An overview of how this iterative process unfolds across the thesis is provided in Section 1.7 (Figure 1.1), which serves as both a visual map of the research process and a structural map of the chapters that follow.

1.6 Scope, Assumptions, and Limitations

This research is situated at the intersection of HCI, interaction design, and behavioural science, drawing particularly from cognitive psychology to understand and support core cognitive functions in digital contexts.

Scope: The thesis concentrates on the interaction layer of digital applications, rather than the content, infrastructure, or hardware. It focuses specifically on interface-level patterns, temporal dynamics, and engagement structures that influence cognition during interaction. The scope encompasses everyday digital environments such as productivity platforms, social media applications, digital reading systems, and general-purpose communication tools. These systems are selected for their pervasive influence on cognitive routines, decision-making, and knowledge processing. The research does not intend to reduce digital use, but instead seeks to reconfigure the conditions under which it occurs to elevate the cognitive integrity of engagement within these systems.

The design investigations are bounded within typical, non-clinical user groups—such as students, knowledge workers, and general adult populations. While the insights might be valuable for specialised domains (e.g., healthcare or education), the primary focus remains on commonly encountered user experiences in everyday contexts. As such, the designs and principles proposed aim to be broadly applicable, yet are tailored toward digital environments where cognitive load, attentional fragmentation, and informational saturation are prevalent challenges.

Assumptions — Several foundational assumptions underpin this work:

- Users' cognitive processes are continually shaped by the structural, interactional, and temporal characteristics of digital interfaces.
- Cognitive performance is not solely a function of usage volume or screen time, but of the interaction patterns and attentional demands embedded within systems.
- Prevailing usability metrics (e.g., efficiency, error rates, task completion time) are insufficient to capture subtle and sustained cognitive effects.
- Design can be purposively directed to promote cognitive continuity, resource protection, and mental stamina through structured affordances.
- Research-through-Design (RtD), with its emphasis on generative and reflective practice, offers a viable path for constructing, testing, and evolving design strategies that centre cognitive functioning and resilience.

Limitations — This work is bounded in the following ways:

- This study does not extend into clinical cognitive diagnostics or long-term psychological tracking. The evaluations are intentionally scoped around short- and medium-term indicators of cognitive consistency, task fluency, and perceived cognitive load.
- The participant pools, while diverse, are constrained in size and demography, limiting broader statistical generalisability.
- This thesis does not attempt to theorise cognitive mechanisms at a neurological level but draws on cognitive theory to inform practically oriented design interventions.
- The iterative, design-led methodology varies in evaluation depth across the three design studies, with controlled empirical assessment concentrated in SmartPause, while Attention Mode and ReasonScape are evaluated through usability testing and expert feedback respectively.

Despite these boundaries, the scope is sufficient to identify key patterns, propose a coherent body of new design knowledge, and inform both practical application and further research into cognitively resilient interaction design.

1.7 Thesis Structure and Chapter Overview

This thesis is organised into eight chapters that collectively respond to the hypothesis set out in Section 1.3. Figure 1.1 provides a visual roadmap of the research process.

The numbered stops on the figure correspond to the eight chapters of the thesis: from the hypothesis and research questions established in this introduction (Ch. 1), through the gaps and design opportunities identified in the literature from a cognitive resilience

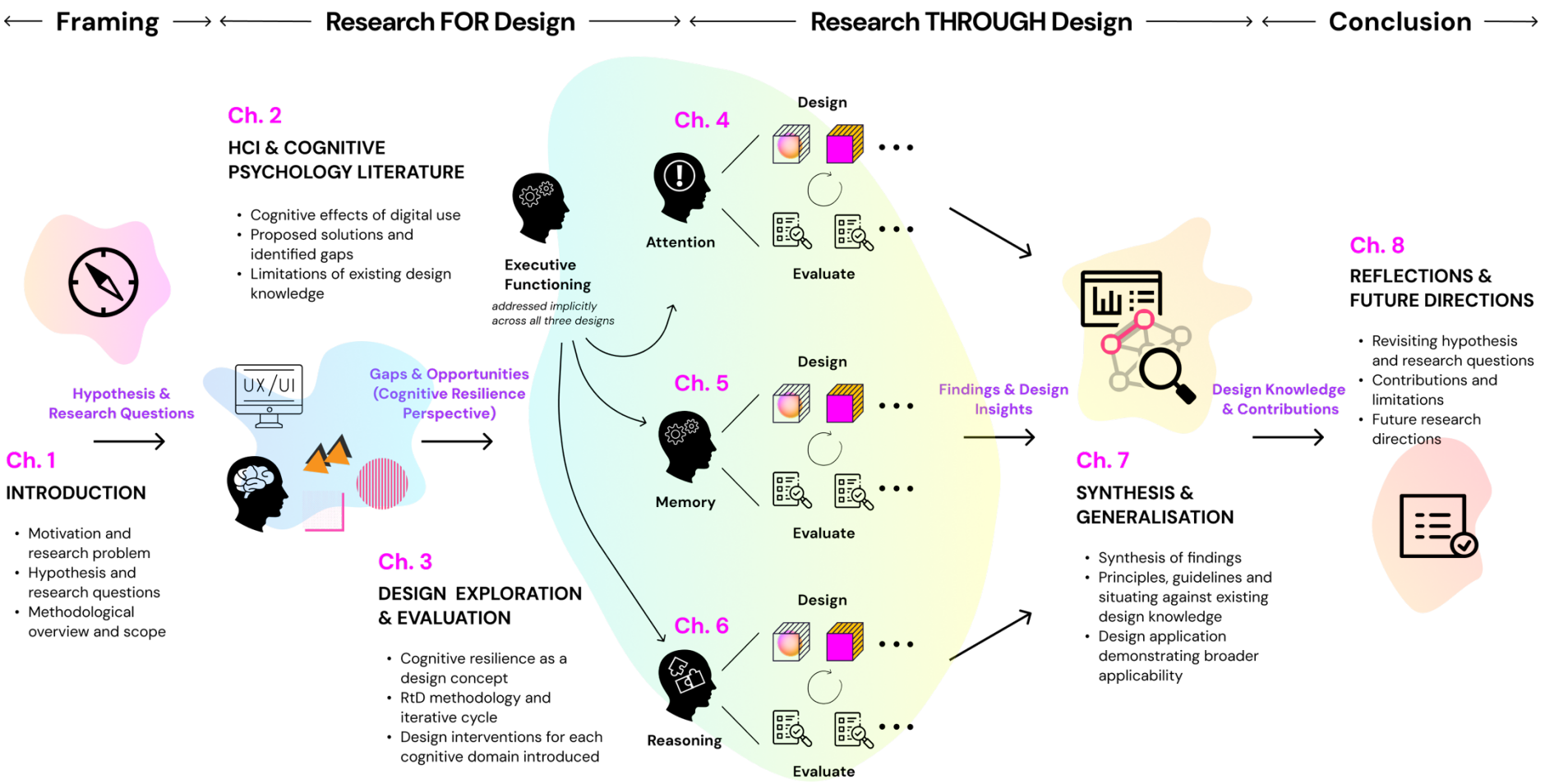


Figure 1.1: Thesis roadmap. Labels Ch. 1 to Ch. 8 correspond to the eight chapters of the thesis, tracing the research process from research questions through three iterative design studies to consolidated design knowledge and concluding reflection.

perspective (Ch. 2), into the methodological framework that operationalises Research through Design (Ch. 3), across three iterative design studies addressing attention (Ch. 4), memory (Ch. 5), and reasoning (Ch. 6), into the synthesis of cross-case findings into design principles, guidelines, and a framework, including their generalisability beyond the three studies (Ch. 7), and finally to the reflective conclusion of the thesis (Ch. 8).

The figure is referenced again in Chapter 3 (Section 3.2.2), where the methodological stages it depicts are described in detail. The remainder of this section describes each chapter in turn.

Part I - Framing

Chapter 1 – Introduction establishes the research context, articulating the motivation, problem statement, research hypothesis, and objectives. It further outlines the methodological approach and delineates the scope, assumptions, and limitations underpinning the study. It also introduces and justifies the use of cognitive resilience as the central conceptual construct, framed not as repair but as the preservation of baseline cognitive capacities such as attention regulation, memory integration, and deliberative thought.

Chapter 2 – Background and Related Work reviews relevant literature across three domains: foundational usability principles and UX research; cognitive psychology research on mechanisms including attention, memory, executive functions, reasoning, and critical thinking; and socio-cultural discourse on the mental and behavioural consequences of ubiquitous digital environments. This synthesis identifies gaps and den opportunities in existing design responses and sets the conceptual stage for the thesis's contribution.

Chapter 3 – Research Design and Methodology elaborates the research framework and design strategy, positioning cognitive resilience as a core principle for interaction design. It discusses the epistemological commitments of Research through Design (RtD) and explicates the iterative cycle of exploration, evaluation, and synthesis underpinning the empirical work. This chapter also clarifies the operationalisation of cognitive resilience as a design lens, differentiating it from well-being, accessibility, or behavioural efficiency models.

Part II – Design Studies

Chapter 4 – Design Study 1: Attention Mode for Sustained Attention in Digital Media Use introduces *Attention Mode*, a cross-platform interface intervention designed to reduce distractions and support attentional focus. It explains the design rationale, grounded in

theories of attentional control and interface minimalism, and presents findings from usability interviews and System Usability Scale (SUS) evaluations. The methodology combines qualitative feedback with standardised usability metrics, yielding insights into how interface adjustments can scaffold sustained attention. Design implications are drawn to inform future distraction-aware systems.

Chapter 5 – Design Study 2: SmartPause for Memory Continuity in Digital Reading presents *SmartPause*, a digital reading intervention designed to enhance memory retention through strategically timed pauses, while also addressing attention regulation and cognitive load management. It details the design rationale, grounded in theories of encoding, pacing, and cognitive offloading. The methodology involves two controlled studies combining System Usability Scale (SUS) data with task-based recall assessments and self-reported workload measures (e.g. NASA-TLX). Findings demonstrate how temporal structuring can support memory performance and influence subjective mental effort, even in the absence of measurable attentional effects. The chapter concludes with design implications for creating cognitively adaptive digital reading environments.

Chapter 6 – Design Study 3: ReasonScape for Reasoning and Critical Thinking in AI Assistant Use explores *ReasonScape*, a conceptual AI-based chatbot designed to externalise reasoning progress and stimulate critical thinking. It outlines the speculative design concept, presents insights from expert feedback, and offers an interpretive summary of its cognitive and design implications. The chapter reflects on the value of conceptual artefacts as exploratory tools for engaging with cognitive processes that are difficult to observe or measure directly, and highlights how such designs can open new directions for supporting reasoning and critical thinking in AI-assisted interaction.

Part III – Synthesis and Conclusion

Chapter 7 - From Synthesis to Generalisation: Design Principles and Guidelines for Cognitive Resilience synthesises insights across the three design studies to derive six design principles and fourteen guidelines for cognitively resilient interaction. It situates these against existing design knowledge including (Nielsen, 1994a, 1994b; Norman, 2013), and emerging AI interaction frameworks, and demonstrates their broader applicability through a design application to social media feeds.

Chapter 8 – Conclusion reflects on the research process and outcomes, revisiting the research questions and hypothesis, and summarising the conceptual, methodological, and practical contributions of the thesis. It critically appraises limitations and proposes

directions for future research, including ways to evaluate resilience over time and integrate cognitive-centred design principles into education, industry practice, and policy.

Collectively, these chapters form a coherent narrative that bridges theory, design practice, and empirical investigation. This structure ensures a rigorous and reflective progression, supporting the thesis's ambition to advance the field's understanding of cognitive resilience as both a conceptual and practical imperative in digital interaction.

Chapter 2

Background and Related Work

This chapter reviews the scholarly foundations and current debates that lead to the identification of gaps and the shaping of research questions posed in the thesis. It first examines how usability and UX traditions have incorporated cognition, showing that cognitive skills have usually been framed as constraints to be minimised rather than capacities to be supported. It then examines how contemporary digital technologies may undermine core processes such as attention, memory, and reasoning, while also noting occasional cases where they may benefit cognition. Finally, it reviews existing solutions and considers their limitations. Taken together, this analysis identifies which interaction contexts most affect specific cognitive processes, what kinds of solutions have been attempted or proposed, and how new design priorities centred on cognitive resilience may begin to address these challenges.

2.1 Foundations of Usability and UX

2.1.1 The Limited-Capacity View of Usability

Usability has been a defining concern of Human–Computer Interaction (HCI) since its earliest roots in the mid-20th century. In the decades following the Second World War, human factors engineering and engineering psychology emerged to address the challenges of operating complex systems, particularly in aviation and the military. Early applied psychology investigated why pilots made errors despite technically functioning aircraft (Fitts & Jones, 1947) and why sustained vigilance was difficult in radar and watchkeeping tasks (Mackworth, 1948). These studies framed performance problems in terms of human limitations that could be analysed and mitigated through design.

By the late 1970s, HCI was beginning to emerge as a distinct field. Shackel first introduced a formal definition of usability in 1981, later republished in *Human Factors for Informatics Usability* (Shackel, 1991), describing it as the capability of a system to be

used "easily and effectively" in human-functional terms. This marked one of the earliest attempts to conceptualise usability explicitly in relation to computing.

A decisive step came with Card, Moran, and Newell's *The Psychology of Human–Computer Interaction* (2018), which codified usability within predictive cognitive models of interaction. Their work operationalised usability in terms of task efficiency, speed, and error rates, reflecting an engineering orientation. Their models included the Model Human Processor (MHP), which conceptualised humans as information-processing systems; the GOMS framework (Goals, Operators, Methods, Selection rules), which predicted task strategies; and the Keystroke-Level Model (KLM), which quantified performance at the level of primitive actions. Together, these tools made usability measurable, predictable, and evaluable, consolidating the ethos of cognitive efficiency.

This orientation was later formalised in psychology. Engineering psychology articulated sequential stages of perception, memory, decision-making, and response, each vulnerable to overload or error (Wickens et al., 2013). Similarly, cognitive psychology framed cognition as information processing, likening it to computational systems that encode, store, and retrieve symbolic representations (Anderson, 2015, pp. 7–12). These frameworks reinforced the conception of usability as the reduction of barriers to task completion and the mitigation of human error.

As a result, usability in its formative period was aligned with a limited-capacity view of cognition. Interfaces were to be designed to accommodate bounded attention, limited working memory, and susceptibility to slips and mistakes. The success of a system was measured by how well it reduced cognitive burden, shortened task times, and lowered error rates. This framing would go on to underpin much of HCI's first wave.

2.1.2 First Wave HCI: Cognition and Task Performance

The first wave of HCI, spanning the 1970s and 1980s, was closely tied to engineering psychology and human factors research. With computing situated in contexts such as air traffic control, cockpit displays, and command-line interfaces, interaction was framed as a problem of optimising human–machine performance. Usability was operationalised through quantitative indicators such as time to learn, speed of task completion, rate of errors, retention over time, and subjective satisfaction (Shneiderman et al., 2018, pp. 33–34).

It was in this period that the field consolidated around a number of influential frameworks that systematised the knowledge into general and practical design principles and guidelines:

Nielsen's 5 Usability Characteristics (learnability, efficiency, memorability, error recovery, satisfaction), which would later be reflected in international usability standards, codified usability as a set of measurable attributes that could be systematically assessed in evaluation studies (Nielsen, 1993). *Learnability* ensured that novices could quickly become competent; *efficiency* measured the performance of expert users; *memorability* captured whether users could return to the system after a period of non-use without extensive relearning; *errors* concerned both the frequency of mistakes and the ease of recovery; and *satisfaction* addressed subjective user experience. While memorability directly linked usability to cognitive retention, it was typically framed as preventing forgetting between uses rather than supporting deeper processes of memory consolidation or longer-term cognitive development.

Nielsen's 10 Usability Heuristi*cs* provided a widely adopted toolkit for practical interface evaluation (Nielsen, 1994b). These included guidelines such as visibility of system status, match between system and the real world, user control and freedom, error prevention, recognition rather than recall, and flexibility and efficiency of use. Their intent was to ensure that interfaces were intuitive and predictable, reducing the need for users to hold complex states in working memory. In particular, the heuristic of "recognition over recall" tries to directly reduce memory burden by externalising information into the interface itself. While this approach lowered cognitive demands in the short-term, it also implicitly encouraged reliance on external prompts rather than internal memory processes.

Don Norman's 6 Principles of Design —visibility, mapping, feedback, constraints, consistency, and affordances—emphasised the importance of aligning interfaces with users' mental models (Norman, 2013). By making system functions visible, mapping controls logically to outcomes, providing immediate feedback, and constraining possible errors, designers could reduce the cognitive effort required to interpret and operate systems. Consistency across interfaces further reinforced learned behaviours, while affordances signalled possible actions without explicit instruction. Collectively, these principles advanced usability by reducing ambiguity and cognitive interpretation costs. However, in doing so, they also reinforced the idea that systems should adapt to human limitations rather than challenge or extend users' cognitive capacities.

Shneiderman's 8 Golden Rules, first introduced in the 1987 edition and reiterated in later editions (Shneiderman et al., 2018), provided some of the earliest systematic guidance for user interface design. These rules included principles such as striving for

consistency, offering informative feedback, designing dialogs to yield closure, permitting easy error recovery, reducing short-term memory load, and supporting internal locus of control. Collectively, they reflected an emphasis on minimising user error and cognitive strain by reducing reliance on working memory, providing clear system responses, and ensuring that users could recover from mistakes without losing progress. While these principles enhanced usability and accessibility, they also reinforced a perspective in which mental effort was treated as a cost to be avoided rather than as an opportunity to support or strengthen cognitive skills.

Together, these frameworks entrenched a usability ethos centred on cognitive efficiency. Users were treated as bounded decision-makers whose limitations should be compensated through design. Interfaces were judged by their ability to reduce the need for recall, prevent mistakes, and enable rapid, frictionless operation. This had the advantage of making computing accessible to non-experts but also reinforced the idea that mental effort was a liability.

Critically, from the perspective of cognitive functions, this first-wave approach positioned usability around what might be termed *cognitive minimisation*: the treatment of core cognitive processes as liabilities to be reduced or circumvented. While this facilitated performance in safety-critical domains, it left little space to consider how sustained reliance on such systems might affect users' core cognitive abilities negatively

2.1.3 Second Wave HCI: Context and Collaboration

The second wave of HCI, emerging in the late 1980s and 1990s, coincided with the rise of personal computing, graphical user-interfaces (GUIs), and networked work practices. With computing moving from specialised technical contexts into offices, homes, and collaborative environments, usability broadened beyond error minimisation to encompass learnability, discoverability, and social practices (Bødker, 2006; Carroll, 1997). This shift aligns with the rise of personal computing—which made technology accessible to everyday users and imposed new usability demands beyond traditional task performance. This shift was underpinned by new theoretical frameworks that emphasised context and distribution:

Distributed Cognition (Hollan et al., 2000; Hutchins, 1996) reconceptualised cognition as extending beyond the individual to encompass people, artefacts, and representational media. Hutchins' ethnographic study of ship navigation demonstrated how charts, instruments, and collaborative routines collectively formed a cognitive system, showing that external representations actively shape thought. Hollan, Hutchins

and Kirsh elaborated this view for HCI, identifying three dimensions of distribution: across members of a social group, between internal and external structures (such as displays or documents), and across time. They argued that work artefacts and interfaces are constitutive elements of cognition rather than passive aids, cautioning that poorly designed systems could disrupt established distributed processes. For usability, this implied that user-interface design fundamentally restructures cognitive activity, influencing how information is represented, coordinated, and remembered.

Activity Theory (Kaptelinin & Nardi, 2009; Kuutti, 1995) provided a complementary perspective by situating interaction within historical, social, and cultural contexts. It conceptualised humans as active subjects engaged in goal-directed activities, mediated by tools and embedded within communities governed by rules and division of labour. Unlike information-processing models that treated cognition as capacity-limited processing, Activity Theory emphasised development over time, showing how repeated engagement with artefacts supports learning, adaptation, and intentionality. A central principle was the dynamics of action and operation: as skills develop, deliberate actions become routinised operations, while contradictions in practice generate new forms of activity. This highlighted usability not only as error prevention or efficiency but also as part of a broader trajectory of skill formation and socio-technical practice. Despite this conceptual richness, however, Activity Theory was only partially integrated into mainstream usability engineering, functioning more as a critical alternative to cognitive models than as a standard evaluation method.

Usability practice during this period integrated these insights with established methods. Cognitive walkthroughs, heuristic evaluation, and usability testing became standardised, ensuring that user interfaces were assessed not only for efficiency but also for ease of learning and error recovery (Nielsen, 1994b; Norman, 2013). The widespread adoption of GUIs and direct manipulation interfaces further reduced the need for recall, privileging recognition and immediate action.

From the perspective of cognitive functions, second-wave HCI extended usability into the social and temporal domain but continued to see short-term task performance as the primary goal. Memorability was framed as ease of re-engagement with a system after periods of non-use, not as reinforcement of cognitive capacities. Distributed cognition, while recognising externalisation, did not address the long-term effects of offloading memory to digital systems. Activity Theory, though offering a richer account of learning and development, remained unevenly applied in usability practice.

Taken together, the first and second waves established usability as a cornerstone of HCI. They codified design guidance into principles and heuristics, institutionalised evaluation methods, and enabled the rapid diffusion of computing into everyday life. Yet, they also entrenched a limitations-based framing of cognition: mental effort was something to be reduced or bypassed, not cultivated. By prioritising efficiency, error reduction, and recognition over recall, these approaches risked sidelining the question of how interaction shapes cognitive abilities.

2.1.4 Third Wave HCI and Beyond: Experience, Affect, and Wellbeing

By the early 2000s, HCI entered what has been described as its third wave (Bødker, 2006; Harrison et al., 2007), expanding beyond cognition and collaboration into domains of experience, affect, embodiment, and everyday life. Whereas the first and second waves emphasised efficiency and usability in technical and organisational contexts, the third wave shifted attention towards the felt qualities of interaction—pleasure, meaning, and emotional engagement.

A central influence in this period was Don Norman's work on emotional design (2004), which argued that systems should not only be usable but also desirable and emotionally satisfying. Norman proposed three levels of design, visceral, behavioural, and reflective, each shaping how users perceive and evaluate interactive experiences. Building on Norman's contribution, (Hassenzahl & Tractinsky, 2006) advanced user experience (UX) as a research agenda that extended HCI beyond usability. They argued that interaction should encompass not only pragmatic qualities such as efficiency but also hedonic and experiential dimensions, including pleasure, beauty, and meaning. UX was thereby positioned as a paradigm explicitly concerned with affect and positive experience, rather than merely the prevention of error or frustration. This reframed usability from a narrow focus on error reduction and efficiency toward a broader conception of UX, where affective response and emotional resonance became central design outcomes.

This evolution was also institutionalised in standards such as ISO 9241-210:2019, which defines UX as a person's "perceptions and responses resulting from the use and/or anticipated use of a product, system or service" (International Organization for Standardization (ISO), 2019, Section 3.15). Unlike earlier definitions of usability that emphasised effectiveness, efficiency, and satisfaction (International Organization for Standardization (ISO), 2018), the UX perspective broadened the scope to encompass *holistic, subjective experiences* shaped by context, expectations, and affective qualities. The rise of UX as a professional domain further cemented this shift, embedding

experiential considerations into both academic discourse and industry practice. This broadening of scope marked a decisive shift from *usability* to *user experience*, embedding emotional, social, and contextual factors into design practice. Whereas usability had been primarily concerned with reducing error, effort, and inefficiency, the UX perspective highlighted that interaction is also shaped by affective responses, cultural expectations, and the meanings attached to technology in everyday life. From this foundation, it became possible to extend HCI's agenda further toward concerns of human wellbeing, positioning interactive systems not only as tools for performance or sources of enjoyment, but also as environments that influence users' capacity to live balanced, meaningful, and sustainable lives.

Third-wave HCI also increasingly attended to wellbeing. Harper et al.'s *Being Human* manifesto (2008) highlighted the need to design for richer human values and experiences as computing became ubiquitous in everyday life. More recently, the field of digital wellbeing has emerged, with scholars such as Vanden Abeele (2021) conceptualising it as a dynamic construct that reflects not only the absence of harm but also the capacity of users to pursue meaningful and balanced lives in digital environments. Calvo and Peters (2014) similarly advocate for technology designed to support human potential, positioning positive computing as a design orientation concerned with flourishing rather than merely preventing harm. However, these wellbeing frameworks do not address the specific cognitive resources that enable users to think, remember, and reason effectively. This gap points directly to the concerns of this thesis: how everyday interactive systems shape and strain cognitive processes, and how design might instead support resilience, issues explored in the following section.

2.2 Cognitive Processes Affected by Digital Technologies

Cognitive psychology looks at the different mental processes that shape how we think and behave. These processes are closely connected and build on each other in layers.

Figure 2.1 presents a layered framework of cognitive processes, adapted from models in cognitive psychology (Anderson, 2015; Goldstein, 2019; Wickens et al., 2013). At the foundation are attention (choosing what to focus on) and memory (holding information for the short or long term). On top of these, executive functions act like the brain's manager, organising and controlling how we use our mental resources to reach our goals. Higher-level abilities such as reasoning and problem-solving help us reflect and make deliberate decisions. Sitting above all other levels, Metacognition monitors and regulates

the entire cognitive chain, while Motor/Response Processes represent the final stage at which these cognitive operations are translated into observable behaviour.

The figure also shows examples of digital interaction that can negatively affect that specific process. For instance, notifications can grab our attention, applications can store information for us instead of our memory, and AI systems can lead us to trust their answers too much, sometimes at the expense of our own critical thinking.

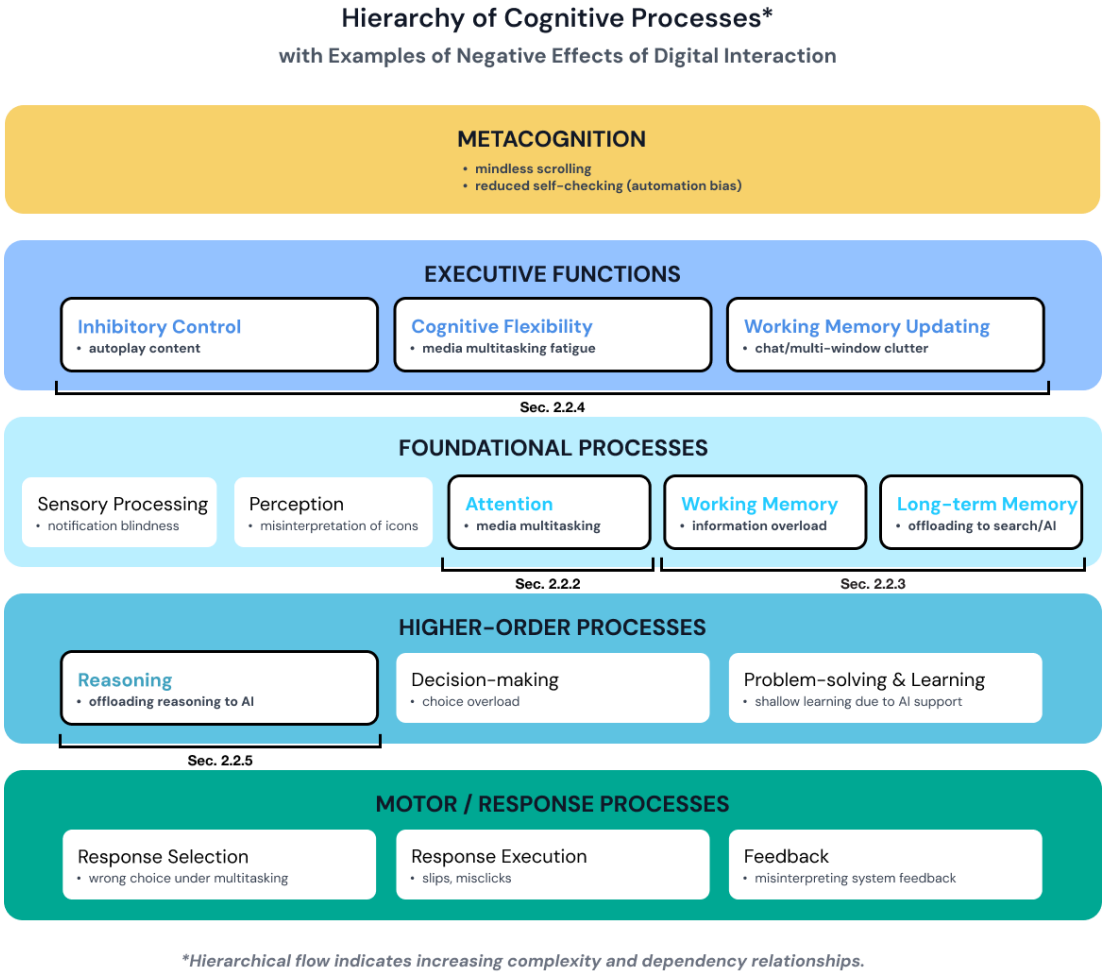


Figure 2.1: A hierarchical framework of cognitive processes. It is synthesised from cognitive psychology literature (Anderson, 2015; Goldstein, 2019; Wickens et al., 2013), showing examples of how digital interaction can negatively affect each process. Section references indicate the cognitive domains examined in this thesis.

The focus in this chapter is on four domains where research is most developed, attention, memory, executive functions, and reasoning. The framework serves as a map to guide the next sections (2.2.2–2.2.6), each of which examines how digital technology influences these processes, drawing on findings from psychology, neuroscience, and human–computer interaction. This analysis lays the foundation for Research Question 1 (RQ1): which features of digital technologies can harm our thinking abilities, whether in

the moment, with repeated use, or over time? While these four domains are central, other processes such as perception, decision-making, problem-solving, and response processes remain part of the broader picture and are also potentially affected by digital technologies, which requires further research.

2.2.1 Literature Search and Paper Selection

This section draws on a broad review of literature across databases including Google Scholar, ACM Digital Library, PubMed, PsycINFO, Scopus, and IEEE Xplore. Two types of search terms were used: broader terms such as "cognitive effects of digital media use" and "digital technology and cognition," and more specific terms combining cognitive processes with digital contexts, such as "attention and digital technology," "memory and digital media," and "reasoning and HCI." Boolean operators were used to combine and refine these terms. Reference lists of identified papers were additionally screened for relevant work. The search was primarily focused on the past twenty years and included empirical studies, reviews, and conceptual contributions involving adult populations. From this broader pool of over 300 papers, 59 papers were selected as key studies across the four cognitive domains covered in this chapter: 21 on attention, 17 on memory, 11 on executive functions, and 10 on reasoning and critical thinking. These were selected on the basis of methodological influence, citation impact, and direct relevance to RQ1. They are not the only papers informing this section, but these 59 papers form the empirical and conceptual core of the review in each domain.

The figures accompanying each subsection reflect the distribution of themes, methods, populations, and solution types across the reviewed studies in each domain and are intended as a qualitative characterisation of the literature rather than statistically representative analyses.

2.2.2 Attention

Attention is a fundamental but limited cognitive resource. Early models in psychology conceptualised attention as a selective filter (Broadbent, 1958). Later Posner and Petersen (1990) identified three interacting attentional networks: alerting, orienting, and executive control, showing that attention spans vigilance, selection, and top-down regulation. Kahneman (2003) further distinguished between System 1, which is fast and automatic, and System 2, which is slower and requires deliberate effort. This distinction is particularly relevant in digital contexts, where interface features such as notifications and infinite scroll tend to engage System 1 while depleting the resources needed for System 2. Cognitive Load Theory adds another dimension, distinguishing between intrinsic load

(task complexity), extraneous load (poor interface design, irrelevant information), and germane load (productive cognitive effort that supports learning). Digital systems frequently introduce unnecessary extraneous load, capturing attention with irrelevant content and reducing capacity for meaningful engagement (Sweller, 1988; Sweller et al., 1998).

2.2.2.1 Overview of Key Studies on Attention in Digital Contexts

Of the 59 key studies, 21 focus on attention and are summarised in Table 2.1 and Figure 2.2. Several introduced methodological innovations that continue to shape the field, including interruption cost metrics (Bailey & Iqbal, 2008), the *Media Multitasking Index* (Ophir et al., 2009), and naturalistic logging of attentional switching (Yeykelis et al., 2014). Others have been widely cited in debates about how digital media affect attention (e.g., Rosen et al., 2013 on classroom multitasking; Ward et al., 2017 on device presence). A smaller subset extends beyond laboratory tasks to address developmental, lifespan, or policy contexts (e.g., Baumgartner et al., 2025; Small et al., 2020). Together, they represent the range of topics, approaches, and methods in the attention literature, though the broader literature is also drawn upon throughout this section.

Methods and measures. Laboratory experiments dominate, from interruption timing (Adamczyk & Bailey, 2004; Cutrell et al., 2001) to media multitasking tasks (Cain & Mitroff, 2011; Ophir et al., 2009). Observational methods add ecological validity, whether in classrooms (Rosen et al., 2013) or everyday digital use (Yeykelis et al., 2014). Survey-based approaches extend the scope to population-level associations (Fisher et al., 2023; Misra & Stokols, 2012). Neurocognitive methods reveal attentional lapses and anticipatory processes (Madore et al., 2020; Zhang et al., 2025). Reviews consolidate this evidence, providing broader syntheses (Baumgartner et al., 2025; Small et al., 2020; Uncapher & Wagner, 2018).

Participant populations. The majority of experiments rely on university students (e.g., Chiossi et al., 2023; Ophir et al., 2009; Ward et al., 2017). Broader populations are represented in workplace surveys (Misra & Stokols, 2012), panel studies (Fisher et al., 2023), and naturalistic logging (Yeykelis et al., 2014). Reviews expand coverage to children (Baumgartner et al., 2025) and across the lifespan (Small et al., 2020), though older adults remain underrepresented.

Historical context. Attention research began with interruption studies in technology-rich workplaces (Czerwinski et al., 2004), before shifting to multitasking studies and later to ecological and neurocognitive methods. Recent work reflects platform-specific concerns

(Chiossi et al., 2023 on short-form video) and lifespan perspectives (Baumgartner et al., 2025). Despite methodological variety, the literature remains constrained by demographic narrowness, limiting generalisability.

Taken together, this body of work shows that attention in digital contexts is fragmented, resource-limited, and highly sensitive to contextual cues. The following subsections mainly draw on these 21 studies while also referencing the broader literature where relevant.

2.2.2.2 Sustained Attention

Sustained attention is the most heavily investigated form, addressed in the majority of the reviewed studies. Early vigilance studies showed that people struggle to maintain focus over time. Mackworth's Clock Test (1948) found that when observers watched for rare signals, their accuracy steadily declined, a pattern later called the "vigilance decrement" (Parasuraman, 1979). Robertson's *Sustained Attention to Response Task (SART)* extended this work, showing that lapses reflect failures of executive control. These classic findings highlight that sustained attention is naturally fragile, a weakness made even more apparent in digital settings where distractions are frequent and deliberately designed to capture attention. The dominant finding from key literature is that digital technologies fragment sustained concentration, leading to lapses and reduced task performance. Rosen, et al. (2013) showed that classroom interruptions via Facebook and texting disrupted student focus, fragmenting study sessions. Bailey and Iqbal (2008) quantified the costs of interruptions, showing how even short task-switches delay resumption and impair sustained engagement. Ward et al. (2017) demonstrated the "brain drain" effect, where the mere presence of a smartphone reduced available attentional resources, echoing theories of cognitive offloading (Risko & Gilbert, 2016). Misra and Stokols (2012) linked perceived information overload to attentional disruption and stress, while Yeykelis et al. (2014) observed that adults switched tasks on average every 19 seconds, indicating fragmented engagement and challenges for sustained focus. Real-world smartphone logging also supports these patterns: Mehrotra et al. (2016) showed that frequent, poorly timed notifications disrupted ongoing tasks and eroded sustained engagement.

From a cognitive perspective, these findings align with theories of cognitive load and executive control depletion. For example, environments where primary tasks are repeatedly interrupted by push notifications or background alerts create extraneous cognitive load, continually depleting attentional resources. Neuroscience evidence reinforces this view: Small et al. (2020) argue that heavy technology use contributes to

Table 2.1: Summary of key studies on digital technologies and attention (1/2)

Reference	Context	Method Type	Population	Attention Processes Affected	Solution Suggestions	Role in the Literature
Cutrell, Czerwinski, & Horvitz (2001)	Notifications & Interruptions	Empirical – Experimental	Adults	Sustained: impaired Divided: impaired	**General/Design –** Suggested notification filtering/timing; abstract principle	Classic HCI study on notification costs
Adamczyk & Bailey (2004)	Notifications & Interruptions	Empirical – Experimental	Adults	Sustained: impaired	**General/Design –** Breakpoint principle for interruptions; no system or interface built	Seminal HCI interruption timing study
Czerwinski, Horvitz, & Wilhite (2004)	Notifications & Interruptions	Empirical – Observational	Adults	Sustained: impaired	**General/Design –** Proposed interruption management systems; no validated design	Seminal workplace evidence on interruptions & resumption failures
Bailey & Iqbal (2008)	Notifications & Interruptions	Empirical – Experimental	Adults	Sustained: impaired	**General/Design –** Developed interruption cost metrics; theoretical contribution	Landmark quantification of interruption costs
Ophir, Nass, & Wagner (2009)	Media multitasking	Empirical – Experimental	Young adults	Selective: impaired Divided: impaired	**None –** Identified multitasking deficits, but offered no solutions	Foundational media multitasking study
Cain & Mitroff (2011)	Media multitasking	Empirical – Experimental	Young adults	Selective: impaired	**None –** Replicated filtering deficits, but no interventions suggested	Replication/extension of media multitasking deficits
Misra & Stokols (2012)	Notifications & Interruptions	Empirical – Survey	Adults	Sustained: impaired	**General/Self-control –** Recommended workload management and boundary-setting; lacks implementation detail	Influential overload framework
Rosen, Carrier, & Cheever (2013)	Media multitasking	Empirical – Observational	Adolescents, Young adults	Sustained: impaired Selective: impaired	**Concrete/Self-control –** Introduced "tech breaks" and classroom phone restrictions	Seminal classroom study on digital multitasking
Benedetto et al. (2013)	Digital reading	Empirical – Experimental	Adults	Sustained: impaired	**Concrete/Design –** Hardware solution; not generalisable UX guidance	Landmark linking display type to attentional strain
Yeykelis, Cummings, & Reeves (2014)	Media multitasking	Empirical – Observational	Adults	Sustained: impaired Switching: impaired (compulsive)	**General/Design –** Implied that interfaces should reduce compulsive switching; vague, no concrete mechanisms	Naturalistic evidence of compulsive media switching
Ward et al. (2017)	Device presence	Empirical – Experimental	Young adults	Sustained: impaired	**Concrete/Self-control –** Suggested removing phones from sight	Seminal "brain drain" evidence

Table 2.1: Summary of key studies on digital technologies and attention (2/2)

Reference	Context	Method Type	Population	Attention Processes Affected	Solution Suggestions	Role in the Literature
Uncapher & Wagner (2018)	Media multitasking	Review	Young adults, Adults	Sustained: impaired Selective: impaired Divided: impaired	**General/Design –** Called for better measures; broad and policy-like	Authoritative synthesis/review
Madore & Wagner (2019)	Media multitasking	Review	Young adults	Sustained: impaired	**General/Self-control –** Advocated attention regulation and cognitive training	Conceptual contribution
Madore et al. (2020)	Media multitasking	Empirical – Neurocognitive	Young adults	Sustained: impaired	**Concrete/Self-control –** Suggested structured breaks, limiting multitasking, and focus training	Landmark neurocognitive evidence
Small et al. (2020)	General digital media	Review	General population	Sustained: impaired Selective: impaired Divided: impaired	**General/Self-control –** Promoted digital hygiene (mindful use, screen-time limits)	Integrative neuroscience review
Mehrotra et al. (2016)	Notifications & Interruptions	Empirical – Observational	Adults	Sustained: impaired	**Concrete/Design –** Proposed context-aware notification management; deployment-oriented concept, but not UX-tested	Authoritative real-world evidence
Jian (2022)	Digital reading	Empirical – Experimental	Young adults	Sustained: impaired	**General/Self-control –** Encouraged re-reading/metacognitive supports for digital readers; not systemic support	Eye-tracking evidence of shallow digital reading
Chiossi et al. (2023)	Media multitasking	Empirical – Experimental	Young adults	Sustained: impaired Prospective: impaired	**General/Design –** Suggested redesign of short-form apps with structured pauses; conceptual suggestion	Emerging media-format evidence
Fisher, Hopp, Chen, & Weber (2023)	Media multitasking	Empirical – Survey	Adults	Sustained: impaired Selective: impaired	**General/Design –** Recommended tailoring interventions to media profiles; methodological, not design-focused	Methodological innovation
Baumgartner et al. (2025)	Device use & Screen Time	Review	Children, Young adults	Sustained: impaired Selective: impaired Divided: impaired	**Policy/Education –** Advocated guided media use and parental regulation; applies mainly to youth/parental mediation	Authoritative synthesis
Zhang et al. (2025)	Media multitasking	Empirical – Neurocognitive	Young adults	Anticipatory: enhanced	**N/A –** Reported positive attentional effects	First ERP support for "trained attention hypothesis"

attention problems through repetitive shifting and multitasking, which impair executive control. They also note that constant device use reduces opportunities for restorative offline rest, a state thought to be important for attentional recovery (Greicius et al., 2003). Together, these mechanisms suggest that digital environments not only fragment sustained attention in the moment but may also undermine its recovery over time.

However, not all perspectives are deficit-oriented. Madore and Wagner (2019) reframed lapses of sustained attention as potential targets for training, proposing regulation strategies to strengthen attentional stability. This perspective is relatively rare but valuable, shifting the debate from inevitability of decline to the possibility of resilience.

2.2.2.3 Selective Attention

Selective attention, the ability to focus on relevant information while ignoring distractions, has been a central theme in multitasking research. The "cocktail party effect" (Cherry, 1953) illustrates selective filtering in auditory contexts, while theories such as biased competition (Desimone & Duncan, 1995) and load theory (Lavie, 2005) provide foundational models of how this process works. Biased competition theory suggests that different stimuli compete for the brain's limited processing resources, and attention works by favouring what is most relevant. Load theory explains when distractions are more likely: under high perceptual load (e.g., searching for a target letter among many similar letters), distractor processing is reduced, while under low perceptual load or high working memory load, distraction is more likely (e.g., remembering a digit sequence while doing another task). It is important to note that in Load Theory "visually demanding" refers to necessary main task complexity that absorbs capacity and protects against distraction. By contrast, in Cognitive Load Theory (Sweller et al., 1998) *extraneous load* refers to unnecessary design-induced complexity that impairs attention and learning. In digital environments, these vulnerabilities are amplified, as competing signals are constant and often deliberately engineered to capture attention. For instance, notification banners that appear during a reading task illustrate low perceptual load conditions where distractors readily intrude, while multitasking across multiple tabs or windows imposes high working memory load that weakens distractor resistance.

Empirical evidence from selected key literature supports these theoretical accounts. Ophir et al. (2009) study showed that heavy media multitaskers exhibited impaired filtering and weaker voluntary control. Cain and Mitroff (2011) replicated these deficits in a visual search paradigm. Earlier HCI research already demonstrated how notification

intrusions disrupt filtering efficiency: Cutrell et al. (2001) and Czerwinski et al. (2004) showed that interruptions fragment attention and prevent resumption of the focal task, while Bailey and Iqbal (2008) quantified the costs of switching as measurable losses in filtering and task control. Fisher et al. (2023) showed that multitasking is not an isolated behaviour but a network of interlinked habits: individuals who multitask in one context (e.g., texting while studying) are more likely to multitask in others, and those with denser multitasking networks report greater selective attention difficulties. Survey-based evidence also links filtering difficulties to perceptions of overload: Misra and Stokols (2012) found that individuals reporting higher information overload were more vulnerable to distraction in everyday contexts. Uncapher and Wagner (2018) reinforced this from a neuroscience perspective, reviewing evidence that heavy media multitaskers show reduced efficiency in brain networks responsible for filtering distractions.

Together, these studies highlight selective attention as particularly vulnerable in digital contexts, where multiple signals constantly compete for cognitive priority. Yet interventions remain limited: most focus on blocking distractions (e.g., ad blockers, app timers) rather than supporting attentional filtering itself. From a design standpoint, this marks a critical blind spot as HCI has not yet systematically explored how user interfaces might actively strengthen selective attention rather than merely suppress stimuli.

2.2.2.4 Divided and Switching Attention

Divided and *switching attention* represent two further dimensions of attentional control that are especially relevant in digital contexts. In cognitive psychology, divided attention refers to attempting to allocate resources across tasks simultaneously, yet performance reliably deteriorates when tasks draw on overlapping resources (Pashler, 1994). Switching attention, by contrast, refers to alternating between tasks and comes with measurable switch costs, characterised by slower responses and increased errors each time cognitive control is reconfigured (Monsell, 2003). These mechanisms differ from selective attention, which concerns filtering irrelevant inputs: while selective failures arise from distraction, divided and switching attention are constrained by the structural limits of resource allocation and reconfiguration. In digital environments, most behaviours labelled as "multitasking" exceed the limits of divided attention and instead take the form of frequent switching, with associated cumulative performance costs.

Early HCI research demonstrated these costs in interruption contexts. Czerwinski et al. (2004) showed that workplace interruptions often prevented users from resuming their original task, while Adamczyk and Bailey (2004) found that disruptions were least costly

when delivered at natural breakpoints. These findings established the measurable burdens of task switching well before modern media multitasking studies extended them to broader digital contexts.

Empirical studies confirm that digital contexts amplify the limitations of divided and switching attention. Classroom experiments demonstrate that interruptions from messaging or social media degrade performance and slow recovery once attention has been diverted (Rosen et al., 2013). Naturalistic research highlights the rhythm of fragmentation: users were found to switch tasks on a computer roughly every 19 seconds, illustrating not only disruption of sustained engagement (as discussed in 2.2.2.2) but also the habitual alternation patterns that impose recurring switch costs (Yeykelis et al., 2014). Neuroscience reviews further conclude that media multitasking compromises executive attentional control, undermining both divided focus and switching efficiency (Uncapher & Wagner, 2018). Lifespan-oriented syntheses extend this concern, showing that children and adolescents are particularly vulnerable to multitasking-induced performance costs when required to divide or switch attention across competing tasks (Baumgartner et al., 2025).

From a cognitive perspective, divided and switching attention are structurally limited processes that become chronically overloaded in digital environments. The normalisation of fragmented attention raises concerns about long-term consequences, as repeated switching is associated with cumulative inefficiencies in executive control and reduced capacity to maintain task goals. A minority perspective suggests potential adaptive outcomes: Zhang et al. (2025) found that heavy multitaskers showed enhanced anticipatory brain signals, indicating that habitual switching may under certain conditions strengthen preparatory mechanisms. Yet this evidence remains isolated, without clear implications for design.

The literature converges on the view that divided and switching attention function as liabilities in digital environments, associated with fragmentation, inefficiency, and reduced cognitive control. Existing interventions largely focus on user self-regulation, such as limiting multitasking or disabling notifications, while systematic exploration of interface design strategies to scaffold attentional management remains limited.

2.2.2.5 Emerging Dimensions: Anticipatory Attention and Attention in Prospective Memory

Alongside sustained, selective, and divided or switching attention, researchers have begun to highlight newer forms of attentional control that are increasingly relevant in

digital contexts. Two of these are *anticipatory attention*, which concerns preparing for upcoming information or demands (Zhang et al., 2025), and attentional processes supporting *prospective memory*, which involve monitoring for the appropriate moment to execute a future intention (McDaniel & Einstein, 2007).

Anticipatory attention refers to how people ready themselves for what is likely to happen next. For example, glancing at a notification icon may prime a user to expect a message before it arrives. Early findings suggest that heavy digital multitasking may sometimes sharpen this form of preparation. Zhang et al. (2025) reported that frequent media multitaskers showed stronger anticipatory brain signals, raising the possibility that repeated switching could train a kind of "readiness" for change. At the same time, it is unclear whether this is beneficial or whether it simply reflects heightened reactivity to external cues, which can also increase distraction.

Attentional processes supporting prospective memory relate to the ability to remember to carry out intentions in the future. Everyday digital life constantly tests this capacity: replying to an email after finishing a document, returning to a tab after being pulled into a notification, or remembering to submit a form later in the day. Chiossi et al. (2023) found that short-form video use, which combines rapid context switching with highly engaging content, significantly impaired prospective memory, making it harder to resume delayed intentions. This suggests that digital environments not only fragment ongoing focus but also make it easier to lose track of what one *meant* to do.

These emerging dimensions extend the picture of how attention is shaped by technology. Anticipatory attention points to a possible adaptive side of multitasking, training quick readiness for change while prospective memory processes highlight the risks of losing future goals amid constant interruptions. For HCI, both raise important design challenges: how to support users in holding onto deferred intentions, and how to avoid overstimulating anticipatory readiness in ways that increase distraction.

2.2.2.6 Critical Synthesis: Solutions and Design Gaps

A synthesis of the 21 key studies reveals clear patterns in both the focus of research and the orientation of proposed interventions. As Figure 2.2 shows, sustained attention is the most extensively examined process, addressed in 14 of the 21 reviewed studies. This emphasis reflects both its tractability in experimental settings and its centrality to educational and workplace performance. Selective and divided attention are also recurring themes, though less consistently targeted, while emerging dimensions such as anticipatory (Zhang et al., 2025) and prospective attention (Chiossi et al., 2023) have

only recently entered the literature. This distribution indicates a tendency to equate "digital attention effects" primarily with the erosion of continuous focus, leaving other mechanisms comparatively underexplored.

The solution space across these studies shows a striking imbalance. Most proposals centre on behavioural self-regulation**,** including scheduled "tech breaks" and classroom phone restrictions (Rosen et al., 2013), workload management and boundary setting (Misra & Stokols, 2012), removing phones from sight (Ward et al., 2017), structured breaks and focus training (Madore et al., 2020), or general digital hygiene practices such as mindful use and screen-time limits (Small et al., 2020). Conceptual reviews echo these orientations, emphasising regulation strategies (Madore & Wagner, 2019) or broad guidelines (Uncapher & Wagner, 2018).

By contrast, concrete design-oriented contributions are rare. Some HCI interruption studies offered principles such as breakpoint timing (Adamczyk & Bailey, 2004) or notification filtering and scheduling (Cutrell et al., 2001; Mehrotra et al., 2016), but these remained proof-of-concept or conceptual proposals rather than tested UX interventions. Hardware solutions such as E-ink displays to reduce visual fatigue (Benedetto et al., 2013) represent one of the few directly applicable design responses, though tied to a narrow medium. Later contributions (e.g., Chiossi et al., 2023; Fisher et al., 2023) imply system redesigns or tailored interventions, yet remain at a theoretical or methodological level.

Positive or adaptive outcomes, such as enhanced anticipatory readiness among heavy multitaskers (Zhang et al., 2025), are rare and insufficiently theorised. What is missing is a systematic exploration of how interface structures might support attentional stability and resilience, shifting responsibility away from individuals and towards design strategies that align with cognitive constraints. This gap motivates the direction of the present thesis. Accordingly, this body of work establishes attentional disruption as a primary locus of digital cognitive cost, identifying notifications, multitasking affordances, and continuous media streams as key design features that impair focus. These insights directly address RQ1, clarifying which interaction patterns most negatively affect attentional functioning across short-term and repeated use.

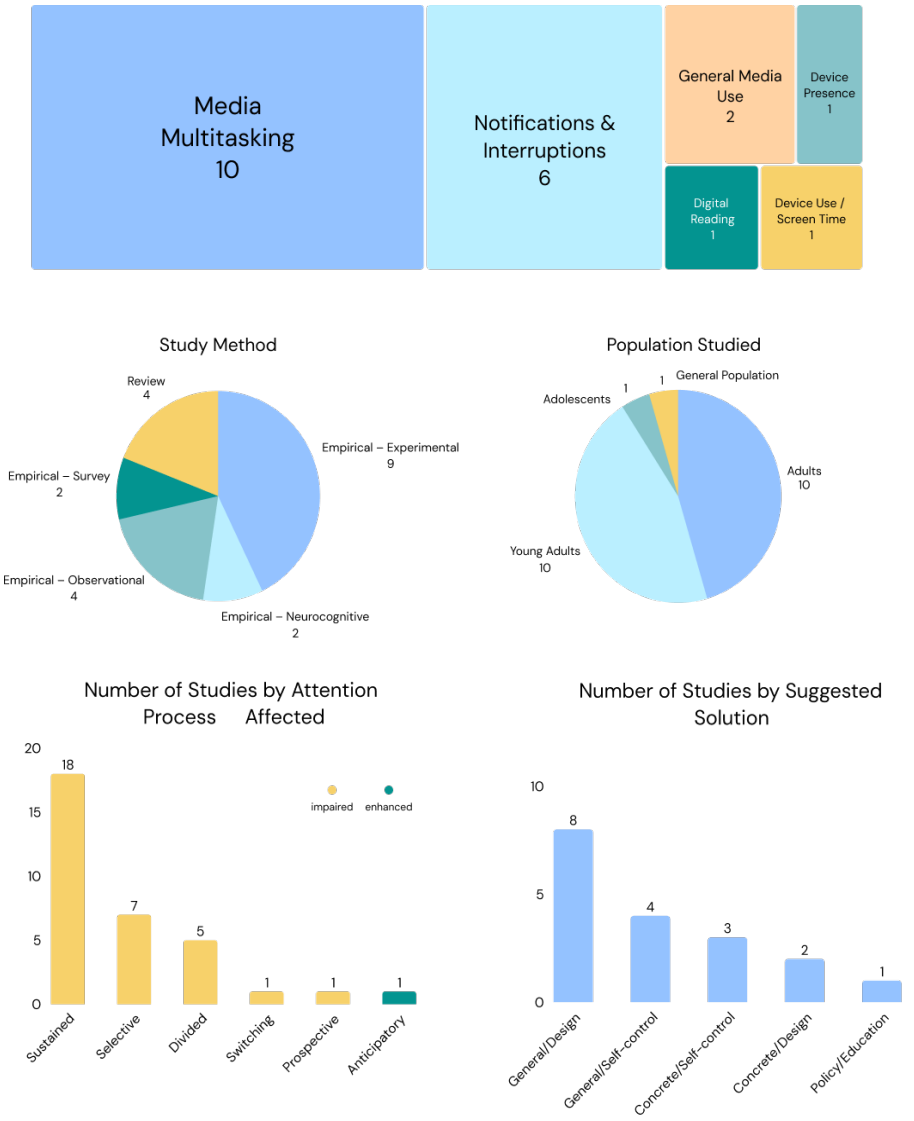


Figure 2.2: Overview of key literature on digital technologies and their impact on attention.

2.2.3 Memory

Memory is a fundamental but limited cognitive function enabling humans to encode, store, and retrieve information across time. Working memory, as refined by Baddeley and Hitch (1974), holds and manipulates information over short periods, with capacity limits of around four items (Cowan, 2010), making it especially vulnerable to overload in digital environments. Within long-term memory, episodic memory supports recall of events and experiences, while prospective memory the ability to remember to execute future intentions, is particularly fragile in digital contexts where interruptions and divided attention are frequent (Einstein & McDaniel, 1990). Schacter's (2022) framework of the "seven sins of memory" further highlights how digital interaction may amplify natural memory vulnerabilities, accelerating transience through constant notifications, absent-

mindedness through habitual device checking, and misattribution through algorithmic cues.

2.2.3.1 Overview of Key Studies on Memory in Digital Contexts

This section draws on 17 of the 59 key studies on memory, summarised in Table 2.2 and Figure 2.3. These include foundational field studies of workplace fragmentation (Czerwinski et al., 2004; González & Mark, 2004), experimental methods examining such as media multitasking (Ophir et al., 2009), cognitive offloading (Sparrow et al., 2011), and device presence (Ward et al., 2017), as well as neurocognitive evidence (Froud et al., 2024; Madore et al., 2020), Some have been widely cited, including Sparrow et al.'s (2011) "Google effect" and Ward et al.'s (2017) "brain drain," while others introduced influential approaches (Barasch et al., 2017; Henkel, 2014) or provided rare longitudinal perspectives (Xavier et al., 2014). Authoritative reviews consolidate these findings (Madore & Wagner, 2019; Risko & Gilbert, 2016; Schacter, 2022; Small et al., 2020; Uncapher & Wagner, 2018), while studies of everyday practices such as photo-taking (Barasch et al., 2017; Henkel, 2014) and social media multitasking (Chiossi et al., 2023; Frein et al., 2013) show how digital behaviours reshape episodic, prospective, and semantic memory. Several of these papers also appear in the attention literature (e.g., Madore et al., 2020; Ophir et al., 2009; Small et al., 2020), reflecting the close relationship between attention and memory in digital contexts.

Methods and measures. Laboratory experiments dominate the field, from the demonstration of the "Google effect" (Sparrow et al., 2011), to the "brain drain" of device presence (Ward et al., 2017). Memory studies also include the photo-taking impairment effect (Barasch et al., 2017; Henkel, 2014) and multitasking measures (Ophir et al., 2009), while neurocognitive work links attention lapses to episodic failures (Madore et al., 2020). Field methods add ecological validity through workplace logging (Czerwinski et al., 2004; González & Mark, 2004) and observational studies of media switching (Yeykelis et al., 2014). Longitudinal surveys (Xavier et al., 2014) and integrative reviews (Risko & Gilbert, 2016; Schacter, 2022; Small et al., 2020) extend scope across contexts and populations.

Participant populations. As with attention research, reliance on university student samples remains a limitation, with most experiments conducted on young adults (e.g., Henkel, 2014; Ward et al., 2017). Exceptions include older adult populations in longitudinal surveys (Xavier et al., 2014) and lifespan-oriented reviews (Small et al.,

2020). Prospective and autobiographical memory remain underexplored relative to episodic and working memory.

Historical context. The trajectory of research on digital memory mirrors that of attention. Early work was concentrated in experimental approaches with student populations, while broader ecological and lifespan perspectives emerged later. Recently, platform-specific studies (Chiossi et al., 2023 on short-form video; Froud et al., 2024 on digital reading) highlight distinct cognitive burdens across media. Design-oriented interventions remain scarce, leaving responsibility with users rather than systems.

Overall, memory research has shifted from demonstrations of impairment toward mapping trade-offs between internal recall and external offloading. The recurrence of several studies across both memory and attention reinforces this thesis's argument that these domains must be treated together when analysing cognitive costs of interaction.

2.2.3.2 Working Memory

Working memory, central for temporarily holding and manipulating information, emerges as one of the most consistently impaired processes in digital environments. Across six key studies, no evidence was found of enhancement; instead, multitasking, device presence, and interruptive media repeatedly reduced working memory performance.

Media multitasking. Ophir et al. (2009) seminal experiment demonstrated that heavy media multitaskers showed reduced ability to filter irrelevant stimuli, resulting in weaker working memory updating. Yeykelis et al. (2014) extended this finding in a naturalistic setting using logging and eye- tracking, showing that users switched tasks every 19 seconds on average, fragmenting encoding and imposing high cognitive switching costs. Uncapher and Wagner's (2018) systematic review consolidated this body of evidence, emphasising that heavy multitaskers consistently demonstrate lower working memory capacity. Madore et al. (2020) combined behavioural tasks with EEG measures to show that attentional lapses during multitasking predicted failures in working memory maintenance.

Interruptions and device presence. Field-based studies confirm that disruptions in digital settings degrade working memory. Gonzalez and Mark (2004) observed that fragmented work patterns, with tasks rarely lasting beyond three minutes, left individuals unable to maintain continuity across projects. Ward et al. (2017) offered a striking experimental demonstration: even when not actively used, the mere presence of a smartphone reduced participants' working memory scores, an effect strongest among those most dependent on their devices.

Table 2.2: Summary of key studies on digital technologies and memory (1/2)

Reference	Context	Method Type	Population	Memory Processes Affected	Solution Suggestions	Role in the Literature
Gonzalez & Mark (2004)	Media multitasking	Empirical – Observational	Adults	Working: impaired Prospective: impaired	**General/Design** – Suggested workplace strategies to reduce fragmentation; conceptual	Classic field study on workplace fragmentation
Czerwinski, Horvitz, & Wilhite (2004)	Notifications & Interruptions	Empirical – Observational	Adults	Prospective: impaired	**General/Design** – Proposed interruption management; not tested in system design.	Seminal workplace evidence of prospective memory failures
Ophir, Nass, & Wagner (2009)	Media multitasking	Empirical – Experimental	Young adults	Working: impaired	**None** – No solutions proposed	Foundational media multitasking study
Sparrow, Liu, & Wegner (2011)	Cognitive offloading (Internet search)	Empirical – Experimental	Adults	Episodic: impaired Transactive: enhanced	**None** – Descriptive study, no interventions	Landmark "Google effect" paper
Frein et al. (2013)	Media multitasking	Empirical – Survey	Adults	Episodic: impaired	**General/Self-control** – Suggested limiting Facebook use	First to tie Facebook use to episodic recall disruption
Henkel (2014)	Cognitive offloading (Photo-taking)	Empirical – Experimental	Young adults	Visual episodic: impaired	**General/Self-control** – Suggested active/intentional photo-taking	Defined the "photo-taking impairment effect"
Yeykelis, Cummings, & Reeves (2014)	Media multitasking	Empirical – Observational	Adults	Working: impaired Episodic: impaired	**General/Design** – Implied design changes to reduce switching; no specific interventions	Naturalistic evidence of compulsive media switching
Xavier et al. (2014)	Device use / Screen time	Empirical – Survey	Older adults	Episodic: enhanced	**General/Design** – Suggested structured digital engagement; not a validated program.	Rare evidence of positive effects on ageing memory
Risko & Gilbert (2016)	Cognitive offloading	Review	General population	Episodic: impaired Prospective: enhanced Transactive: enhanced	**General/Design** – Proposed better reminder/offloading tools; conceptual	Influential review; established "cognitive offloading" as a formal concept

Table 2.2: Summary of key studies on digital technologies and memory (2/2)

Reference	Context	Method Type	Population	Memory Systems Affected	Solution Suggestions	Role in the Literature
Barasch et al. (2017)	Cognitive offloading (Photo-taking)	Empirical – Experimental	Adults	Visual episodic: enhanced Auditory episodic: impaired	**General/Self-control** – Suggested intentional capture practices; problem: vague, no specific UX design	Nuanced extension of the photo-taking effect; framed as cognitive offloading trade-off
Uncapher & Wagner (2018)	Media multitasking	Review	Young adults, Adult	Working: impaired Episodic: impaired	**General/Design** – Called for better multitasking measures, guidelines; problem: no concrete interventions	Authoritative synthesis/review
Ward et al. (2017)	Device presence	Empirical – Experimental	Young adults, Adult	Working: impaired	**Concrete/Self-control** – Suggested removing phones from sight; problem: simple but only behavioural	Seminal "brain drain" evidence.
Madore et al. (2020)	Media multitasking	Empirical – Neurocognitive	Young adults	Episodic: enhanced	**Concrete/Self-control** – Suggested structured breaks and focus training; problem: individual-level, not integrated into design	Landmark neurocognitive evidence.
Small (2020)	General digital media	Review	General population	Working: impaired Episodic: enhanced	**General/Self-control** – Suggested digital hygiene (screen-time limits); problem: broad, no protocol	Integrative neuroscience review
Schachter (2022)	General digital media	Review	General population	Episodic: impaired Prospective: enhanced Transactive: enhanced	**None** – purely theoretical framing, not offering concrete or behavioural solutions	Theoretical anchor reframing classic memory theory in the digital age
Chiossi et al. (2023)	Media multitasking	Empirical – Experimental	Young adults	Prospective: impaired	**General/Design** – Suggested app redesign with pauses; problem: conceptual, no tested prototype	Emerging media-format evidence
Froud (2024)	Digital reading	Empirical – Neurocognitive	Adolescents	Episodic: impaired Semantic: impaired	**General/Design** – Implies hybrid print-digital strategies; problem: no specific interface solutions	First ERP evidence of weaker encoding under digital reading

These studies highlight working memory as particularly fragile in digital contexts. Multitasking affordances, constant interruptions, and ambient device presence converge to reduce the ability to hold and manipulate information over short time spans. This body of evidence positions working memory impairment as a core mechanism linking digital interaction to broader cognitive costs, and provides a foundation for identifying interaction patterns that undermine attentional stability and cognitive resilience.

2.2.3.3 Long-Term Memory

Long-term memory, encompassing episodic, prospective, semantic, and transactive processes, shows a more mixed pattern in digital contexts than working memory. While episodic memory is consistently vulnerable, prospective and transactive memory display both impairments and enhancements, depending on context and design features.

Episodic memory, the recollection of events and experiences, is the most frequently examined and most consistently impaired. Frein et al. (2013) found that heavy Facebook users performed worse on free recall tasks, suggesting reliance on externalised digital traces may weaken consolidation. Yeykelis et al. (2014) demonstrated that frequent media switching fragmented encoding and disrupted episodic retention. The "photo-taking impairment effect" (Henkel, 2014) further showed that photographing objects reduced subsequent recall, unless participants zoomed or focused deliberately while Barasch et al. (2017) showed that volitional photo-taking enhanced visual recall but impaired auditory recall. Most recently, Froud (2024) provided neurocognitive evidence that adolescents reading digital rather than print texts showed weaker episodic encoding.

Prospective memory, the ability to remember to carry out delayed intentions, also shows sensitivity to digital environments. Gonzalez and Mark (2004) and Czerwinski et al. (2004) observed that workplace fragmentation left many intentions unfulfilled, while Madore et al. (2020) linked attentional lapses during multitasking with failures of prospective recall. Chiossi et al. (2023) showed platform-specific effects: TikTok-style short-form videos impaired prospective memory more than interruptions from Twitter or YouTube. In contrast, Xavier et al. (2014) found that structured digital engagement may strengthen prospective memory in ageing populations.

Transactive memory allows people to remember who or what holds information rather than the information itself (Wegner, 1987). Digital media extends this mechanism to human–technology interactions. Sparrow et al.'s (2011) "Google effect" demonstrated that participants expecting online access recalled fewer facts themselves but more effectively remembered where to locate the information, a process formalised by Risko

and Gilbert (2016) as cognitive offloading. These studies indicate that digital contexts enhance transactive memory, but often at the expense of retaining information internally.

Evidence for *semantic memory* effects remains sparse. Froud (2024) found that adolescents reading digital texts encoded semantic content less effectively than those reading print, highlighting potential risks for conceptual learning.

Long-term memory shows a more varied pattern than working memory across processes. Episodic memory is predominantly impaired, prospective memory shows both risks and benefits depending on context, transactive memory is reliably enhanced but shifts recall externally, and semantic memory remains underexplored. These findings collectively suggest that digital environments do not simply weaken long-term memory but change how it works, shifting from remembering information to remembering where to find it, with direct implications for interaction design.

2.2.3.4 Critical Synthesis: Solutions and Design Gaps

Across the seventeen studies reviewed, a consistent pattern emerges: episodic memory is the most intensively investigated and the most frequently impaired. This reflects its methodological accessibility, recall and recognition tasks are straightforward to operationalise, and its centrality to educational and professional performance.

Working memory is also regularly examined, particularly in multitasking studies (e.g., Madore et al., 2020; Ophir et al., 2009), where diminished updating and filtering capacity are recurrent findings. In contrast, prospective and semantic memory appear only sporadically in the literature, despite their salience for everyday planning and conceptual understanding. Transactive memory, meanwhile, shows a different trajectory: digital reliance tends to strengthen memory for "where" information is stored but at the expense of remembering the content itself. Overall, the field has concentrated narrowly on episodic failures, leaving other aspects of memory underrepresented. Figure 2.3 illustrates these patterns, showing the distribution of memory processes examined, methods used, and solution types proposed across the 17 reviewed studies.

The solution space remains limited. Most proposals focus on behavioural strategies at the individual level: placing phones out of sight (Ward et al., 2017), managing multitasking habits (Madore et al., 2020) or adopting intentional photo-taking practices (Henkel, 2014). Notable exceptions include workplace structuring to reduce fragmentation (González & Mark, 2004) and suggestions for platform redesign to mitigate prospective

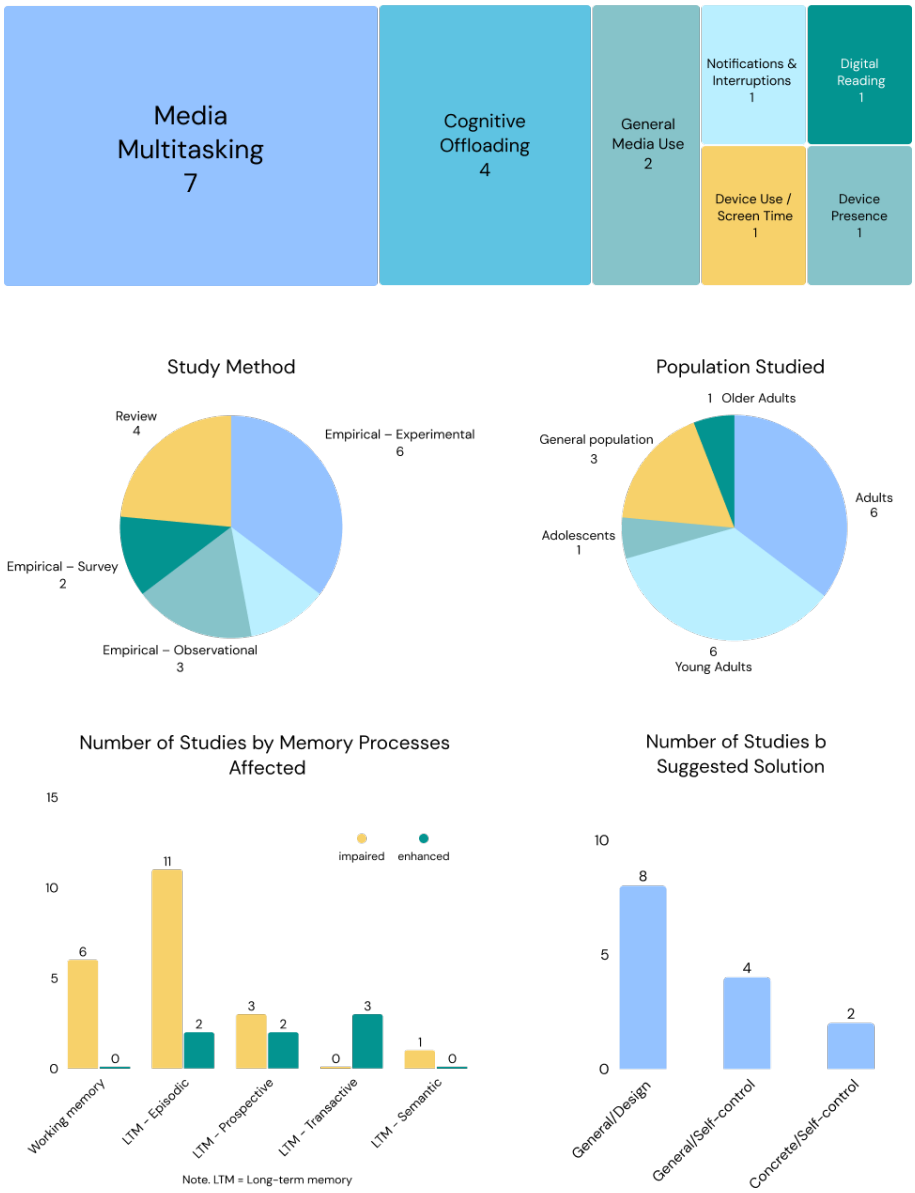


Figure 2.3: Overview of key literature on digital technologies and their impact on memory

memory failures (Chiossi et al., 2023), though these remain conceptual rather than empirically validated interventions.

Taken together, this body of work characterises memory in digital contexts as a system prone to fragmentation and externalisation, with relatively few pathways for constructive support. Positive outcomes such as older adults experiencing slower decline through structured digital use (Xavier et al., 2014) remain scattered findings rather than a cohesive research direction. What is notably absent is systematic inquiry into how interaction design itself could scaffold memory processes. Addressing this gap speaks directly to RQ1, by clarifying which recurring interaction patterns (multitasking, constant device

presence, and reliance on externalised traces) most consistently undermine memory performance in everyday contexts.

2.2.4 Executive Functions

Executive functions (EFs) refer to the higher-order cognitive processes that regulate thought and behaviour, which help individuals to plan, inhibit impulsive responses, adapt to novel circumstances, and coordinate complex tasks (Lezak, 1982; Luria, 1973). They are often described as supervisory control mechanisms that orchestrate attention, working memory, and other cognitive resources to support "goal-directed action" (Norman & Shallice, 1986). EFs should not be confused with metacognition, which concerns the awareness and evaluation of one's own cognitive processes (Flavell, 1979).

Miyake et al.'s (2000) "unity and diversity" model identifies three core components: *inhibitory control* (suppressing irrelevant or automatic responses), *cognitive flexibility* (switching between tasks or mental sets), and *working memory updating* (monitoring and revising information held in mind). Later work has added planning, reasoning, and monitoring as additional aspects of EFs (2013). While working memory was discussed in the memory section as a storage system, here it refers to how information is actively controlled and updated during task performance.

In digital contexts, these processes are persistently challenged: failures in inhibitory control result in impulsive device checking, impaired cognitive flexibility slows recovery from interruptions, and weakened monitoring diminishes capacity to plan and reason effectively.

2.2.4.1 Overview of Key Studies on Executive Functions in Digital Contexts

A subset of 11 studies among the 59 key studies (Table 2.3; Figure 2.4) provides the foundational evidence on EFs in digital contexts. As in the attention and memory sections, they either introduced influential experimental approaches that have since shaped much of the research in this area (e.g., Ophir et al., 2009; Ward et al., 2017), synthesised existing findings and provided comprehensive reviews (e.g., Davis, 2001; Madore & Wagner, 2019; Uncapher & Wagner, 2018), or extended the evidence by trialling new interventions or examining different participant groups (e.g., Cardoso-Leite et al., 2021; Throuvala et al., 2020). Several of the same papers appear across attention, memory, and executive function (e.g., Madore et al., 2020; Ophir et al., 2009; Ward et al., 2017). This overlap shows that digital effects do not fall into one domain but often cut across multiple cognitive systems. As the evidence shows, they are interdependent, executive control cannot be isolated from attention or working memory regulation.

Table 2.3: Summary of key studies on digital technologies and executive functions

Reference	Context	Method Type	Population	Executive Functions Affected	Solution Suggestions	Role in the Literature
Davis (2001)	Internet Use & Social Media	Review – Conceptual	General	Inhibitory control: impaired	**None** – conceptual framing only	Early cognitive–behavioural model of internet overuse
Ophir et al. (2009)	Media multitasking	Empirical – Experimental	Young adults	Inhibitory control: impaired Cognitive flexibility: impaired	**None proposed**	Foundational media multitasking study
Cain & Mitroff (2011)	Media multitasking	Empirical – Experimental	Young adults	Inhibitory control: impaired	**None proposed**	Extension of Ophir, reinforced EF deficit
Uncapher & Wagner (2017)	Media multitasking	Review – Systematic	Young adults, Adults	Inhibitory control: impaired Working memory: impaired Cognitive flexibility: impaired	**General/Design** – Called for better media-use guidelines	Benchmark in EF–media multitasking debate
Ward et al. (2017)	Device Presence & Distraction	Empirical – Experimental	Young adults, Adults	Inhibitory control: impaired Working memory: impaired	**Concrete/Self-control** –Suggested remove phones from sight	Seminal device presence evidence
Madore & Wagner (2019)	Media multitasking	Review – Conceptual	Young adults	Working memory: impaired Cognitive flexibility: impaired	**General/Self-control** – Proposed regulation strategies	Conceptual synthesis shifting EF debate
Du et al. (2019)	Internet Use & Social Media	Empirical – Survey	Adults	Inhibitory control: impaired	**General/Self-control** – Suggested strengthening self-regulation	Direct tie between EF lapses and social media overuse
Madore et al. (2020)	Media multitasking	Empirical – Neurocognitive	Young adults	Inhibitory control: impaired Working memory: impaired	**Concrete/Self-control** – Suggested structured breaks and focus training	Landmark evidence linking EF lapses to memory
Throuvala et al. (2020)	Device Presence & Distraction	Empirical – Experimental	Adolescents, Young adults	Inhibitory control: impaired	**Concrete/Self-control** – Proposed online training (tested)	Rare controlled intervention for EF in digital use
Freytag (2021)	Internet Use & Social Media	Empirical – Survey	Adults	Inhibitory control: impaired Cognitive flexibility: impaired	**General/Self-control** – Suggested boundaries around availability	Extended EF dysfunction to stress and connectivity
Cardoso-Leite et al. (2021)	Media multitasking / Gaming	Empirical – Survey + Cognitive tasks	Children (8–12)	Inhibitory control: impaired Working memory: mixed Cognitive flexibility: impaired	**General/Self-control** – Recommended balanced use	Important child evidence; mixed outcomes

Methods and measures. Controlled experiments have played an important role in showing how digital media shape executive control. Ophir et al.'s (2009) finding that heavy media multitaskers performed more poorly on tasks requiring inhibition and cognitive flexibility, was reinforced by Cain and Mitroff (2011). Ward et al. (2017) showed that the mere presence of a smartphone can impair working memory and inhibitory control. Through behavioural tasks with EEG, Madore et al. (2020) extended this evidence and linking attentional lapses during multitasking to failures in executive memory. Conceptual contributions have also been equally influential. Davis (2001) proposed distorted patterns of thinking can interfere with inhibitory control, while Uncapher and Wagner (2018) synthesised behavioural and neuroimaging findings to argue that media multitasking causes lasting negative effects on EFs.

Survey and intervention studies provides even more evidence about the effect on EFs. Du et al. (2019) found that impulsivity and habit strength predict disruptions in social media self-control. Freytag (2021) reported that constant connectivity was linked to reduced cognitive flexibility. Cardoso-Leite et al. (2021) showed that media multitasking impaired inhibition in children, although gaming appeared to support working memory in the same study.

Participant populations. Most EF research in digital contexts still relies on university students (Cain & Mitroff, 2011; Madore et al., 2020; Ophir et al., 2009), while adults have also been included in survey-based studies (Du et al., 2019; Freytag et al., 2021). Adolescents and children are represented in only a few interventions and mixed-method studies (Cardoso-Leite et al., 2021; Throuvala et al., 2020). In short, these 11 studies define the key evidence base for executive functions digital contexts. Inhibition control emerges as impaired in almost all of them, while working memory and flexibility are also negatively affected in several studies. The recurrence of some studies across multiple subsections reinforces that EFs cannot be studied in isolation but must be considered together with other core cognitive functions, especially attention and memory.

2.2.4.2 Critical Synthesis: Solutions and Design Gaps

Looking across these 11 studies, three patterns emerge. The most prominent is that inhibitory control is the function most often reported as impaired. The reviewed studies consistently report negative effects across different interaction contexts, including resisting phone distraction (Ward et al., 2017), controlling impulses in social media use (Du et al., 2019), and managing inputs when multitasking (Ophir et al., 2009). Working memory is similarly negatively affected in several studies, for example when users

multitask or when phones are nearby (Madore et al., 2020; Ward et al., 2017). However, there is also evidence that gaming can support children's working memory (Cardoso-Leite et al., 2021), suggesting that digital effects are not uniformly negative. Cognitive flexibility has been studied less than other functions, but task-switching experiments show that heavy media multitaskers experience greater switch costs, indicating slower cognitive flexibility (Ophir et al., 2009). Additional evidence shows that constant online connectedness is associated with reduced adaptability (Freytag et al., 2021).

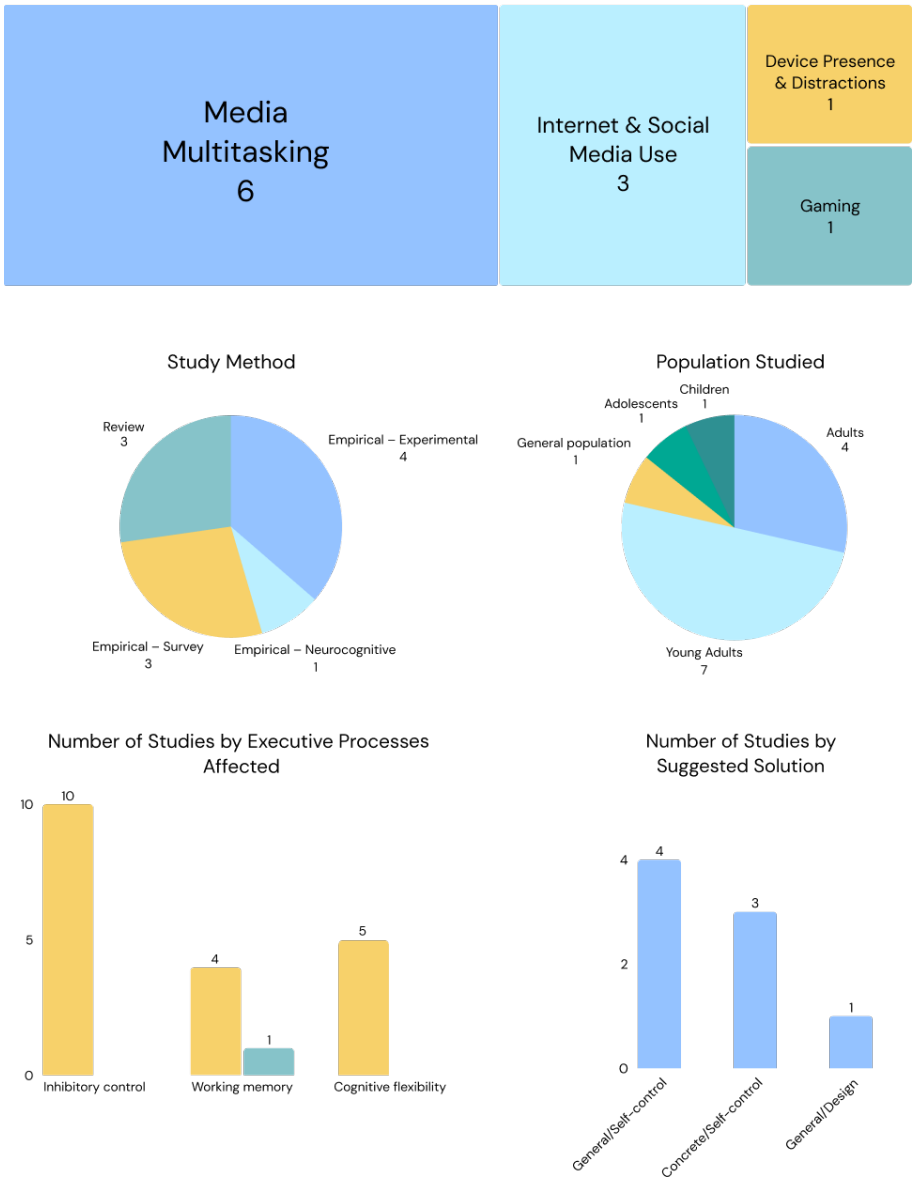


Figure 2.4: Overview of key literature on digital technologies and their impact on executive functions

As for solutions, most research still emphasises individual self-control rather than design modifications to support cognition. Removing phones out of sight (Ward et al.,

2017), scheduling structured breaks (Madore et al., 2020) and limiting online availability (Freytag et al., 2021) are among the strategies suggested. Reviews have also called for training or regulation (Davis, 2001; Madore & Wagner, 2019), but these proposals are rarely tested empirically. Only a small number of studies have trialled actual interventions, such as Throuvala et al. (2020), who tested an online training programme. This gap in design-oriented work links to RQ1, by showing that features such as multitasking affordances, phone presence, and constant connectivity are the main patterns that weaken executive control in everyday use.

2.2.5 Reasoning and Critical Thinking

2.2.5.1 Cognitive Psychology Foundations of Reasoning and Critical Thinking

Reasoning is a higher-order cognitive process that has been widely studied in cognitive psychology. Researchers have explored how people solve problems and make decisions, from solving logical puzzles to judging probabilities and weighing choices (Evans, 2002; Johnson-Laird, 1980; Kahneman & Tversky, 1972). There are different ways to reason: *deductive reasoning* means following strict logical rules to reach a certain conclusion (Johnson-Laird, 1980); *inductive reasoning* involves drawing general lessons from specific examples (Osherson et al., 1990); *analogical reasoning* is about spotting similarities and transferring ideas from one situation to another (Gentner, 1983); and *causal reasoning* tries to explain why things happen by linking causes and effects (Sloman, 2005; Waldmann & Hagmayer, 2005). Dual-process theory further distinguishes between System 1, which is fast and automatic, and System 2, which is slower and deliberate (Kahneman, 2012; Stanovich & West, 2000), a distinction particularly relevant in digital contexts where interface features tend to engage System 1 while depleting the resources needed for System 2.

Critical thinking (CT) is not a formal cognitive process and therefore does not appear in Figure 2.1. It has been developed more in education and philosophy, where it is described as the ability to evaluate arguments, weigh evidence, and check one's own thinking to reduce bias (Ennis, 1996; Facione, 1990; Halpern, 1998). It is included here because, from a cognitive standpoint, it represents an applied combination of reasoning, executive control, and metacognition. In general, it is about reflecting on whether conclusions are sound, resisting quick judgments, and actively monitoring one's own strategies (Kuhn, 1999; Stanovich & West, 2008). Different traditions highlight specific types of CT skills, such as *analytical* (breaking down arguments) (Facione, 1990), *evaluative* (judging credibility) (Facione, 1990), *reflective* (monitoring one's own

thinking) (Lipman, 2003), *creative* (generating alternatives) (Halpern, 1998), and *scientific* (testing hypotheses) (Halpern, 2014).

This foundation helps explain why reasoning and critical thinking are particularly vulnerable in digital environments, where AI tools and information overload increasingly shape how people think and make decisions.

2.2.5.2 Overview of Key Studies on Reasoning and Critical Thinking in Digital Contexts

Among the 59 key studies, 10 forms the basis for how digital technologies are seen to affect reasoning and CT (Table 2.4; Figure 2.5). These works were included because they either introduced highly influential ideas (e.g., Risko & Gilbert, 2016; Ward et al., 2017), provided comprehensive reviews (Shanmugasundaram & Tamilarasu, 2023; Zhai et al., 2024), or offered novel empirical evidence on AI-assisted reasoning and CT (e.g., Danry et al., 2023; Drosos et al., 2025; Kosmyna et al., 2025; H.-P. Lee et al., 2025). As in the memory and EF sections, several of the same papers overlap with earlier discussions (e.g., Risko & Gilbert, 2016; Ward et al., 2018), showing that reasoning and critical thinking cannot be treated in isolation but build on attention, memory, and executive control.

Methods and measures. Earlier contributions examined cognitive offloading and device presence (Risko & Gilbert, 2016; Ward et al., 2017), while the research has shifted towards AI systems in recent years which included neurocognitive evidence, reviews or surveys (Danry et al., 2023; Drosos et al., 2025; Kosmyna et al., 2025; H.-P. Lee et al., 2025; Oakley et al., 2025; Zhai et al., 2024).

Participant populations. Experimental studies were mostly included university students and young adults (Danry et al., 2023; Kosmyna et al., 2025; Ward et al., 2017). In broader reviews (e.g., Oakley et al., 2025; Zhai et al., 2024), findings were extended to other groups as well, although experimental studies beyond university student samples are few. Fabio and Suriano's (2023) observational study stands out as one to examine children.

These 10 studies illustrate what research on reasoning and CT in digital environments included and how it has shifted over time. Rapid rise of AI tools raised new questions about when digital tools compromise independent reasoning and when they can help foster reflection. These issues connect directly to the more detailed discussions of reasoning and CT in the following sections.

Table 2.4: Summary of key studies on digital technologies, reasoning and critical thinking

Reference	Context	Method Type	Population	Reasoning Processes Affected	Critical Thinking Skills Affected	Solution Suggestions	Role in the Literature
Risko & Gilbert (2016)	Cognitive offloading	Review	General population	Deductive: impaired Inductive: impaired Analogical: impaired	Reflective: mixed	**General/Design** – Highlighted need for design awareness	Authoritative review linking offloading to reasoning
Ward et al. (2018)	Device presence & distraction	Empirical – Experimental	Young adults, Adults	Deductive: impaired Inductive: impaired	Analytical: impaired	**Concrete/Self-control** – Remove phones from sight	Seminal device presence study; showed direct reasoning deficits
Fabio (2023)	Device presence & distraction	Empirical – Observational	Pre-adolescents	Inductive: impaired Causal: impaired	Evaluative: impaired	**Concrete/Self-control** – Reduce smartphone use	Child study linking smartphone use to weaker critical evaluation
Shanmugasundaram & Tamilarasu (2023)	General digital media & AI	Review	General population	Inductive: impaired Causal: impaired	Evaluative: impaired Creative: mixed	**General/Self-control** – Call for balanced, guided use	Broad review framing digital tech impacts on cognition
Danry et al. (2023)	AI use & reliance	Empirical – Experimental	Young adults	Deductive: enhanced	Analytical: enhanced	**Concrete/Design** – AI prompts for reasoning	Early experimental design showing AI can foster reflection
Zhai et al. (2024)	AI use & reliance	Review	General population	Deductive: impaired	Evaluative**:** impaired Analytical: impaired	**General/Design** – Recommend scaffolds to reduce dependency	Key systematic review on AI reliance and reasoning decline
Kosmyna et al. (2025)	AI use & reliance	Empirical – Neurocognitive	Young adults	Deductive: impaired Inductive: impaired	Analytical: impaired Creative: impaired	**General/Self-control** – Encourage reflection	First neurocognitive evidence of AI-induced reasoning debt
Oakley et al. (2025)	AI use & reliance	Review	General population	Inductive: impaired Causal: impaired	Scientific: impaired	**General/Design** – Stress role of stored knowledge	Anchor on why reasoning needs internal knowledge
Drosos et al. (2025)	AI use & reliance	Empirical – Experimental	Young adults, Adults	Analogical: enhanced Causal: enhanced	Reflective: enhanced Creative: mixed	**Concrete/Design** – Add reflection triggers in AI systems	Empirical proof that design can restore reasoning in AI contexts
Lee et al. (2025)	AI use & reliance	Empirical – Survey	Young adults	Deductive: impaired Abductive: enhanced Inductive: mixed Analogical**:** mixed	Evaluative: enhanced Reflective: enhanced Scientific: impaired	**General/Design** – Suggested balanced integration	Likely benchmark study on generative AI & reasoning

2.2.5.3 Reasoning and Critical Thinking

Reasoning heavily relies on working memory, so it becomes weaker when mental resources are stretched (Kane & Engle, 2002). Deductive and inductive reasoning appear to be especially vulnerable (Kazali, 2025). Studies in key literature show that both are often affected at the same time. (Risko & Gilbert, 2016) argued that people practice fewer logical steps and weaker generalisations when thinking is offloaded to external tools. Lee et al.'s study (2025) concluded deduction was disrupted by strong dependence on AI, and induction declined when broad patterns were accepted too quickly. More recently, Kosmyna et al. (2025) found that people skipped deductive steps and repeated similar reasoning patterns in essay writing with AI weakening induction. In these cases, handing over the task to technology undercut both processes at once.

Other studies highlight one process more than the other. Deduction is often the first to drop under distraction. Ward et al. (2017) found that the drop in sustained attention and working memory caused by smartphone presence also showed up as poorer deductive reasoning performance. This potentially shows the close link between these processes. Zhai et al. (2024) reported that users of AI dialogue tools often failed to check the logic of the answers provided.

Induction and causal reasoning, on the other hand, are affected when digital aids replace the process of building knowledge and cause-and-effect analysis. Fabio and Suriano (2023) found that children as heavy smartphones users opted for shortcuts rather than forming sound generalisations. Shanmugasundaram and Tamilarasu (2023) and Oakley et al. (2025) also noted that ongoing digital reliance can weaken the knowledge required for inductive reasoning in different populations. Additionally, it can erode the knowledge structures needed to link causes and effects.

Shanmugasundaram and Tamilarasu (2023) and Oakley et al. (2025) also noted that ongoing digital reliance can weaken the knowledge required for inductive reasoning. Across different populations, it can also erode the knowledge structures needed to link causes and effects.

By contrast, Drosos et al. (2025) showed that when AI systems asked users to pause and think, people were more likely to reconsider the causes behind things instead of just accepting them.

Findings on analogical and abductive reasoning are more mixed. Generative AI can act as a brainstorming partner, helping users think through analogies and different angles, but only if the system produces logically consistent suggestions and the user takes time to

judge them (H.-P. Lee et al., 2025). Drosos et al. (2025) further showed that critique prompts encouraged users to compare ideas and question outcomes rather than simply accept them. These findings indicate that reasoning is not simply weakened across digital contexts. With tools that encourage reflection, processes like induction, abduction, and analogy may actually grow stronger.

Critical thinking (CT) shows a related but distinct pattern. The ability to evaluate information appears fragile across age groups, with reliance on digital tools linked to shallow checking of information quality (Fabio & Suriano, 2023; Shanmugasundaram & Tamilarasu, 2023; Zhai et al., 2024). Analytical thinking weakens when digital tools provide quick answers, and scientific thinking becomes harder as information is increasingly stored outside ourselves (Oakley et al., 2025; Zhai et al., 2024)**.** Reflection and creative thinking show more potential: when tools are designed to break routine and ask questions, reflective engagement can return (Danry et al., 2023; Drosos et al., 2025), and digital tools used as prompts rather than final answers can support more original thinking. In short, analytical, evaluative, and scientific CT skills are most vulnerable under digital reliance, while reflective and creative skills show potential for improvement when technologies trigger questioning and exploration.

2.2.5.4 Critical Synthesis: Solutions and Design Gaps

A clear pattern in the reviewed literature is that most recent studies on reasoning and critical thinking focus on AI. Earlier work had looked at issues such as the presence of devices or the use of digital tools to offload thinking (e.g., Risko & Gilbert, 2016; Ward et al., 2017). Recently, as a result of the rapid spread of AI tools, research focus has shifted toward how relying on these affects the way people think at higher levels.

When it comes to reasoning, the findings are fairly consistent. Deductive and inductive reasoning are often impacted negatively when people depend too much on digital tools, whether because of distraction, offloading, or relying on AI. On the other hand, CT shows a more mixed picture. Evaluating information or checking claims scientifically seem fragile while reflective and creative thinking sometimes improve based on the context, through questioning and pushing users to think from different perspectives.

As Figure 2.5 illustrates, a number of the reviewed papers proposed design-oriented solutions, structured questions, design aids and provocative questions that encourage reflection in AI systems (Danry et al., 2023; Drosos et al., 2025; Zhai et al., 2024).

Risko & Gilbert (2016) also highlight the importance of raising awareness how digital tools might change how people think and reason. But so far, most of these ideas remain



Figure 2.5: Overview of key literature on digital technologies and their impact on reasoning and critical thinking

at a very general level, with little detail about how they could work in real systems. This leaves a gap not only for reasoning or critical thinking, but also attention, memory and executive functions: while the literature recognises design as the way forward, it rarely specifies which interaction contexts are most harmful or how they should be addressed.

These gaps provide the basis for **RQ1**, which focuses on identifying such contexts, before later questions turn to their redesign (**RQ2**) and implications for design knowledge (**RQ3**).

2.3 Media and Public Discourse: Perceptions of Cognitive Impact

The cognitive implications of everyday digital technologies are not only investigated within academic research but are also the subject of extensive debate in journalism and public commentaries. Over the past decade, headlines across major media outlets such as *The Guardian*, *The New York Times*, *BBC*, and *The Atlantic* have repeatedly framed technology as contributing to an "attention crisis," "digital dementia," or the "outsourcing" of memory. While the media helps to highlight real concerns, it often emphasises personal willpower or institutional regulations as the main solutions. On the other hand, design-level solutions require a solid base of research, analysis and creative application of findings in order to mitigate the problems effectively, making them far more challenging to propose and discuss in public debate.

To better examine and communicate the media response, a website resource titled *Digital Habits, Cognitive Shifts: Reflections from the Media*[1] was created at the start of this research to archive news articles reporting on the cognitive implications of everyday digital technology use. Articles were collected through ongoing monitoring of major English-language outlets including The Guardian, The New York Times, BBC, The Atlantic, and similar publications, supplemented by targeted searches for coverage of key topics such as attention, memory, screen time, and AI. An article was included if it directly addressed cognitive effects of digital technology use or proposed responses to these effects, whether through self-regulation, policy, or design. Articles were excluded if they focused primarily on physical health, cybersecurity, or unrelated aspects of technology use.

This website includes 163 articles published between 2015 and 2026 (Figure 2.6). The articles are grouped into two broad categories: "Cognitive Impacts" and "Solutions". The impact side covers issues such as executive function disruption, attention degradation, memory decline, reduced reasoning and critical thinking, and affective or social-cognitive difficulties. The solutions side highlights responses like self-regulation, cognitive training, restricting devices or apps, and broader policy or platform reforms. This way of

[1] Supplementary media article list; see Appendix A. Also available at https://designwithmind.notion.site/Digital-Habits-Cognitive-Shifts-Reflections-from-the-Media-20f52bca2530817e9f38d96f2b74e422

organising the material shows not only how risks are framed in the media, but also what kinds of remedies are suggested. Alongside functioning as a searchable archive, the resource offers a clear structure for comparing public narratives with research findings in psychology and human–computer interaction.

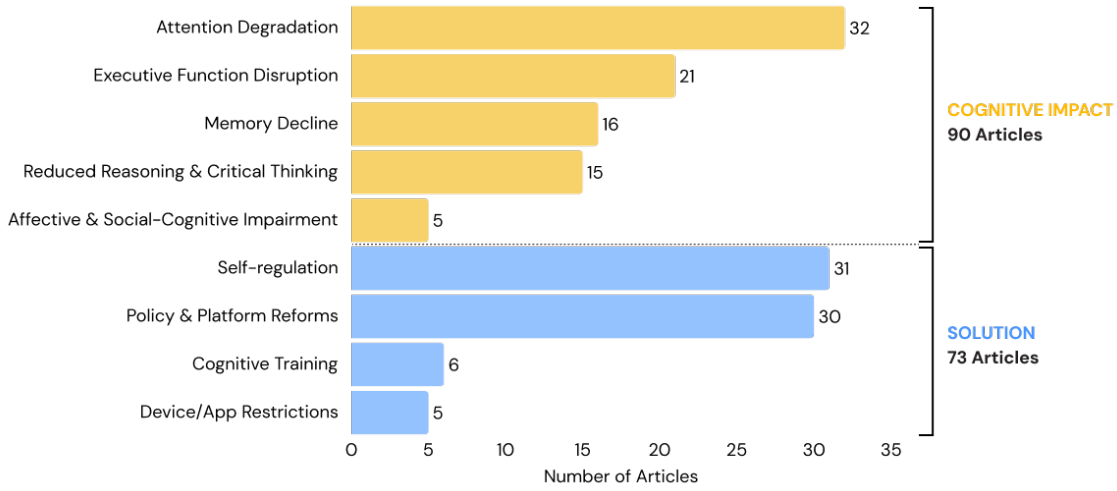


Figure 2.6: Distribution of cognitive impact and solution themes in media articles. Across the 163 media articles archived in "Digital Habits, Cognitive Shifts" (Appendix A), yellow bars show cognitive impact themes (90 articles) and blue bars show solution themes (73 articles), illustrating coverage weighted toward problem narratives, with self-regulation and policy reform dominating the solution space.

2.3.1 Dominant Frames of Cognitive Decline

The most prominent theme in the collection is *attention degradation*, with 32 out of 90 articles focusing on cognitive impacts of digital technology. These reports describe difficulties in maintaining focus, often using phrases such as an “attention crisis” (*Are Attention Spans Really Collapsing?*, 2022; Kirk, 2019) or comparisons to a “goldfish generation” (Thain, 2022). Attention is seen as a vulnerable resource under pressure from the design of apps and platforms. A common argument is that people are finding it harder to concentrate, suggesting that sustained attention is the most widely recognised form of attention discussed in relation to digital technology’s impact.

The topic of *memory decline* has entered media through similar phrases such as “digital amnesia” (Coughlan, 2015) and the “Google effect” (Roberts, 2015). Many of the articles addressing memory problems frame this as a cultural shift since people now search for knowledge rather than recall them directly. These accounts reflect a concern that growing reliance on external tools, particularly search engines and AI applications, could atrophy memory. At the same time, some coverage suggests that offloading memory may not always be harmful since this can free up cognitive resources that would allow people to

focus on reasoning and problem-solving (Pearson, 2025). What also stands out across this subset of collection is the wider question of whether digital technologies are changing what it means to remember in the first place.

21 articles addressed *disruptions in executive functions*, especially difficulties with self-regulation, planning, and decision-making. he behaviours most often described included resisting notifications, which is frequently discussed in relation to difficulties in maintaining self-control (Barry, 2023) and multitasking reduces the ability to stay on track (Parikh, 2025). The notion of "alert fatigue" was also used to describe the exhaustion that arises from being exposed to dozens of notifications a day, draining mental resources by the need to repeatedly filter, ignore, or respond to (Savage, 2025). Together, these reports indicate that the issues with executive control now has become part of everyday conversations about digital life, with inhibitory control as the most taxing domain.

Reasoning and critical thinking have become an increasingly visible concern, too, particularly in the most recent wave of articles from 2025 that focus on the rise of AI (Chow, 2025; Grose, 2025; Hymel, 2025; Stokel-Walker, 2025). Much of this coverage questions whether reliance on AI tools discourages independent thought and reduces the effort involved in analysis. The argument often presented is that such technologies encourage shallow engagement with information although they provide speed and convenience. Beyond AI, doubts have also been raised that constant digital device use encourages compulsive and shallow engagement with trivial content, popularly described through terms such and "doom scrolling" and "brain rot", the latter named Oxford Word of the Year in 2024 (Boyle, 2024; *'Brain Rot' Named Oxford Word of the Year 2024*, 2024).

Within this body of media collection, public concern appears to have shifted from issues of distraction and memory loss to questions of reasoning. This shift suggests that public discourse is no longer only about the capacity to manage information, but about the deeper intellectual qualities that shape judgement, decision-making, and the ability to engage meaningfully with knowledge.

2.3.2 Proposed and Existing Solutions in Public Discourse

In contrast to the extensive coverage of problems, the dataset shows that the range of proposed solutions in the media is comparatively narrow. Out of 163 articles, 73 (45%) focused on interventions, and these cluster into four categories (Figure 2.6)**.**

The largest group, *self-regulation* (31 articles; 42% of solutions), emphasises user responsibility in reducing usage of particular features, apps, or devices. Suggested strategies primarily emphasise avoidance and restriction rather than constructive or design-oriented solutions. These include silencing notifications, deleting distracting apps, undertaking digital detox routines or switching to dumbphones that have only offer basic mobile phone functions and lack smart features such as constant connectivity and social media apps. These approaches can be really effective when practiced, however they rely on users having both an awareness of potential harms and the knowledge to adopt coping strategies, making them heavily dependent on individual motivation and sustained effort.

The second-largest group, *policy and platform reforms* (30 articles; 41% of the solutions), covers rules or regulations made by governments and institutions to manage how technology is used. Topics range from legislative proposals to impose social media age limits, to obligations on platforms to introduce safety features, and debates about banning phones in schools. These measures acknowledge that the problem is beyond individual behaviour, but media coverage portrays them as controversial, facing enforcement challenges and pushback from the tech industry.

The remaining categories form much smaller groups. *Cognitive training* refers to activities in digital settings aimed at improving overall cognitive performance or targeting specific processes such as working memory and attention. Media coverage often presents these as promising in certain contexts (puzzles, video games, learning activities) or age groups (older adults). At the same time, the coverage points out that there is uncertainty about how effective they are in the long term.

Another small subset of the collection, *device and app restrictions* include articles featuring solutions on system level, such as screen-time reporting and default usage limits. As the only design features within the current state of platforms, most of these still require users to know where to locate, turn on them and actively use which means the responsibility stays with individuals instead of changing the basic design of digital environments. One article out of five called for rethinking how platforms is designed which will help with pausing and reflecting, not only about adding a few safety and reporting settings (Suciu, 2024).

This analysis shows that the public is generally aware of the cognitive effects of digital technology use, but struggles to imagine solutions beyond regulation and limitation. Whether self-imposed or enforced by institutions, these strategies focus on limiting use

rather than rethinking how technologies could be designed to better support cognitive resilience.

2.4 Intervention Strategies and Their Limitations

Efforts to mitigate the cognitive costs of digital technologies span individual practices, institutional initiatives, advocacy organisations, and design-based research. Together, they form a diverse but fragmented landscape. Each has value, but all are constrained in ways that leave fundamental gaps in both theory and practice.

Self-regulation is the most common response suggested in both research and public discourse. These methods can be effective when practiced, however they are not sustainable for long periods of time for two reasons. First, this requires a large amount of cognitive effort, such as self-control and sustained attention, but these are exactly the skills that digital environments often weaken. Second, they are difficult to maintain in everyday contexts. Office workers cannot turn off emails notifications for extended periods of time at work and in social life there is pressure to stay connected with friends and family, whereas daily tasks such as banking, shopping, or travel depend on digital access. Hari (2022) characterises such approaches as a form of pre-commitment that places the entire burden of responsibility on individual users, an approach he considers ethically questionable, as it overlooks how system design actively shapes behaviour. As a result, self-regulation approaches are fragile and rarely sustainable over time.

Institutional and policy efforts can enforce restrictions on digital technology use in certain contexts, such as schools, or impose obligations on companies for cognitively resilient designs. However, such measures still face clear limits as they cannot directly address the inherent design features that cause cognitive harms. In addition, enforcement mechanisms and legislative processes often move more slowly than technological developments.

To accelerate these processes and support communities, civil society organisations have emerged as prominent actors in this space. One such entity, The Center for Humane Technology (*What We Do: How Change Happens*, n.d.)[2] addresses attention capture as a societal challenge among other digital infrastructure issues by raising public awareness, training technologists, and advocating for design reform. In a related way, the DQ Institute (*DQ Framework*, n.d.)[3] embeds digital wellbeing within its digital intelligence framework, providing measurement tools and educational programmes to promote

[2] Center for Humane Technology. https://www.humanetech.com/how-change-happens
[3] DQ Framework, DQ Institute. https://www.dqinstitute.org/global-standards/

healthy technology use in organisational settings. This research included a placement at DQ Lab Pte. Ltd. (February–May 2024), the R&D and commercialisation arm of the DQ Institute, where DQ client programmes were analysed through qualitative coding and iterative improvement, and candidates for the Research Committee were evaluated. The experience provided direct insight into how global digital literacy programmes integrate wellbeing criteria into practice.

Other organisations such as the Digital Wellness Institute (*Wellness For Workplaces | World Leading Digital Wellness Solutions*, n.d.)[4] and Consciously Digital Institute (*About Us*, n.d.)[5] also develop frameworks and training for digital wellbeing, though these efforts remain focused on organisational behaviour and policy rather than interaction-level design, leaving a gap in systematic evaluation of software against cognitive criteria. Collectively, while these initiatives have been influential in shaping public awareness, they are constrained by limited enforcement power and remain largely persuasive rather than operational.

Redesigning digital environments is the most targeted way to influence cognitive outcomes, but current strategies remain either overly general or constrained within narrow and specific areas. Existing interface-level work includes context-aware notification systems (Adamczyk & Bailey, 2004; Mehrotra et al., 2016), physiologically-triggered media bookmarks (Pan et al., 2011), mindful smartphone non-use tools (Hiniker et al., 2016), and AI interaction redesigns that embed reflective prompts (Danry et al., 2023; Drosos et al., 2025). The closest conceptual precedent is Balasubramanian et al. (2017) who proposed design principles for everyday applications that maintain users' cognitive abilities while reducing over-reliance on technology, a direction this thesis extends and builds upon. Balasubramanian et al. propose a broader set of design principles across multiple applications but evaluate them only through a design workshop. Danry et al. and Drosos et al. provide empirical evidence but focus exclusively on reasoning. The remaining contributions each address a single interaction mechanism without evaluating broader cognitive outcomes. What is missing is a consolidated design framework that spans multiple cognitive processes and is systematically evaluated.

As outlined in Section 2.1, none of the major waves of HCI design knowledge have explicitly addressed this gap. First-wave frameworks (e.g., Nielsen's heuristics, Norman's principles, Shneiderman's rules) treated mental effort as a liability to be

[4] Digital Wellness Institute. https://www.digitalwellnessinstitute.com/
[5] Consciously Digital. https://www.consciously-digital.com/about

reduced. Second-wave approaches like Distributed Cognition and Activity Theory placed interaction in social and cultural context, but did not ask what happens to cognitive skills when people keep relying on technology. Third-wave perspectives on user experience and wellbeing expanded design goals to include pleasure and meaning, but left cognitive resilience largely untouched. In other words, widely accepted design knowledge accumulated so far, while proving useful in supporting learnability and efficient task completion, is little guidance on how to preserve or strengthen cognition. As a result, both research prototypes and commercial tools remain fragmented without offering integrated cognitive support.

Commercial tools that claim to promote "digital wellbeing" through system settings, third-party applications and community-built plug-ins remain poorly integrated into everyday interaction. Apple's Screen Time (Apple, n.d.-b)[6] and Android's Digital Wellbeing (*Manage How You Spend Time on Your Android Phone with Digital Wellbeing*, n.d.)[7] are buried deep in settings and require effort to set up with layered options. Website and application blocker tools like Freedom (*Freedom*, n.d.)[8] and RescueTime (*Track Your Time. Transform How You Spend It.*, n.d.)[9] are locked behind paywalls. News Feed Eradicator (West, 2026)[10] and DF Tube (Focus, 2026)[11] are examples of browser plug-ins that block distracting features on websites and require users to actively discover them. Even when discovered and used, they mostly rely on restriction methods such as usage limits and app blocking. In doing so, they shift responsibility to the user and blur the boundary between design support and self-control.

Alongside restriction-oriented tools, there are also digital training applications and programmes that aim to improve general cognitive abilities such as memory, attention, and problem-solving. Examples include mobile and web applications such as Lumosity (*Brain Training Games | Exercise Your Mind*, n.d.)[12] and Elevate (*Elevate Brain Training App*, n.d.)[13], which provide training for the general population through game-like exercises. Another form of example is Cogmed (Pearson Clinical UK & International,

[6] Screen Time, Apple Support. https://support.apple.com/en-gb/guide/iphone/iphbfa595995/ios
[7] Digital Wellbeing, Google Help. https://support.google.com/android/answer/9346420?hl=en
[8] Freedom. https://freedom.to
[9] RescueTime. http://rescuetime.com/
[10] News Feed Eradicator, Chrome Web Store. https://chrome.google.com/webstore/detail/news-feed-eradicator/fjcldmjmjhkklehbacihaiopjklihlgg
[11] DF Tube, Chrome Web Store. https://chromewebstore.google.com/detail/df-tube-new-distraction-f/kchgllkpfcggmdaoopkhlkbcokngahlg
[12] Lumosity. https://www.lumosity.com/en/
[13] Elevate, The Mind Company. https://themindcompany.com/apps/elevate

n.d.)[14], a clinically structured programme aimed at children with attention difficulties, students with learning challenges, and adults in cognitive rehabilitation, consisting of five weeks of training focused specifically on working memory.

These kinds of platforms have significant reach and research shows they can improve performance on the tasks they directly train (Melby-Lervåg et al., 2016). However, the evidence also shows that such benefits do not reliably extend to broader cognitive abilities. Redick et al. (2013) found no transfer to intelligence or any other cognitive abilities in a large placebo-controlled trial. Reviews and meta-analyses further highlight inconsistent results and methodological limitations, including small samples, short follow-ups, and selective reporting (Melby-Lervåg et al., 2016; Shipstead et al., 2012). They are therefore far from adequate as a means of compensating for the cognitive capacities already strained in everyday digital interaction.

2.5 Summary of Gaps and Concluding Synthesis

The earlier sections have shown four different perspectives: how HCI design principles developed over time (Section 2.1); what negative effects digital technologies have on core cognitive processes and what solutions have been proposed in research (Section 2.2); how these issues and potential solutions are represented in media and public debate (Section 2.3); and which interventions currently exist, along with their advantages and limitations (Section 2.4). When considered together, these perspectives provide a starting point but also leave areas that require further development. To frame the direction of this thesis, the following section brings these strands together and sets out four categories of gaps that remain to be addressed.

1. **Gaps in cognitive findings.** Research has shown that digital technologies can affect attention, memory, executive functions, and reasoning, thereby substantially addressing **RQ1**. While this evidence base is strong, it is primarily based on short-term tasks and controlled studies. Fewer studies examine everyday contexts or long-term patterns of use. Other skills such as problem-solving, creativity, comprehension, and decision-making are also less well understood. This leaves room for further work that looks at sustained and cross-domain effects. For this thesis, the existing evidence provides a necessary foundation for building design guidance.

[14] Cogmed. https://www.cogmed.com/

2. **Gaps in proposed solutions.** Academic and public debates have introduced a range of approaches such as notification scheduling/filtering, screen-time limits, structured technology breaks and focus training, removing phones from sight, classroom phone restrictions, and reflective pauses in short-form media, critique prompts in AI systems. Most of these remain conceptual, small-scale and difficult to sustain over time, and few are tested longitudinally, across diverse populations, or in ecologically valid settings. As a result, there is limited evidence about which approaches are effective and sustainable in practice, leaving open space for further work that will help answer **RQ2**.

3. **Gaps in existing interventions.** Current responses are fragmented. Self-regulation strategies depend on skills such as focus and self-control, which digital environments often challenge. Policy measures face difficulties of enforcement and slower adaptation than technological change. Design interventions from scientific research have produced few promising prototypes relevant to **RQ2**, but these remain isolated and are not integrated into mainstream platforms. Responsibility often falls on individuals while mainstream UI templates that do not take into account the cognitive needs of their users continue to dominate

4. **Gaps in design knowledge.** Widely used design principles in HCI have focused on usability, efficiency, and experience but have not addressed how to maintain or strengthen cognitive functions over time. What is missing is a systematic framework that treats attention, memory, executive control, and reasoning as resources to be preserved and developed. Without such a framework, design interventions risk remaining reactive and fragmented rather than providing sustained cognitive support. Addressing this gap is therefore central to **RQ3**.

Concluding Synthesis. The analysis presented in this chapter demonstrates that concerns about the cognitive effects of digital technologies are grounded in substantial evidence, particularly in relation to the processes examined in this thesis: attention, memory, executive functions, and reasoning. These effects are not theoretical; they are already experienced in daily life and reported in public platforms. On the other hand, solutions that are sustainable over time, effective in mitigating negative effects, and accessible to the average user remain absent, and comprehensive design guidelines to assist designers in creating them have not been established.

This points to a systemic misalignment, where coping is left to individuals while design continues to privilege efficiency and engagement. Although research has generated a

growing body of findings, digital technologies continue to be designed mainly for efficiency, engagement, and convenience, while their impact on cognitive processes is rarely addressed in design practice.

The implication is that the question is no longer whether cognitive effects exist as **RQ1** has been addressed in this chapter, but how design can be reoriented so that everyday technologies support rather than undermine mental capacities. This thesis therefore turns to two further questions: how interaction contexts can be reconfigured through design to promote cognitive resilience (**RQ2**), and how these insights can be consolidated into a guiding framework for HCI (**RQ3**). By addressing these questions, this thesis aims to move beyond reactive and fragmented solutions and towards design approaches in HCI that support and sustain human cognitive capacities.

Chapter 3

Research Design and Methodology

3.1 Research Lens: Cognitive Resilience in HCI

3.1.1 Cognitive Resilience: Existing Definitions and This Thesis's Perspective

Cognitive resilience has been an important concept across psychology and neuroscience. In psychology, it is commonly described as "a dynamic process encompassing positive adaptation within the context of significant adversity" (Luthar et al., 2000, p. 543). This perspective highlights how individuals negotiate, adapt to, or manage significant sources of stress or trauma (Windle, 2011), and how resilience may be demonstrated across diverse forms of adversity, from everyday pressures to more substantial challenges (Fletcher & Sarkar, 2013).

In neuroscience and ageing research, cognitive resilience is often discussed together with the term of *cognitive reserve*, though the two are sometimes described in overlapping or inconsistent ways (Kremen et al., 2022; Montine et al., 2019). Stern (2009) describes cognitive reserve in terms of differences in mental processes that allow some individuals to cope better with brain pathology. Ten years later, Stern et al. (2019) argued that mechanisms such as reserve, brain maintenance (keeping cognitive function stable over time by slowing or avoiding decline, for instance through healthy brain processes or continuous cognitive activity) and compensation (achieving the same goal by using alternative strategies or brain regions when usual ones become less efficient) all contribute to what he describes as cognitive resilience. In a more recent collaborative paper, Stern et al. (2020) further noted that resilience is used as a more general term that refers to several processes related to reserve. While that framework concentrated on cognitive reserve, its recognition of resilience as a broader concept provides an important foundation for how this thesis positions resilience in HCI.

Other authors have provided more straightforward definitions of cognitive resilience. Montine et al. (2019) view it as the capacity to maintain cognitive abilities despite

age-related brain changes and disease. Kremen et al. (2022) emphasise resilience as performing at a higher level than would normally be expected given the degree of adversity. Zammit et al. (2024) frame it as a scale, ranging from low to high ability to sustain cognition despite evidence of neurological diseases.

Across these perspectives, a common theme emerges: cognitive resilience concerns sustaining (or exceeding expected) cognitive performance under adverse conditions. What varies is the source of adversity, which may stem from stress, ageing, or disease, and how resilience is understood, whether as recovery, adaptability, better-than-expected performance, or a spectrum of capacity.

Building on these definitions but shifting the context to HCI, this thesis defines *cognitive resilience* as the capacity to preserve core cognitive functions when facing both immediate challenges and prolonged demands created or amplified by digital interactions as outlined first in Chapter 1. The adversity here is everyday digital interactions (for example, interruptions, media multitasking, AI offloading), rather than traumatic events or neurological changes.

3.1.2 Cognitively Resilient Design: Reorienting Usability Frameworks

As discussed in Chapter 2, existing HCI frameworks establish foundations for usability but do not explicitly engage with the stability of core cognitive processes during or across digital interactions. Building on the construct of cognitive resilience, this thesis defines *cognitively resilient design* as the translation of that concept into an orientation for HCI to fill this gap. Whereas cognitive resilience describes an individual's capacity to sustain core functions under adversity, cognitively resilient design concerns how interactive systems can be shaped so that they do not undermine this capacity, and ideally create conditions that help to preserve or strengthen it in everyday digital environments.

Cognitively resilient design can be considered from two perspectives. The *immediate resilience perspectiv*e focuses on how design helps users maintain stable functioning during ongoing interaction, for example, sustaining focus on a single task. The *cumulative resilience perspective*, on the other hand, assesses how design reduces the strain that builds up over time, across repeated sessions of digital use**.**

These perspectives can also serve as a lens for re-examining traditional usability, which prioritises dimensions such as effectiveness, efficiency, ease-of-use and satisfaction. For example, Norman's principle of "making things visible" (Norman, 2013), Nielsen's heuristic of "recognition rather than recall" (Nielsen, 1994a, 1994b), and Shneiderman's rule to "reduce short-term memory load" (Shneiderman et al., 2018) all reduce cognitive

strain that is deemed "unnecessary". A resilience perspective should reframe these principles by asking whether the strain is always unnecessary, or whether in some contexts a degree of cognitive effort may be beneficial. In doing so, it reveals where existing design knowledge may fall short and reorients it so that it complements resilience, highlighting whether usability aims are achieved in ways that safeguard cognitive functioning or are, at times, compromised by design choices that prioritise short-term performance over long-term stability.

Cognitively resilient design also differs from related orientations. Digital well-being models (Calvo & Peters, 2014; Vanden Abeele, 2021) focus on the emotional side of technology use, while the concern here is the cognitive side. Accessibility frameworks address the needs of users with specific impairments, while the concern here is the cognitive strain affecting all users in everyday use. Behavioural efficiency models such as persuasive technology (Fogg, 2003) aim to guide users towards specific behaviours, while the aim here is the opposite: to protect users' capacity to function cognitively on their own.

Taken together, this reframing positions cognitive resilience both as a dimension of design quality, a criterion that can be evaluated alongside efficiency, learnability, or satisfaction, and as a design anchor, providing a novel orientation that reinterprets and extends existing principles. As a dimension, it enables practical assessment of how interfaces avoid undermining and, where possible, help sustain cognitive processes; as an anchor, it reorients design priorities so that supporting cognitive resilience becomes a central value of interaction design and more broadly of digital technology design.

3.1.3 Positioning the Research for Cognitively Resilient Design

Cognitively resilient design can be categorised into three groups: *awareness support*, *pre-commitment mechanisms*, and *integrated design approaches*. Each one represents a different level at which resilience can be addressed in interactive systems.

Awareness support aims to increase the user's understanding of how digital interactions undermine their cognitive processes. This includes monitoring tools such as screen time reports as well as feedback on potential consequences, for example, showing how multitasking may interfere with attentional processes. By making such risks visible, awareness approaches give users the opportunity to self-regulate. At the same time, they can also add to cognitive load by requiring constant monitoring and may place too much responsibility on the user if applied in isolation.

Awareness support provides information that helps users monitor their behaviour, but leaves regulation largely in their hands. By allowing users to set boundaries in advance pre-commitment mechanisms reduce the need for constant self-control and take a more active role. These mechanisms work by taking some of the control off the user instead of relying on willpower in the moment. Among the common examples are muting notifications, activating "do not disturb" modes, and placing time limits on app use.

One limitation of these mechanisms is that they require users to predict when and for how long they will need protection. This can be challenging since priorities and demands often shift in everyday life. For instance, a blocked notification or email may later prove important, and extra effort may be needed to mitigate the repercussions. Another limitation is that these mechanisms rely on users upholding their initial commitment. Their effectiveness is reduced if restrictions are abandoned when they become inconvenient. This approach provides support that is limited in its sustainability.

Integrated design approach goes further by embedding cognitive resilience directly into the structure of interaction. Rather than just relying on tools that monitor behaviour or limit use, integrated design embeds mechanisms that protect core cognitive functions within the interaction process. This means that cognitive resilience is supported through the interaction itself since users would not need to locate, configure, or activate separate features on their devices.

Unlike the other two categories, integrated design has very few existing examples, which underlines its importance as an area of investigation. This scarcity is consistent with the current orientation of design knowledge and usability frameworks in HCI, as discussed in Section 3.1.2. It may still incorporate awareness support, for example, to explain negative effects of certain interaction behaviours to motivate users towards integrated design solutions, or draw selectively on pre-commitment mechanisms such as lightweight adjustments to limit use of particular features. But these are absorbed into the design rather than functioning as external add-ons. Therefore, integrated design represents the most systemic approach as it reframes all three levels within a broader orientation where resilience is intrinsic to interaction design.

Awareness support and pre-commitment mechanisms provide partial safeguards but do not directly address how interaction itself can shape cognitive resilience. Integrated design is therefore the main focus here, as it offers the most direct and sustainable way to ensure core cognitive functions are preserved through the way systems are built. At the same time, because integrated approaches remain rare in current practice, this work also

seeks to expand understanding of how they can be developed. The following section outlines the research approach used to investigate this orientation.

3.2 Research Approach

3.2.1 Research-through-Design and Complementary Approaches

This work leverages Research-through-Design (RtD) as the overarching methodological foundation to address the last two research questions by providing a way to redesign problematic interaction contexts within specific platforms for cognitive resilience (RQ2) and examine the potential to translate the insights from their evaluation into more generalisable forms of design knowledge (RQ3).

First outlined by Frayling (1993) and developed in HCI by Zimmerman, Stolterman, and Forlizzi (2007), RtD treats design not only as the creation of artefacts but also as a way of generating knowledge. Prototypes are considered more than tentative solutions. They embody ideas, provoke responses, and make visible aspects of interaction that may remain hidden in abstract theorising (W. Gaver, 2012; Höök & Löwgren, 2012). This makes RtD particularly suited to ill-defined problems, where goals and evaluation criteria are not fully established. Cognitive resilience construct derived here is one such domain. Since it is not yet an established design dimension or principle, it cannot be measured against a benchmark. It must instead be explored and shaped through cycles of design, use, and reflection.

At the same time, this work does not rely on RtD in isolation. It combines three complementary modes of inquiry:

- **Research for Design**, which aims to generate knowledge that supports future design activity, typically involves gathering insights about user needs, contexts of use, or emerging technologies to guide the direction of design work (Frayling, 1993). In this thesis, it provided the conceptual and exploratory grounding. The literature review and synthesis of cognitive psychology informed the framing of cognitive resilience as a design concern, but also directly fuelled the exploratory design process by highlighting opportunities within specific interaction contexts and by identifying directions where existing usability principles may fall short. In this sense, Research for Design underpinned the generation of speculative concepts and early design probes, ensuring that the exploratory strand of the thesis was anchored in both theoretical insight and practical relevance.
- **Research through Design** structured the generative exploration as mentioned before. Prototypes functioned as knowledge instruments, enabling tentative ideas

about cognitively resilient design to be materialised, tested, and refined through cycles of making and reflection.

- **Empirical evaluation methods** including controlled experiments, assessments, self-report surveys and usability interviews were embedded within RtD cycles to supply targeted evidence about user experience and cognitive outcomes, supporting the evaluative strand of the work.

Table 3.1: Modes of design research and their role in the thesis

Mode	Focus	Role in This Thesis
Research into Design	Studying the design process itself (e.g., how designers think, act, or collaborate).	Not applied directly; acknowledged as part of Frayling's taxonomy.
Research for Design	Generating knowledge to support future design activity	Provided conceptual grounding: literature on cognitive psychology and HCI revealed where usability principles fall short and where cognitive resilience could open new directions. Anchored the exploratory design process.
Research through Design (RtD)	Using design practice itself to generate knowledge	Central orientation: prototypes served as knowledge probes, enabling cycles of iteration, evaluation, and reflection. Produced conceptual, methodological, and practical knowledge.
Design as Research (extended framing)	Treating design and research as inseparable practices.	Considered as overlapping with RtD; in this thesis, the creation of design artefacts was inseparable from knowledge generation.

Table 3.1 and Figure 3.1 situate this methodological orientation within the broader taxonomy of design research. *Research into Design* is acknowledged as part of Frayling's original framework (1993), but it is not directly applied here as it deals with the analysis of the design process itself. *Design as Research* is included to recognise an extended framing often discussed in design research. In this work, however, it is treated as overlapping with RtD: the act of creating artefacts was inseparable from the process of generating knowledge, but the primary lens remains RtD.

These modes form a multi-layered methodological framework. This integration made it possible to investigate cognitive resilience not only as an outcome to be measured but also as a design construct to be defined, iterated, and embedded in practice.

Building on this integrated methodological stance, the following section outlines how these approaches were operationalised to explore, prototype, and evaluate cognitive resilience as a design construct across iterative research cycles.

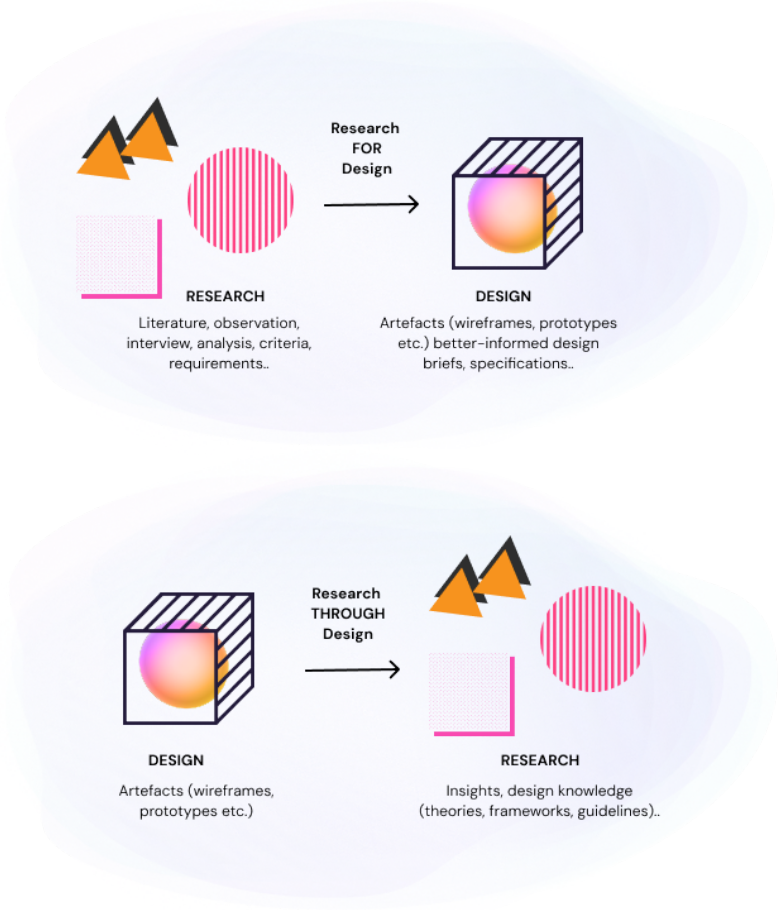


Figure 3.1: Research for Design and Research through Design processes. Research for Design uses research to inform artefacts, while Research through Design uses artefacts to generate knowledge.

3.2.2 Operationalising RtD for Cognitive Resilience

Operationalising RtD in this thesis involved structuring the inquiry into an iterative process that continuously linked theory, design, and evaluation. Since cognitive resilience is not an established design principle with fixed criteria, the methodological task was to explore, prototype, and refine it through practice while grounding the process in conceptual insights. Figure 3.2 illustrates how this process unfolds across three stages, each described below with reference to its corresponding region of the figure.

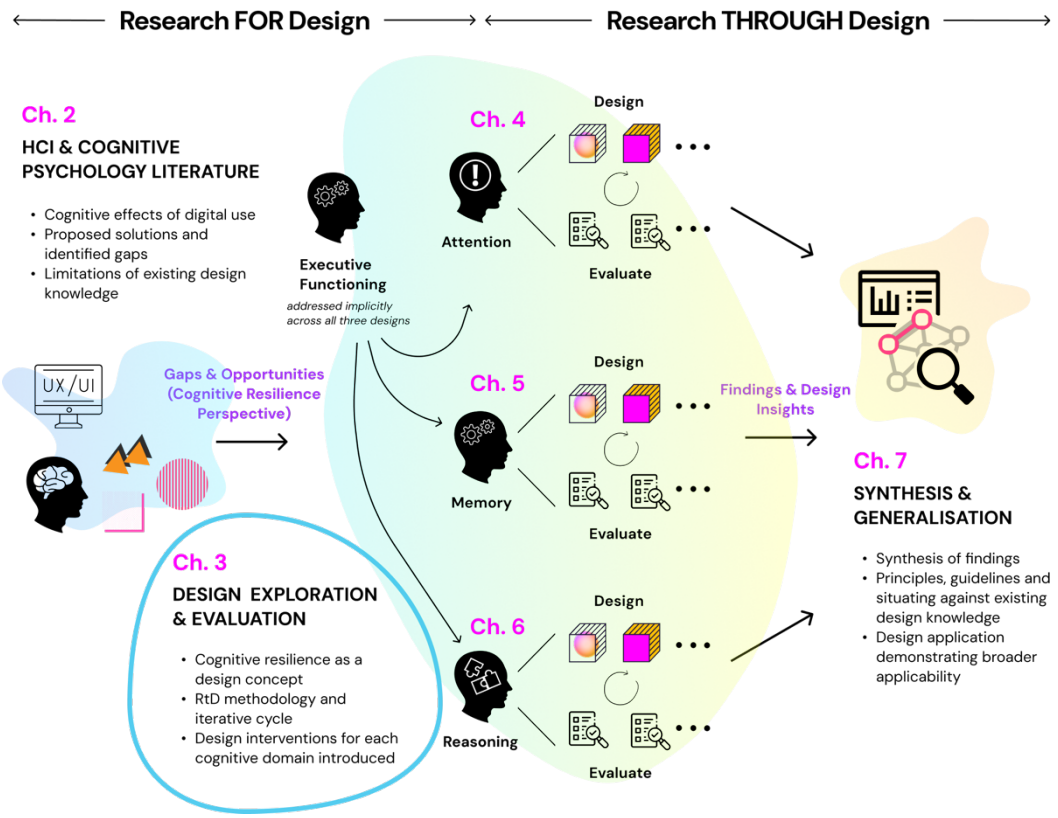


Figure 3.2: Iterative research process for cognitive resilience across Chapters 2-7 (The area highlighted in blue marks this chapter's focus).

Stage 1 – Research for Design: The process began with Research for Design, drawing on the literature review (Chapter 2), which mapped four cognitive domains most relevant to digital interaction: attention, memory, executive functions, and reasoning/critical thinking. This is shown at the top-left corner in Figure 3.2.

The synthesis identified both the risks posed by persistent digital use (e.g., distraction, working-memory overload, erosion of self-regulation, superficial reasoning) and the opportunities for design to mitigate or prevent them. From here, this input feeds into the methodological framework elaborated in this chapter (Chapter 3), which guides the iterative design work described in Stage 2.

Stage 2 – Iterative Design and Evaluation: From these insights, exploratory design probes were generated (see central region of Figure 3.2, spanning chapters 4, 5, 6). These probes translated abstract cognitive concerns into tentative design directions, surfacing opportunities where existing usability principles were insufficient. They functioned less as finished solutions and more as provocations, intended to test boundaries and open up the design space. Promising concepts from this stage were iterated into three core prototypes, where principles of cognitively resilient design could be enacted in practice.

The prototypes embodied hypotheses about how interaction design might sustain or restore attention, support memory continuity or promote deeper reasoning while scaffolding executive control.

The prototypes were evaluated with users using a mix of empirical methods including controlled experiments, interviews, surveys, and usability assessments. These evaluations provided targeted evidence on whether and how the designs supported cognitive resilience in practice while also revealing limitations and trade-offs. Findings and design insights from this stage fed into a growing set of guidelines and framework elements.

Stage 3 – Synthesis and Generalisation: Reflection on the results across cycles produced consolidated design knowledge, including conceptual refinements (e.g., clarifying what constitutes cognitively resilient design), methodological lessons (e.g., evaluating continuity of attention or memory), and practical guidelines for embedding resilience into interaction design (see right-end of Figure 3.2). The accumulated insights were iteratively refined into a set of augmented principles, criteria, and heuristics that contribute to the broader HCI knowledge base. Their applicability was further examined through a generalisability probe, in which the framework was applied to a new design problem in a different domain, demonstrating how the principles transfer to contexts beyond the original three studies. For a thesis-wide view of how this methodological process maps onto the overall chapter structure, see Figure 1.1 in Section 1.7.

3.3 Methodological Execution and Rigour

Methodological rigour in this thesis was achieved by combining different research methods in an iterative and coherent way, as outlined in the previous section. The process was designed to make the reasoning behind each action visible to ensure that the user findings and design conclusions were supported by evidence. Rather than relying on rigid standardisation, rigour was maintained by keeping clear connections between theory, design practice, and reflection. This balance kept the study open to creative exploration while maintaining methodological discipline. As a result, the insights gained through the process developed into design knowledge informed by both empirical findings and reflective analysis.

3.3.1 Iterative Research-through-Design Cycle

The iterative design cycle operationalised the RtD process shown within Stage 2 of Figure 3.2. Within each study, the Design–Evaluate cycles form the core engine of this stage, translating conceptual insights from cognitive psychology and HCI into practical design artefacts.

Each iteration progressed through four overlapping phases:

1. **Exploration:** Grounded in Research-for-Design, this phase synthesised theoretical and empirical findings from the literature across cognitive domains researched. Key interaction contexts that interferes with these cognitive skills were translated into design opportunities.
2. **Prototyping:** Promising concepts were iteratively developed into interactive artefacts, addressing RQ2 by exploring how digital systems might mitigate or prevent cognitive disruptions within existing interaction contexts, thereby contributing to more cognitively resilient UI/UX. Several directions remained conceptual, whereas others evolved into mature prototypes suitable for empirical evaluation.
3. **Evaluation:** Empirical studies were integrated within the RtD cycles. Depending on the prototype, these employed qualitative, quantitative, or mixed methods, such as cognitive performance measures, usability assessments, interviews, and self-report surveys which are discussed in detail in the following sections. The first prototype, *Attention Mode* (Hacioglu et al., 2023b, 2023a), was evaluated through a usability test combined with semi-structured interviews. The second, *SmartPause* (Hacioglu, Leva, Kim, et al., 2025; Hacioglu, Leva, & Lee, 2025a), employed both between-subject and within-subject designs, using statistical analyses such as ANOVA and *t*-tests, along with the System Usability Scale (SUS) (Brooke, 1996). The third prototype, ReasonScape (Hacioglu et al., 2026; Hacioglu, Leva, & Lee, 2025b), was assessed through expert feedback to gather reflective and domain-specific insights. Data from these evaluations informed assessments of design effectiveness as well as theoretical reflection, revealing tensions between usability efficiency and cognitive resilience.
4. **Synthesis:** Findings from each evaluation were first synthesised to identify relationships and conceptual patterns across the prototypes. This synthesis enabled the comparison of how different design choices influenced cognitive resilience in interaction. The resulting insights were then consolidated into transferable design knowledge. Stage 3 takes up their further development and applies them to a new context through a subsequent design probe.

By integrating insights from the literature with cycles of design development, evaluation, and synthesis, the process connected conceptual framing with practical implementation. This iterative process provides the methodological context for the core

design interventions, which are briefly introduced and justified in the following section before being examined in detail in later chapters.

3.3.2 Core Design Interventions and Justification

The design interventions in this research were developed to explore how digital interfaces can support cognitive resilience across different but connected aspects of human cognition. Their selection was guided by the literature on cognitive psychology and HCI, which identifies attention, memory, and reasoning as key cognitive functions frequently challenged in digital environments. These domains are essential for sustained engagement, comprehension, and decision-making, yet they are often disrupted by multitasking, notifications, and cognitive offloading to digital systems.

Each prototype focused primarily on one cognitive function researched (Chapter 2), namely attention, memory, or reasoning. These domains were selected because they represent some of the most established areas of cognitive research, particularly attention and memory, which have received comparatively greater focus than others. However, research connecting these cognitive domains to digital interaction remains an emerging area of inquiry within cognitive and design research. The prototypes sought to advance this developing area by applying established cognitive concepts within practical design contexts to examine cognitive resilience. While each prototype targeted one cognitive function, these processes were understood as overlapping and mutually influential, and should not be regarded as entirely independent from one another.

A dedicated prototype for executive function was not developed. Executive functions act as a higher-level system that manages and coordinates other cognitive activities, and therefore play a role in all interaction contexts. Executive functioning can also be influenced by factors beyond direct interaction, such as the mere presence of a digital device, which can modulate self-regulation and task focus even when not actively used (Ward et al., 2017). For these reasons, executive control was treated as an implicit component embedded across all interventions rather than as a separate focus.

The three interventions developed in this research are summarised below. Each was produced as an interactive prototype or design concept rather than a deployed application:

- Attention Mode (Chapter 4) – a cross-platform interaction concept designed to support sustained attention in media multitasking environments. Developed and tested across desktop, tablet, and mobile devices, it helps users manage interruptions and distractions through a single control that limits elements such as notifications and suggested content during browsing, reading, and streaming. The

feature integrates into existing applications to help maintain attentional stability and task continuity without imposing restrictive controls or reducing user autonomy.

- SmartPause (Chapter 5) – a digital reading interface designed primarily for tablets but adaptable to other e-reading contexts. It introduces guided pausing and lightweight note-taking at natural breakpoints to reduce memory fragmentation and manage cognitive load. The design was intended to enhance long-term memory while also supporting selective attention and reducing perceived mental effort during reading. To examine these cognitive effects under controlled conditions, SmartPause was evaluated through both between-subject and within-subject experimental designs. This approach allowed systematic comparison of reading experiences with and without strategic pausing, and helped capture individual variations across different reading sessions.
- ReasonScape (Chapter 6) – a conceptual design exploring reasoning and reflection in AI-augmented environments. It was developed from a position paper submitted to the CHI 2025 *Human–AI Interaction for Augmented Reasoning* Workshop, which addressed problematic interaction contexts such as automation bias and cognitive offloading in AI-supported reasoning. The concept positioned AI as a structured reasoning guide rather than an automated answer provider, aiming to foster critical engagement and reflective thought. It was evaluated through structured expert feedback gathered during the workshop and in subsequent ad-hoc expert interviews, which were used to identify its design directions and explore its potential to support reflective reasoning in AI-assisted contexts.

The contexts and platforms selected for each prototype reflected real-world digital practices. The choice of interventions was based on two main criteria: addressing dominant problematic interaction contexts identified in the literature and ensuring feasibility for empirical evaluation. *Attention Mode* and *ReasonScape* addressed the first criterion, focusing on common digital challenges such as media multitasking and AI use and reliance respectively. *SmartPause* met the second criterion, offering a clearly bounded environment for testing primarily memory and comprehension under digital reading conditions.

To ensure ecological validity, the prototypes were developed within familiar and widely used digital environments, such as web browsers, tablet reading interfaces, and AI-assisted tools. This approach ensured that participants interacted with realistic

cognitive demands rather than artificial test conditions and that findings would remain transferable to real-world design practice. Instead of creating entirely new systems, each intervention reinterpreted existing interfaces to examine how subtle design adjustments could support cognitive resilience without restricting usability or autonomy.

Together, these interventions operationalised theoretical constructs from cognitive research within practical interaction scenarios. The following chapters examine these interventions in greater detail, presenting their design rationale, evaluation findings, and contributions to understanding cognitively resilient interaction design.

3.3.3 Mixed-Methods Rationale and Evaluation Design

The evaluation strategy of this research followed a mixed-methods orientation, integrating qualitative, quantitative, and interpretive approaches within the broader RtD framework. This mix of methods addressed the dual nature of cognitive resilience, linking experiential insight with empirical observation. Although the study as a whole followed a mixed-methods approach, each prototype used methods suited to its aims and level of maturity. Attention Mode and SmartPause combined quantitative and qualitative measures, whereas ReasonScape was evaluated solely through qualitative expert feedback. This unevenness reflects the RtD principle that methods should fit the case rather than follow a uniform protocol, with the selection justified accordingly (Zimmerman et al., 2007).

Different combinations of qualitative and quantitative evaluation methods were used across the study, depending on whether a prototype could be empirically tested, simulated, or explored through guided interaction. Each evaluation used a tailored combination of approaches to provide complementary forms of evidence with the aim of deepening understanding.

An overview of the evaluation logic and methodological orientation is provided here. The specific procedures, instruments, and analyses for each prototype are explained in detail in Chapters 4–6 for each design intervention.

3.3.3.1 Qualitative Strand: Experience and Interpretation

Qualitative research was an important part of the evaluation process for each prototype, providing insight into how participants and experts understood and reflected on the design interventions. Semi-structured interviews, think-aloud protocols, post-task reflections, and expert feedback were leveraged where appropriate to explore experiences of ease of use, focus, mental effort, and other potential cognitive effects.

In Attention Mode, think-aloud sessions, short post-task interviews and qualitative feedback from open comments in the System Usability Scale (SUS) questionnaire were used to gather feedback on the design's usability and perceptions of its potential to support attentional control, distraction management, and task flow. Employing the think-aloud protocol, in which participants verbalised their thoughts during the task, was possible because Attention Mode was an interactive prototype that allowed direct engagement with the interface.

On the other hand, *SmartPause* focused primarily on cognitive assessment rather than interface interactivity. Therefore, instead of an interactive prototype as in the other two studies, the reading experience was simulated under controlled conditions, with the experimenter guiding participants through predefined interaction points such as pausing and note-taking. As the final step after the cognitive assessments, the interaction flow and interface visuals were presented in a short video, while qualitative feedback was obtained only from open comments in SUS questionnaire.

The *ReasonScape* design was first presented to experts in AI and HCI through visual materials and discussion to gather feedback on its relevance, potential benefits and feasibility. Subsequently, an interactive prototype was developed, and a small-scale usability session was conducted using a think-aloud protocol, short interviews, and the SUS questionnaire, similarly to Attention Mode. These sessions focused on understanding usability and the design's potential to support reasoning and critical thinking in an AI-assisted context.

Beyond the three individual evaluations, qualitative methods also supported the synthesis stage. Cross-case analysis was applied across the design components of the three prototypes to identify recurring interaction-level patterns, which were then developed into design principles, guidelines, and a candidate framework (Chapter 7). This framework was further examined through qualitative comparative analysis against existing design knowledge, identifying points of extension, qualification, and conflict. Its applicability to a new context (social media feeds) was explored through a generalisability probe, demonstrating how the framework transfers to a new design problem rather than empirically validating it.

Across both the prototype evaluations and the synthesis stage, qualitative analysis provided an essential interpretive layer, revealing how users made sense of the designs and how patterns across them could be consolidated into broader design knowledge.

3.3.3.2 Quantitative Strand: Performance and Perception

Quantitative methods complemented the qualitative strand across the study, but played a central role in *SmartPause*, where controlled experiments examined cognitive performance and usability outcomes.

All prototypes incorporated scores from the standardised SUS questionnaire that helped to interpret usability aspect of each design concept. Descriptive statistical analyses of SUS scores were conducted to evaluate perceived usability and benchmark the results against industry-standard usability thresholds.

For SmartPause, the primary goal was to explore how the features of design intervention affected the cognitive performance. Therefore, in addition to the SUS questionnaire, more comprehensive quantitative metrics were collected using established cognitive and personality assessment instruments, including the Stroop Task to measure selective attention and processing speed (Stroop, 1935), the NASA-TLX questionnaire to assess cognitive load (Hart & Staveland, 1988), the Big Five personality traits to examine the moderating effect of individual differences (Smederevac et al., 2024), and recall tests to evaluate long-term memory. A between-subject experiment was first conducted, followed by a smaller within-subject experiment to control for individual differences. ANOVA and paired *t*-tests were used to examine effects in cognitive and personality measures, along with descriptive statistical analyses.

The quantitative strand added precision to the evaluation process by linking observed interaction patterns with measurable outcomes. This combination ensured that both behavioural and experiential dimensions of cognitive resilience were addressed within the overall research framework.

3.3.3.3 Integrative Synthesis

Rather than analysing the qualitative and quantitative strands in isolation, findings from both were integrated to provide a fuller understanding of how the design interventions affected cognition and user experience. Qualitative findings helped interpret quantitative results, while numerical trends guided further questioning and design reflection. This link between data and design reflects the RtD approach, where findings are used both to verify outcomes and to guide new ideas.

For example, in *Attention Mode*, early feedback led to interface adjustments that were later reviewed through the SUS questionnaire and subsequent interviews. The

SmartPause experimental design was refined to reduce learning effects in Stroop task, and a within-subject study type was conducted following the between-subject study to better control for individual differences. In *ReasonScape*, expert feedback led to a study where again SUS questionnaire is used to assess usability. The synthesis stage extended this integrated approach beyond the three individual prototypes, applying it across studies to consolidate findings into broader design knowledge.

3.3.4 Ethical Considerations in Cognitive Research

Because this research involved studying cognitive processes and user experience, careful attention was given to participants' well-being, autonomy, and data privacy. The Attention Mode and SmartPause studies received ethical approval from Dublin City University (see Appendix B). The ReasonScape study collected expert feedback on a design concept rather than personal data from participants, and did not require separate ethics approval. All three were designed to minimise potential risks while ensuring transparency and informed participation. Safeguards were applied across five areas: participant welfare, procedural clarity, data protection and privacy, responsible reporting of results and diversity and accessibility .

3.3.4.1 Participant Welfare

All studies were conducted using everyday digital devices and activities such as browsing, reading, note-taking, and completing short interaction tasks. Both cognitive and usability assessments were entirely non-invasive and carried out through conversations, writing on paper or simple digital interactions, including clicking, navigating, typing, and watching videos. All assessments were designed to reflect entertainment, learning or productivity related cognitive activities rather than clinical testing.

Possible discomforts like mental fatigue or frustration were reduced by keeping participant sessions short, offering breaks, and allowing participants to pause where appropriate or leave at any time without consequence. The content in study materials were neutral and avoided political or sensitive content. Instructions were written and delivered in supportive, clear language, and no evaluative feedback was given or implied about participants' ability or performance.

3.3.4.2 Procedural Clarity

Before participation in the Attention Mode and SmartPause studies, all individuals received a *Participant Information Sheet* and an *Informed Consent Form* (Appendix C). The Participant Information Sheet explained the study's purpose, what participation

would involve, expected time commitment, and how their data would be used with researcher's contact details. The Informed Consent Form confirmed voluntary participation and the right to withdraw at any stage without penalty or explanation. After completing the study participants were debriefed verbally, and in some cases together with written form. It summarised the aims of the research and described how their contribution would inform the wider study.

All forms and sheets were written in plain language and provided contact details for any follow-up questions or to indicate if they wished to receive a summary of the research findings at a later stage.

No participants were selected from vulnerable or sensitive populations. Recruitment targeted English speaking adults with normal digital literacy and no known cognitive impairments ensuring that tasks were accessible for all involved.

3.3.4.3 Data Protection and Privacy

All procedures followed Dublin City University's ethics policies and the principles of the European Union's data protection law, commonly known as the General Data Protection Regulation (GDPR). (Regulation (EU) 2016/679, 2016). Data were collected anonymously, with no identifying details recorded at any stage. Only basic information (such as age, gender, or country) needed for the research was included. No biometric or sensitive personal data were collected, and no recordings of private conversations or unrelated on-screen activity were made.

Quantitative results, such as usability scores and cognitive task data, were stored under these number codes in anonymised form. All files were kept securely on university systems in line with the university's ethics and data protection requirements. Data retention and sharing followed institutional guidelines.

3.3.4.4 Responsible Reporting and Research Integrity

Findings are presented as design insights, not clinical or diagnostic claims. The goal was to understand how design interventions affect cognitive and usability outcomes in everyday digital interactions. Any limitations such as small sample sizes, learning effects or lack of ecological validity are clearly stated in each study.

Results were interpreted through both data and design reflection, following HCI research practices. No personal or identifiable information of participants appears in this thesis or related publications.

3.3.4.5 Diversity and Accessibility

Recruitment aimed to include people with different backgrounds and genders while ensuring participation was safe and comfortable. Accessibility needs were met when requested, such as larger text or extra time. Participants received small tokens of appreciation or compensation when appropriate. The designs aimed to support, not limit, user control, following principles of inclusivity, transparency, and respect for different cognitive and interaction styles.

These measures ensured that all user studies were conducted safely, transparently, and respectfully, while upholding ethical integrity and methodological rigour throughout the research process.

3.3.5 Validity, Reliability, and Research Rigour in RtD

RtD work is commonly judged by the rigour of the design process, the significance of the problem, the novelty and integration of the invention, and the clarity and transferability of the contribution beyond a single instance, as the four lenses of RtD (Zimmerman et al., 2007, 2010). To put this into practice, researchers need to make the guiding inquiry visible, account for the novelty and integration embodied in each prototype, and show how the insights generalise to other contexts, as defined by the four lenses of RtD. In this research, the significance of the problem and the design decisions for the three core designs are shaped by literature and further developed through RtD's iterative inquiry.

RtD does not typically lead to universal laws, so claims are positioned at a practical middle ground: clear, reusable ideas about interaction that others can adapt. (Höök & Löwgren, 2012) refer to these strong concepts, compact design ideas about behaviour over time that can be adapted across projects. To communicate the design ideas in this research clearly, an annotated portfolio of the prototypes is presented in Chapters 7 and 8. Although the prototypes differ in form and interaction contexts, this portfolio illustrates the common broader focus, mitigating cognitive side-effects in everyday digital use. Each entry provides a brief annotation of what the prototype demonstrates and the context in which it was shown (B. Gaver & Bowers, 2012). As Gaver (2012) notes, such outcomes are shaped by their specific context, and this thesis aims to propose design knowledge that can be reused more broadly by indicating the interaction contexts in which each part of the knowledge applies, while also being clear about its limitations.

This way of bringing prototypes together follows how other RtD programmes report their contributions. Work with several prototypes often leads to a strong concept, a design space, or a set of practical lessons for future designs. For example:

- **Höök et al. (2016)** worked with two artefacts, a heated carpet and a breathing-synchronised light explored through guided bodily sessions and body-maps. From these experiments, they described a strong concept showing how technology can support deeper bodily attention.
- **Grønbæk et al. (2020)** examined three collocated-sharing ideas (people sharing content in the same room). By comparing these ideas, they identified key aspects of spatial relations and how people move and interact around shared devices.
- **Alvina et al. (2020)** compared four different concept videos, all evaluated with the same interview method. Looking across the four ideas, they created a design space for cross-device learnability and suggested practical recommendations
- **Weisz et al. (2024)** reviewed several generative-AI prototypes and real products using the same analysis method. By looking across many different examples, they showed how comparing prototypes can help surface more general design principles for generative-AI applications.

Rigour is not achieved by forcing every prototype through the same test, but by ensuring method-question fit and maintaining a clear link from data to insight. RtD remains designerly (i.e., sensitive to context, time pressure, and judgement) so evaluation might need to vary across a project (Stolterman, 2008). This can also be seen in several RtD studies that used different evaluation approaches for different prototypes:

- **Sanches et al. (2010)** combined Wizard-of-Oz sessions (where a human secretly simulates the system's behaviour without the participant knowing), autobiographical use (researchers using the prototype in their own lives), and short-term user trials. Each method probed into different experiential aspects of affective health that could not be captured through a single evaluation approach.
- **Zhu, Hedman, and Li (2017)** mixed interviews, experience-sampling (self-reports collected during everyday use), and reflective sessions. This combination allowed them to understand digital mindfulness practices from multiple angles: moment-to-moment experience, longer-term patterns, and users' interpretations.
- **Windlin, Höök & Laaksolahti (2022)** blended somaesthetic self-exploration (researchers exploring sensations and bodily responses themselves) with participant studies. Although their setup varied across prototypes, the intent was the same: to "sketch with the body" and understand different layers of bodily experience.

- **Bravo, Maier & Cash (2021)** used interviews, co-design workshops, in-situ AR testing (trying the augmented reality experience directly in the environment where it would be used), and remote mobile-AR sessions. Each of these methods revealed different qualities of hybrid AR presentations, from early concept understanding to real-world interaction behaviour.

Alongside method–question fit, basic qualitative good practice helps support the credibility of the research. Sessions were documented through written tables, notes, and prototype traces, providing an anonymised record of what was explored and how participants responded. Short reflective notes captured the researcher's own stance and potential biases during the work. These measures help keep the reasoning behind each insight visible and open to inspection as recommended by qualitative HCI guidance (Blandford et al., 2016).

These practices create a clear and reliable trail from design activity to research insight, forming the basis for the following chapters, where each core prototype is examined as an RtD artefact and its contribution to the design knowledge is presented.

PART II

DESIGN STUDIES

Chapter 4

Design Study 1: Attention Mode for Sustained Attention in Digital Media Use

This chapter introduces *Attention Mode*, the first design study in this thesis and the earliest exploration of how everyday digital interactions might be redesigned to better support sustained attention. This study is motivated by research showing that many digital environments make it harder to maintain attention, due to visual clutter, frequent notifications, and the ease of switching between media. Moving beyond the view that distraction arising from these interactive elements is simply a failure of self-regulation or something to be handled through separate reactive blocking tools, this research examines how the interface itself can be designed to more actively support sustained attention.

Attention Mode puts this idea into practice through a single in-app *Attention Button*, which triggers several distraction-minimising changes at once. This concept was tested using three prototype interfaces in common contexts: a desktop news site, a tablet reading app, and a smartphone video player. Applying a consistent design strategy across platforms helped reveal how distraction-reducing interactions adapt to different interaction modalities, particularly how they are influenced by distinct affordances and interruption patterns.

The chapter is based on two empirical inquiries, both conducted using interactive prototypes rather than deployed applications. First, a study with five participants examined reactions to the early prototypes and informed refinements to interaction details. A subsequent larger usability evaluation with thirteen participants assessed the understandability, usability, and perceived value of Attention Mode across the refined prototypes. Together, these studies provide the first empirical grounding for how proactive distraction-minimising interactions may contribute to cognitively resilient

design. The results presented in this chapter form the basis for the more targeted and mechanism-specific design interventions explored in the following chapters.

Figure 4.1 illustrates where this chapter fits within the overall research process, highlighting the design study reported here. The design study reported in this chapter has been published in the following peer-reviewed conference papers:

- Hacioglu, N., Leva, M.C. and Lee, H. (2023a) 'Re-designing the Interaction of Day-to-Day Applications to Support Sustained Attention Level', *HCI International 2023 – Late Breaking Papers*, Copenhagen, pp. 363–377.
- Hacioglu, N., Leva, M.C. and Lee, H. (2023b) 'Designing Interaction to Support Sustained Attention', *INTERACT 2023*, York, pp. 454–458.

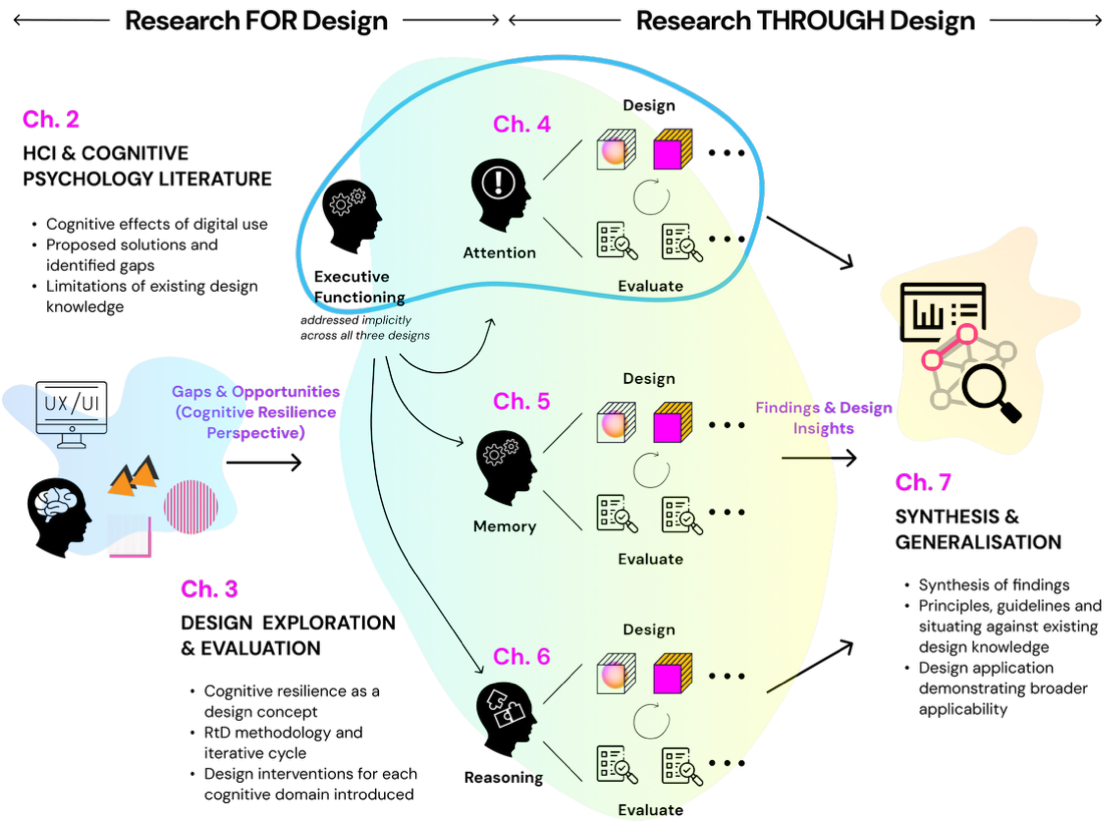


Figure 4.1: The Attention Mode design study within the research process (circled in blue).

4.1 Problem Focus and Design Opportunity

4.1.1 Effects of Attention-Capturing, Multitasking, and Interruptive Interfaces on Attention

In recent years, numerous studies have documented detrimental effects on various cognitive abilities, including memory, decision-making, and problem-solving skills. Among these, attention has emerged as the most extensively studied area concerning the

adverse impact of smart devices and digital applications. People's deteriorated attentional abilities are no longer only in the form of personal anecdotes shared in friendly conversations, as increasing scientific evidence in academic studies and experimental results have appeared for the past 15 years or so (Hari, 2022; Mark, 2023).

In particular, the interactions provided in today's computing systems that facilitate the consumption of media contents and those supporting other daily tasks seem to have been specifically designed to aggravate the situation: web user interfaces are filled with elements diverting the user's attention away from the main task of the page (a myriad of navigational elements such as menu bars, short-cut buttons and other non-content-related information, notwithstanding the commercial advertisements embedded as part of business model); "related" items frequently shown on informational and e-commerce systems almost as de facto standard; operating systems supporting easy switching amongst multiple applications; constant email/message notifications, to name but a few. Cognitive scientists have already established that frequent multitasking reduces the user's cognitive resources while at a task, consequently making the person more susceptible to distractions (Madore & Wagner, 2019; Mark, 2023).

There is a body of evidence from the literature regarding the detrimental effects of digital technology on attentional processes, despite some reported benefits in rare cases. Accordingly, the remainder of this section highlights only a small subset of representative findings to motivate the design opportunity pursued in this chapter.

Various behaviours related to technology usage can disrupt attentional systems and executive control in the short and long term. For instance, adolescents who frequently engage with technology are at a higher risk of developing symptoms associated with ADHD due to multitasking and repetitive shifts in attention (Small et al., 2020). Ophir, Nass and Wagner (2009) found that individuals who engage in extensive media multitasking exhibit decreased voluntary attention allocation performance when faced with distractions.

Extended internet and social media use can potentially deteriorate the executive attention network, which is responsible for executive functions such as inhibitory control and willpower (Davis, 2001; Goldstein, 2019). The continuous bombardment of notifications intervenes with inhibitory control and aggravates the situation further. Habitual social media use makes it harder for people to disengage even when other primary tasks are waiting (Du et al., 2019; Freytag et al., 2021; Misra & Stokols, 2012). However, digital technologies do not only adversely affect attentional systems: regularly

playing video games enhances and improves visual, divided, and sustained attention in some cases (Green & Bavelier, 2003; Misra & Stokols, 2012).

4.1.2 Existing Solutions and Limitations

The scientific literature available today predominantly mentions digital media's negative (and occasionally positive) effects on cognition as their conclusions of the study. Only a small subset of authors proceeds to suggest solutions to these effects. As outlined in Section 2.2.2.6 of Chapter 2, the proposed remedies are dominated by behavioural self-regulation strategies, such as scheduled "tech breaks," boundary setting, keeping devices out of sight, and broader digital hygiene practices or by intensive interventions including cognitive training and cognitive behavioural therapy (CBT). In both cases, the responsibility is placed primarily on the end user, requiring sustained discipline, commitment, and effort, while concrete, empirically tested design-oriented UX interventions that redistribute this burden toward interface-level support remain largely absent.

Findings from the literature suggest that time away from screen-based media improves attention (Throuvala et al., 2020). One study mentions that Intel Corporation implemented "quiet time", where employees took time off from electronic communication during designated periods to minimise distractions to mitigate this problem (Misra & Stokols, 2012). There are also software programs that block the internet for designated periods and web browser extensions that remove irrelevant contents such as notifications, newsfeeds, and advertisements (Focus, 2026; *Freedom*, n.d.; Hill, 2025).

More intensive user-side interventions include cognitive training programmes such as Cogmed (*Focus Learn Get Things Done*, n.d.) which target attention and working memory through structured exercises, and CBT for problematic internet use, which uses methods such as recording internet use and structured time away from devices (Davis, 2001)

4.1.3 Knowledge Gap and Study Aim

The knowledge gap addressed in this chapter is that most suggested solutions treat every day interactive technologies and their attention-shaping interaction patterns as given and attempt to reduce negative consequences during or after use rather than redesigning interaction to be less cognitively costly in the first place. While considering attention from the start of design is likely to be a more holistic route, very little is known about how existing interaction design knowledge (e.g., usability criteria and established principles)

can be applied or extended to support sustained attention as a cognitively resilient design goal.

In this context, a design solution is proposed that aims to minimise such negative impacts on attention by helping control major factors that will make the user more prone to distractions directly on the user interface of the application currently used. This approach can help users turn off potential distractions from tasks more readily, remain focused on them, and reduce cognitive load to improve sustained attention, ultimately expected to improve their overall experience. Insights gained through the design process, usability testing sessions with 13 participants using three prototype mock-ups that implement this idea, and analysis of feedback are presented, including reflection on how established usability criteria and design principles might be augmented or extended to support attention-aware interaction design.

This positions Attention Mode as an integrated cognitively resilient design contribution, aligned with the research-through-design approach and evaluation logic established in Chapter 3. This study operationalises this contribution through concrete prototypes and empirical assessment, forming an initial basis for the mechanism-specific interventions developed in later chapters.

4.2 Attention Mode: A Distraction-Reducing Interface Control

4.2.1 Design Concept

The Attention Mode design presented in this section reflects the final design after iterative refinement informed by formative feedback (reported in 4.4.1). It was produced as an interactive prototype rather than a working application, and all evaluations reported in this chapter used that prototype. By reviewing existing attention-related studies and solutions, insights were gained into short-term and long-term design implications of digital technology on attention such as notifications, visual distractions, and media multitasking. These insights informed design decisions to create user interfaces where potential negative effects would be mitigated.

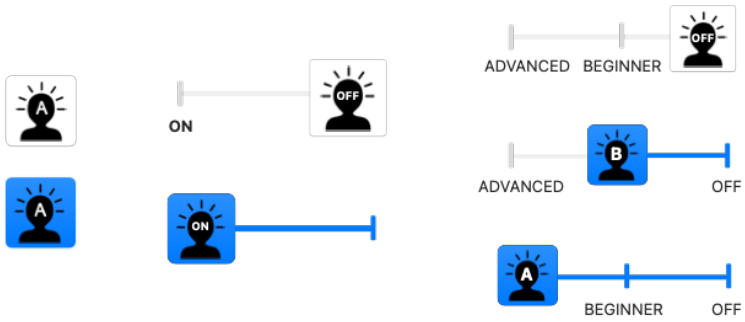
The Attention Mode concept was developed to tackle distractions in diverse contexts. Triggered by clicking, dragging, tapping, or swiping depending on the platform's supported modality, the mode supports the reduction/removal of potential media distractions. This feature bears a resemblance to the "Focus" (Apple, n.d.-d)[15] and

[15] Focus on iPhone, Apple Support. https://support.apple.com/en-gb/guide/iphone/iphd6288a67f/ios

"Downtime" (Apple, n.d.-c)[16] functionalities found on smart devices, which aim to reduce distractions. However, unlike these existing features that require multiple steps scattered across various locations and only address specific distractions, the Attention Mode collectively eliminates designated media distractions with a single action. In this sense, the mode is perhaps more analogous to "airplane mode" of a typical smartphone which, when turned on, will collectively turn off all functions related to mobile/wi-fi usage scattered around in different parts of the settings and options. Furthermore, this feature is intended to be seamlessly integrated into the user interface of applications, allowing users to trigger it more effortlessly while engaging in tasks.

4.2.2 Interaction Model and Mechanism

The Attention Mode button simplifies user interaction by presenting a button strategically placed within the user interface. Upon interaction, this button instantly reveals a set of sub-options that can be selected (Figure 4.2a).



(a) **(b)** **(c)**

Figure 4.2: Attention Button and selectable Attention Mode levels. (a) Attention Button; (b–c) Attention Mode level options (options are displayed when pressed).

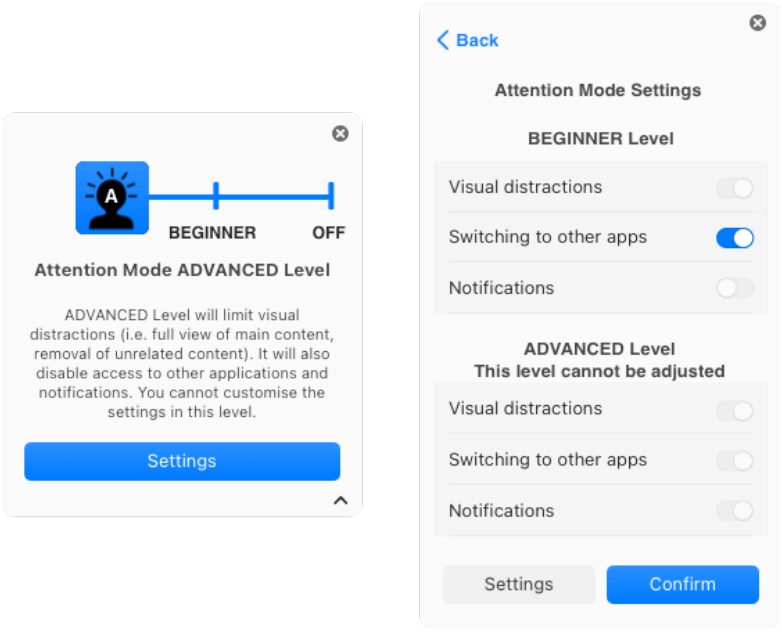
When the button is pressed, users can choose between one or two different modes, depending on the application, platform, and device (Figure 4.2b-c). These modes exclude various distractions. Furthermore, in some instances, the interface provides customisation options in the settings menu, as depicted in Figure 4.3. In this settings menu, users can change pre-set default values for Attention Mode Beginner Level. Customisation options allow users to personalise the mode to their liking (i.e., what distractions should constitute as Beginner Level thus be blocked when it is activated). In contrast, the pre-set default values provide users with a convenient starting point for users who may not want to customise the mode.

[16] Screen Time on Mac, Apple Support https://support.apple.com/en-gb/guide/mac-help/mchl69510069/mac

Once a level is selected, the mode is activated instantly and can be turned off without requiring confirmation. A concise explanation of the Attention Mode is provided within the Options window for first-time users. If users prefer not to see this content, they can collapse the popup window by pressing the "up" arrow in its bottom-right corner (Figure 4.2a). They can display them again by pressing the "down" button. The Options disappear when the close icon or an area outside the window is clicked or tapped. Once it disappears, users can still see the status of Attention Mode on the UI as a single button.

While turning on/off with different option sets is not novel, a few design choices are gathered to enable an interaction that is particularly suitable and unique for this purpose:

- It collects options otherwise scattered around into one location for access; thus, a single button is pressed to activate/deactivate.
- Information about distractions and usage is given to help users raise awareness of digital distractions.
- The user can select one of the levels of attention, each representing a higher-level set of options as needed.
- The widget-level interaction mechanism can be designed slightly differently to suit different applications on different platforms.

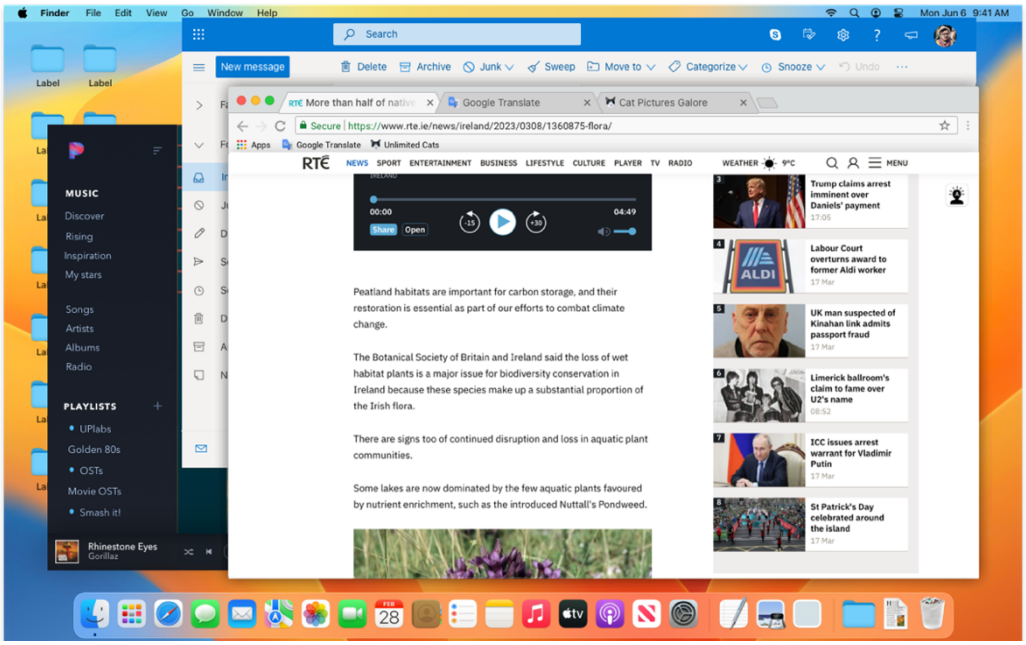


(a) **(b)**

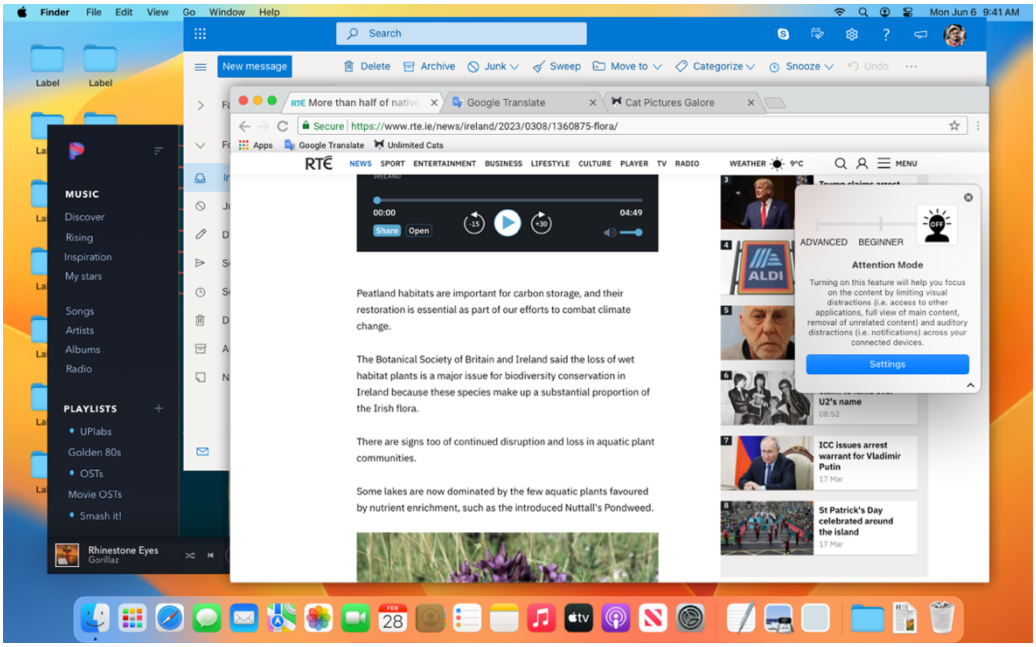
Figure 4.3: Attention Mode customisation, where supported by the application or platform. (a) Attention Mode popup with the Settings button as entry point; (b) Settings page with customisable Beginner Level options and fixed Advanced Level options.

4.2.3 Prototypes

Three different user interfaces were developed, each for a different interaction device: a news website on a desktop, an e-book reader app on a tablet, and a video-streaming app on a smartphone. This diverse set of media was to test how the overarching concept of the Attention Mode strategy could be consistently applied to the three commonly used interaction platforms and what aspects each might require some design customisation due to the unique affordances of each medium. The designs presented below reflect their final form after iterative refinement informed by formative feedback.



(a)



(b)



(c)

Figure 4.4: Attention Mode interaction states on the news website desktop interface. (a) Attention Mode off; (b) settings displayed after selecting the Attention Button; (c) Beginner Level selected.

4.2.3.1 News Website on Desktop

This prototype is designed to demonstrate a desktop environment with minimum distractions when the user's primary task is to read an online newspaper article. Distractions such as recommended articles, website advertisements, browser settings, desktop view, and other open applications on the computer are considered irrelevant to the article itself. To eliminate these distractions and allow users to focus solely on reading the article, Attention Mode can be activated (Figure 4.4).

Here, the Attention Button should be present in the top-right corner of every page. The purpose of the button is to provide a consistent function across all pages, while the specific function may vary slightly depending on the page.

In this example, customisation is available for Attention Mode at the Beginner Level, while the Advanced Level cannot be personalised. The Advanced Level entails the elimination of all distractions, including irrelevant visual content, email, and messaging notifications, and switching to other applications to prevent media multitasking. It is crucial to note that activating the Attention Button on any page will have a global effect on all other site pages ensuring the user's preferences and selected settings are consistently saved and applied throughout the site. Users can allocate their attention more effectively by eliminating visual distractions that may prompt task switching and blocking external

notifications during tasks (Ophir et al., 2009). Helping users focus on their primary task, in turn, reduces the occurrence of attention lapses (Madore et al., 2020) as the opportunities for multitasking behaviour decrease.

4.2.3.2 E-book Application on Tablet

Designing an interface for e-book reading on a tablet requires different considerations than designing for news sites or other browsing activities on a desktop. While both activities involve reading, the reading experience for an e-book is typically longer and requires more sustained focus. Since consistent media multitasking reduces sustained attention ability in the long term (Madore et al., 2020; Madore & Wagner, 2019), it is essential to design an interface that encourages users to stay focused for extended periods by preventing them from switching to other applications (Mark, 2023). Therefore, the user can set a target duration on Attention Mode to stay in the reading task (Figure 4.5), where the user cannot switch to other applications until the specified time is up. Since the app has no visual distraction (tablet apps typically occupy the whole screen visually), only ON-level multitasking and notifications are prevented, unlike the desktop example above.

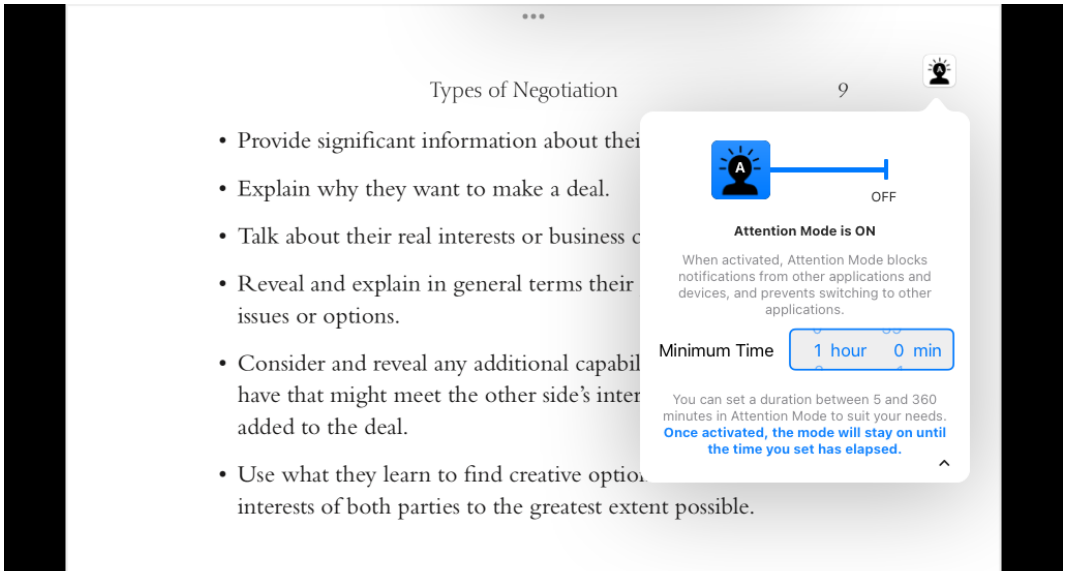
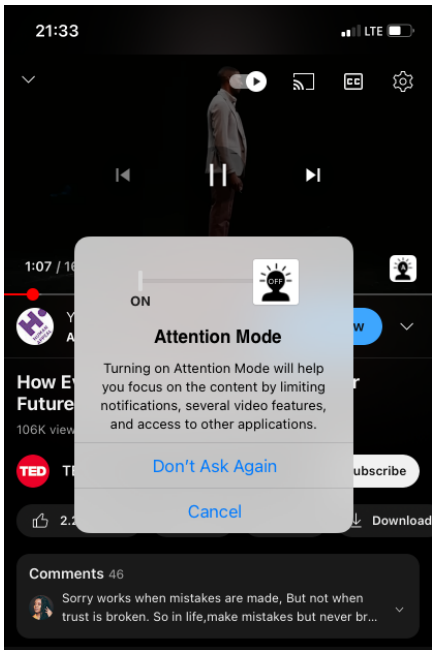


Figure 4.5: Attention Mode options on e-book application on a Tablet.

4.2.3.3 Video Streaming Application on Smartphone

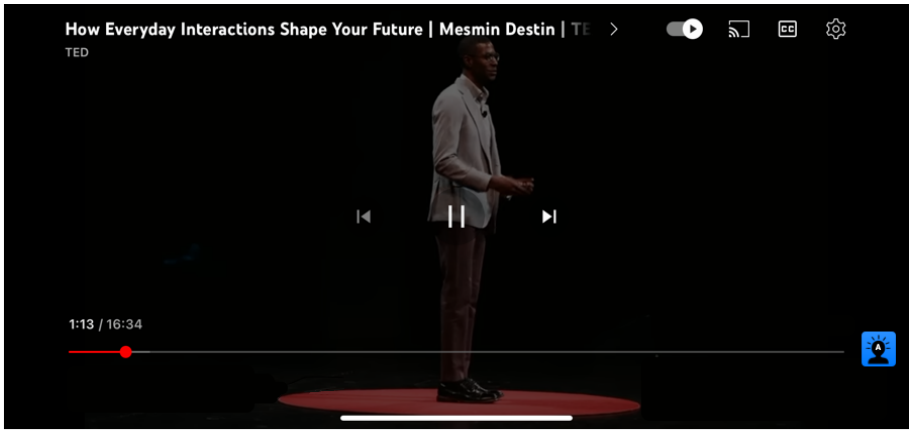
Implementing Attention Mode in this video-watching app was to augment a full-screen button typically featured on many video players by blocking notifications and other distractions, easily selectable in one go. Located at the bottom-right corner of the video



(a)



(b)



(c)

Figure 4.6: Attention Mode interaction states in the video-streaming application on mobile device. (a) Attention Mode off; (b) Attention Mode on, with the video occupying the full screen; (c) Attention Mode on, with notifications disabled, access to other applications prevented, and selected video features removed.

player panel, the user can turn the mode on to maximise the video as in the classic full-screen feature. Additionally, notifications are silenced, switching to other applications is prevented, and buttons like the share, comment and "more videos" buttons are removed, as these options might encourage multitasking at the ON level, thus increasing the user'ssusceptibility to further distraction (Figure 4.6). All three prototypes were implemented in the Sketch prototyping tool[17] to simulate the interactivity required for user testing (Sketch, 2026).

4.3 Evaluation Method

Two empirical inquiries were conducted to examine Attention Mode across the three prototypes. One-to-one preliminary feedback sessions with 5 participants were conducted who were shown design prototypes and discussed to gather feedback on different aspects of the mode. A usability evaluation with thirteen participants assessed the understandability, usability, and perceived value of Attention Mode across the refined prototypes.

4.3.1 Phase 1: Preliminary Feedback Sessions (n = 5)

The development of the prototypes involved a series of iterations in Sketch (prototyping tool). Initially, three different prototypes were created, and these prototypes were refined across four iterative cycles. Following the third cycle (of four), a preliminary feedback session was conducted with five experts from the technology and design fields. The participants, comprising 3 females and 2 males, were aged between 24 and 44, and represented various nationalities including Irish, Chinese, Romanian, Turkish, and German.These one-to-one preliminary feedback sessions involved showing the design prototypes and inviting discussion to gather feedback on different aspects of the mode. The session protocol is provided in Appendix D.1

4.3.2 Phase 2: Usability Evaluation (n = 13)

4.3.2.1 Participants

Thirteen participants (n = 13) from diverse cultural backgrounds (2 French, 2 Indian, 1 Italian, 1 Brazilian, 1 Spanish, 1 Moroccan, 1 Colombian, 1 Chinese, 1 Kazakh, 1 Russian) took part in the study. The sample consisted of seven females and six males, ages 25 to 35 (mean age = 28.5 years). The participants were recruited through events organised by third-level institutions in Ireland. The study protocol was approved by the Ethics Review Commission of the Dublin City University.

[17] https://www.sketch.com/

It is important to acknowledge that the sample size is relatively small, which may limit the generalizability of the results. Nonetheless, efforts were made to include participants from various nationalities and genders within the available pool of participants.

4.3.2.2 Usability Testing Sessions

Prior to the study, participants were provided with plain language statements and informed consent forms, which they were required to read and understand. After reviewing the materials, participants signed the consent form, indicating their willingness to participate in the study. The usability testing sessions were conducted individually, each lasting approximately 15 minutes. Before the testing began, the context of the study was briefly explained to the participants verbally. Participants were then instructed to interact with each of the three prototypes. Using the Sketch tool environment, the news website app was accessed on a MacBook Air M2 2022, the e-book app on a 5th Generation 12.9-inch iPad Pro, and the video streaming app on an iPhone 11. After using each prototype, participants were asked to complete the printed System Usability Scale (SUS) (Appendix D.2)**,** a widely used usability questionnaire originally introduced by Brooke (1996) and later empirically validated across a broad range of systems (Bangor et al., 2008). In addition, participants were encouraged to provide qualitative feedback on their experiences with each prototype, with space provided on the SUS form for written comments and suggestions.

4.3.2.3 Data Analysis Approach

The collected data, including the SUS scores and participant feedback, were analysed to assess the usability of the prototypes and identify areas for further improvement. The SUS scores were aggregated and analysed using descriptive statistics. The qualitative feedback provided by participants was examined to identify recurring themes and patterns. Participant privacy and confidentiality were ensured throughout the study. Data were anonymized and stored securely, and personal identifiers were removed during analysis and reporting.

4.4 Findings

4.4.1 Early User Feedback: Refinement Outcomes (n = 5)

As noted in 4.2.3, the final prototypes emerged from iterative refinement informed by formative feedback sessions with five participants. This section describes the feedback that drove the key refinements, which focused on cross-device coherence, clarity for non-expert users, and reducing unnecessary complexity.

The news website was particularly well-received, with all participants acknowledging the benefits of having a mode that helps them focus more by removing distractions from their desktop environment. This feedback supported keeping a two-level structure for the desktop news prototype, where the desktop context contained multiple concurrent distraction sources (e.g., page clutter, notifications, and cross-application switching), making a graduated "Beginner" versus "Advanced" distinction meaningful in practice.

However, there were differing opinions on the customisation of mode levels. One participant expressed interest in the idea of customising the level of distraction settings, while another participant raised concerns about potential confusion for less technologically inclined users. In response, the explanation text and interaction labels were revised to be more explicit and layperson-oriented, so that the purpose of each level and the rationale for the changes were clear at the moment of activation. In addition, the refinement clarified the relationship between levels by treating Advanced Mode as the non-customisable default configuration, and by preventing the Beginner Level from being customised to match the Advanced Level (to avoid two identical modes with the same settings). This refinement aimed to preserve simplicity while still allowing personalisation where appropriate.

Feedback also indicated that the interaction structure could be simplified on the tablet e-book and smartphone video prototypes. In response, both prototypes were refined to use a single Attention Mode state rather than mirroring the two-level structure of the desktop news prototype. Because these interfaces have limited screen space and typically contain fewer simultaneous visual distractors than desktop web environments, the refinement prioritised one "ON" configuration that focused on preventing notifications and discouraging cross-app switching.

4.4.2 Usability Evaluation Findings (n=13)

Table 4.1 shows the mean and standard deviation values of the SUS scores for each prototype, providing an overview of the usability assessment. The scores for all prototypes exceeded 80, falling within the "excellent" range (Bangor et al., 2008).

Among the three prototypes, the Attention Mode feature on the video streaming app on the smartphone (Prototype 3) received the highest SUS score of 86.3, indicating a high level of usability. On the other hand, the same feature on the e-book app (Prototype 2) obtained the lowest score of 80.96, suggesting slightly lower usability compared to the other prototypes. The participants' preference was more varied for Prototype 2 compared to the other prototypes. Interestingly, despite Prototype 3 having the highest SUS score,

participants were more inclined to use this feature when integrated into a news website on a desktop environment (Prototype 1), evidenced by the higher scores for Question 1 (S1), as seen in Table 4.2. These results suggest that while Prototype 3 performed well in terms of overall usability, Prototype 1 seemed to have an advantage regarding initial user preference.

Table 4.1: Overall SUS score chart for each prototype.

	Prototype 1 News website	**Prototype 2** E-book app	**Prototype 3** Video streaming app
Mean Value	83.65	80.96	86.35
Standard Deviation	13.60	24.14	14.31

Table 4.2: Number of participants based on the score they reported for each question after using prototypes.

	Prototype 1 News website					**Prototype 2** E-book app					**Prototype 3** Video streaming app				
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
	1: Strongly Disagree									*5: Strongly Agree*					
S1	0	-	1	5	7	1	2	2	5	3	-	2	3	3	5
S2	7	5	1	-	-	11	-	1	1	-	8	2	3	-	-
S3	-	-	2	7	4	1	1	1	1	9	-	-	2	4	7
S4	6	3	3	-	1	9	2	1	-	1	8	2	3	-	-
S5	-	-	3	5	5	-	2	1	4	6	-	1	-	6	6
S6	11	1	1	-	-	9	2	2	-	-	12	-	1	-	-
S7	-	1	2	5	5	1	-	1	4	7	-	-	1	6	6
S8	10	3	-	-	-	9	3	-	1	-	10	1	1	1	-
S9	-	-	3	4	6	1	2	-	4	6	-	-	1	5	7
S10	9	2	1	-	1	8	3	1	-	1	11	1	-	-	-

Statements:
S1. I think that I would like to use this feature frequently.
S2. I found this feature unnecessarily complex.
S3. I thought this feature was easy to use.
S4. I think that I would need assistance to be able to use this feature.
S5. I found the various functions in this feature were well integrated.
S6. I thought there was too much inconsistency in this feature.
S7. I imagine that most people would learn to use this feature very quickly
S8. I found this feature very cumbersome/awkward to use.
S9. I felt very confident using this feature.
S10. I needed to learn a lot of things before I could get going with this feature.

Together with SUS scores, the participants' comments provide valuable insights into the strengths and weaknesses of each prototype, as well as recommendations for potential improvements.

Prototype 1 received positive feedback from participants, who recognised the value of the concept and expressed willingness to recommend it to others. However, participants also highlighted the need for a tutorial to aid new users in navigating the prototype. The feedback for Prototype 1 also emphasised its suitability for individuals with attention problems or those who engage in extensive web reading. The participants appreciated the UI's simplicity and ease of use when the Attention Mode is on, while providing suggestions for minor improvements such as reducing the size of the icon. There were differing opinions on the customisation of mode levels. One participant expressed interest in the idea of customising the level of distraction settings, while another participant raised concerns about potential confusion for less technologically inclined users. This feedback highlights the importance of considering the balance between customisation and simplicity in the design of the Attention Mode.

Prototype 2 received mixed feedback, with some participants finding it helpful for avoiding distractions while reading and recommending it to others. Participants also mentioned the desire for a time display as an additional feature. Those unfamiliar with tablet-based interactions found the interface unintuitive and had difficulty using the prototype independently. Several participants reported they would have liked the flexibility to quit the mode whenever they wanted, even if they had set a target duration. The user having control over the usage (including multitasking) is one of the important design guidelines available today. However, prioritising attention by reducing the cognitive cost of task switching means that this guideline may need to be compromised, raising an issue on how the existing usability criteria could accommodate this.

Prototype 3, the integration of the Attention Mode button within the video-streaming application was well-received by participants. However, there were differing opinions regarding the exclusion of certain features, such as the comment section. Participants highlighted the need to balance distraction reduction and retaining desired functionalities. Suggestions were made for including an ad-blocking option that appears when a video is streaming and improvements to the settings' accessibility. One participant liked the minimalist approach with fewer video options which also prevents accidental touches on the screen and unintended interruptions.

Overall, the feedback from the participants indicated that the proposed design approach of Attention Mode was well-received, with participants expressing positive sentiments about the concept of reducing distractions and creating awareness about their digital technology use. Suggestions for additional features, such as customisation options, as well as improvements related to accessibility, were highlighted.

4.5 Discussion: Implications for Cognitive Resilience and Design Knowledge

The results reported in previous section indicate that Attention Mode was perceived as usable across all three contexts, while participant feedback highlighted design tensions that become visible when sustained attention is treated as a primary design goal rather than an assumed user responsibility. In particular, the feedback themes point to trade-offs around (i) user control and flexibility, (ii) the acceptability of feature removal, and (iii) how much personalisation should be offered without increasing complexity for non-expert users. These tensions are not errors in implementation but signals of where established usability priorities may conflict with attention-supportive design aims.

From the perspective of cognitively resilient design used in this thesis, Attention Mode frames sustained attention as a designable interaction outcome rather than a purely individual responsibility. By integrating distraction reduction into the interface and making it available at the point of use, *the design shifts part of the burden of attention management from the user to the interaction itself.* The usability results suggest that this kind of interface-level support can be acceptable across devices, while specific design tensions may arise when cognitive resilience goals are prioritised alongside conventional usability criteria.

These tensions matter because interactive applications' usability and user experience play a crucial role in shaping attentional processes**.** However, it is essential to recognise that an overemphasis on efficiency, effectiveness, and learnability in interaction can negatively affect specific attentional processes in the short and long term. Efficiency-oriented applications prioritise saving time and mental effort, which can lead to reduced cognitive engagement. Users may rely less on attentional systems and executive networks when interacting with such applications. Similarly, when learnability is prioritised, users require minimal attention during initial interactions, potentially leading to decreased attention involvement. These patterns of reduced cognitive effort can contribute to degradation in attention skills over time, like how muscles can weaken without regular exercise. Therefore, it is worth noting that prioritising cognitive well-being, including the

attention process, may sometimes conflict with efficiency and learnability criteria, highlighting the need for careful consideration and balancing of design goals.

In this sense, Attention Mode highlights how "reducing distraction" is not only a matter of removing stimuli but also a matter of reconfiguring interaction expectations. For example, limiting switching opportunities or removing engagement features can support sustained attention, but may also be perceived as reducing autonomy or removing valued functionality. The findings therefore suggest that attention-supportive interaction design may require designers to treat certain conventional usability assumptions (e.g., maximising freedom of action, minimising constraints, preserving all features) as negotiable rather than universal.

Taken together, Attention Mode provides an initial design demonstration that interface-level controls can be used to operationalise attention-supportive interaction patterns across devices. At the same time, the tensions surfaced across contexts suggest that cognitively resilient design is not equivalent to "more usability" in the conventional sense, but a re-balancing of design priorities where sustained attention is treated as an explicit outcome or criterion to support.

4.6 Limitations and Future Work

There are limitations of this study, including the small sample size and potential biases in participant selection. Conducting larger-scale user testing with diverse participants would further validate the findings and provide more comprehensive insights. Future work could also move beyond mock-ups by implementing Attention Mode within functional systems, enabling field deployment where attention-supportive effects can be examined under everyday conditions (e.g., real notification streams, real switching opportunities, and longer sessions). Participants also expressed interest in having analytics to understand how their sustained attention has improved over time. This suggests a further direction for design and evaluation: combining interface-level distraction reduction with feedback mechanisms that make changes in interaction habits visible without reintroducing unnecessary complexity or distraction.

4.7 Conclusion

This chapter demonstrates a design approach that prioritises attentional well-being by minimising digital distractions on everyday digital platforms and examines the usability of this approach on different applications and devices (RQ2)**.** As the design of these prototypes prioritised sustained attention rather than other usability criteria, such as learnability or efficiency, some features conflict with conventional design guidelines. The

tensions identified in this chapter provide a basis for analysing the implications of existing usability knowledge and for developing ways of making sense of designing for attention as an explicit design goal (RQ3).

Key insights from this study include:

- Interface-level suppression of distractions offloads some of the attentional burden from user self-regulation onto the design itself.
- A single trigger that activates multiple distraction-reducing mechanisms has potential to lower the cost of engaging with attentional support.
- Consistent interaction structure across devices may also reduce the effort of using attentional support in different contexts.
- Visibility of the cognitive impact of distractions can motivate engagement with the support.
- Graded levels of support let users start with lighter protection and increase intensity as needed.
- Immediate, no-confirmation deactivation preserves user agency and may lower the perceived commitment of activating the support.

More broadly, the findings suggest that interaction design may need to reconsider and extend established design knowledge in order to better support cognitive resilience, both within single interactions and across repeated everyday use.

Chapter 5

Design Study 2: SmartPause for Memory Continuity in Digital Reading

This chapter presents SmartPause, one of the core design artefacts that contributes to the thesis goal of cognitive resilience by supporting memory retention and task continuity under everyday interruption in digital reading. SmartPause is a context-aware bookmarking concept that nudges users to pause at meaningful breakpoints and, in its fuller form, externalise insights through lightweight notes. The design was developed and iteratively refined through a Research-through-Design (RtD) process and evaluated in two controlled experimental studies. Across these studies, the effects of pausing at natural breakpoints and, where applicable, guided note-taking were examined in relation to cognitive performance, memory retention, and task continuity during digital reading tasks.

The first study evaluates the full SmartPause experience using a between-subjects design (N = 51) with three conditions: a control condition in which participants stopped at a predefined point before a section concluded, a breakpoint condition in which participants paused at the natural breakpoint without additional tasks, and a breakpoint + note-taking condition in which participants paused at the breakpoint and took notes. Participants completed a pre-reading Stroop task, the reading task under their assigned condition, and a post-reading Stroop task, followed by NASA-TLX, personality and demographic measures, and a recall test. A narrated walkthrough of the SmartPause concept was presented after the cognitive measures, and perceived usability was captured using SUS as a complementary interpretation layer rather than as the primary evaluation focus.

The second study is a smaller-scale evaluation that adopted a within-subjects design (N = 14) to reduce individual variability and to isolate exit timing as the core intervention

variable. It tested a simplified SmartPause version in which a context-sensitive nudge was delivered when a mid-section exit was attempted, with the summarisation element removed to avoid additional user burden. The protocol followed a similar structure with targeted refinements, including the addition of affective-state assessment and the removal of personality test, which was less relevant in a within-subjects design.

Together, the two studies reflect an RtD-grounded progression from a between-subjects evaluation comparing breakpoint-aligned pausing with and without note-taking to a method-optimised within-subjects follow-up that re-evaluates the timing-only condition, strengthening the chapter's emphasis on cognitive resilience through memory retention and task continuity in digital reading.

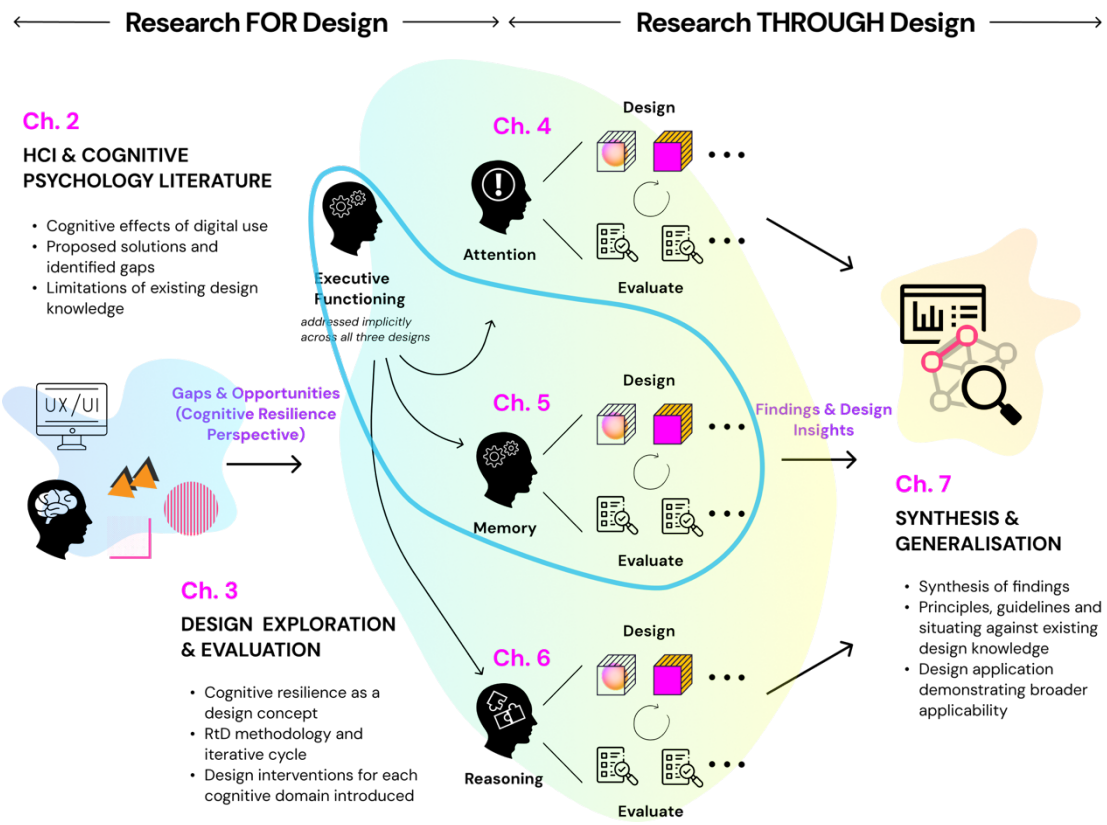


Figure 5.1: The SmartPause design study within the research process (circled in blue).

Figure 5.1 illustrates the scope of this chapter within the overall methodology, with the relevant areas highlighted in blue. The design study presented in this chapter has been published in the following two peer-reviewed conference papers:

- Hacioglu, N. *et al.* (2025) 'Mitigating Interruptions in Digital Reading: Strategic Pauses and Note-Taking for Enhanced Cognitive Performance', in C. Ardito et al. (eds) *Human-Computer Interaction – INTERACT 2025*. Cham: Springer Nature Switzerland, pp. 109–132.

- Hacioglu, N.B., Leva, M.C. and Lee, H. (2025) 'Strategic Pausing in Digital Reading: A Pilot Evaluation of SmartPause on Cognitive Performance'. *38th International BCS Human-Computer Interaction Conference*, BCS Learning & Development, pp. 358–368.

5.1 Problem Focus and Design Opportunity

5.1.1 Effects of Interruption Timing on Cognitive Performance and Memory in Digital Reading

Interruptions during task execution significantly impact cognitive performance, with their disruptive effects varying depending on when they occur. Prior research demonstrates that interruptions at natural breakpoints—moments when fewer cognitive resources are engaged—are less disruptive than interruptions during active task execution, which is characterised by high memory load and intense cognitive demand (Adamczyk & Bailey, 2004; Bailey & Iqbal, 2008). Interruptions disrupt task execution by imposing cognitive and memory demands, interfering with neural mechanisms needed to sustain focus and resume tasks efficiently (Altmann & Trafton, 2004; Clapp et al., 2010; Cutrell et al., 2001). Natural breakpoints, such as subtask completion, are identified as optimal moments for interruptions, as they minimise disruption to the user's mental model (Bailey & Iqbal, 2008). Additionally, well-timed interruptions reduce stress and enhance task performance across domains (Adamczyk & Bailey, 2004; Bailey & Konstan, 2006). However, their impact on reading tasks, particularly comprehension and memory retention, remains understudied.

Especially reading tasks involve unique cognitive processes, such as mental workload management and long-term memory retention, making them an important but understudied context for examining interruption management strategies (Altmann & Trafton, 2002; Grundgeiger et al., 2010; Khalifa & Weir, 2009; Monk et al., 2008). In addition to **t**hese challenges, digital reading has transformed how people consume information, yet it remains cognitively demanding and often less effective than print. Research has linked digital formats to reduced comprehension, visual fatigue, and fragmented attention (Benedetto et al., 2013; Froud et al., 2024; Jian, 2022; Liu, 2005). These effects are often exacerbated interaction-driven features such as scrolling, hyperlinking, and multitasking. Given the dominance of screen-based reading, there is a growing need to optimise digital interfaces for sustained engagement and information retention. These constraints make interruption timing and structured stopping points particularly consequential in digital reading.

5.1.1.1 Memory Retention and the Zeigarnik Effect

The Zeigarnik Effect, first described in 1927, highlights the psychological tension associated with incomplete tasks, which linger in memory more than completed ones (Zeigarnik, 1927, 1938). While this tension can aid task resumption (i.e., returning to the point of task where one left it off after some time), it also increases cognitive load and impedes focus. Strategies such as note-taking externalise this tension, improving mental clarity and enabling more efficient task resumption, particularly in digital contexts where they also enhance memory retention (Hollender et al., 2010; Scullin et al., 2018). Building on these insights, the SmartPause studies combined natural breakpoints with note-taking (where applicable) to manage cognitive load and enhance long-term memory retention during reading. This approach addresses the disruptive impact of interruptions while fostering task continuity.

5.1.1.2 Strategic Pausing and Guided Interventions

Strategic pausing at natural breakpoints offers a promising approach for managing interruptions in cognitively demanding tasks. Such pauses align with cognitive rhythms, facilitating smoother transitions and reducing mental strain (Altmann & Trafton, 2002; Bailey & Iqbal, 2008; Grundgeiger et al., 2010; Khalifa & Weir, 2009; Monk et al., 2008). While this concept has been applied in various experiments for diverse task contexts, the effects on digital reading remain insufficiently evidenced. Combining strategic pausing with interventions such as note-taking can further support memory retention by externalising information, thus reducing cognitive effort (Bannert & Reimann, 2012; Scullin et al., 2018; Westman, 2001). This approach not only holds potential to enhance memory retention but also to maintain task continuity in reading tasks that require complex linguistic integration over time.

5.1.1.3 Self-Interruption and Attention Management

Interruptions are not always external; internal factors, such as curiosity or habitual task-switching, often lead to self-interruptions. González and Mark (2004) found that individuals self-interrupt to seek information or alleviate boredom, disrupting focus and prolonging task completion. These behaviours were categorised as discretionary task-switching, which impedes attention and diminishes productivity, and it was further demonstrated that external interruptions often trigger self-interruptions, creating a feedback loop of fragmented attention (Dabbish et al., 2011; Jin & Dabbish, 2009). In reading, structured interventions, such as guided pauses at logical stopping points, may help manage both external and internal interruptions, fostering sustained focus and

cognitive continuity. Given the significance of sustained attention in comprehension, breakpoint-aligned pausing may improve the user's ability to stay focused and retain information.

5.1.1.4 Managing Cognitive Resources During Reading

Reading is a cognitively intensive activity that demands sustained attention, linguistic processing, and memory integration. Interruptions during reading disrupt these processes, requiring additional cognitive resources to reorient the mental model of the text (Altmann & Trafton, 2002). Strategically-timed pauses at natural breakpoints, such as at the end of a section or chapter, combined with note-taking, can reduce memory demands and improve task resumption efficiency.

Previous systems have explored ways to support users during interruptions. For example, Pan et al. (2011) developed a bookmarking tool that uses galvanic skin response (GSR) to detect orienting responses and place markers during unplanned disruptions. While effective, such systems are reactive and depend on biometric sensing. In mainstream digital reading tools, comparable breakpoint-aware support is typically absent; users rely largely on their own motivation and judgement to decide when to stop, with limited in-the-moment support or awareness of why stopping points matter.

These interventions have yet to be tested in digital reading contexts, especially as end-user features in digital applications. Therefore, investigating their impact on cognitive resources in this domain presents an important research opportunity, particularly for digital reading applications aimed at mitigating cognitive disruption.

5.1.2 Knowledge Gap and Study Aim

While previous research has advanced understanding of interruption management and cognitive load in general task contexts, there remains a significant lack of empirical evidence on how these strategies affect human performance in digital reading tasks. This limitation is particularly consequential for cognitive resilience in everyday digital reading because misaligned disengagement can interrupt consolidation and weaken long-term retention, leaving readers reliant on fragile working-memory traces and increasing the cost of later resumption. The SmartPause studies in this chapter aims to address this gap by investigating how strategic pausing at natural breakpoints and, where applicable, guided note-taking supported cognitive performance, memory retention, and task continuity during digital reading.

Accordingly, this chapter examines whether a user interface and interaction could be designed in which aligning disengagement with natural breakpoints (versus premature

mid-section exit) influenced recall, attentional control, perceived workload, affective state, and engagement in digital reading; and whether combining breakpoint-aligned pausing with lightweight note-taking further supported long-term memory retention and perceived continuity without increasing workload (RQ2). It also assessed how the design of such an interaction could be informed by, and inform, existing design knowledge (RQ3).

5.2 SmartPause: A Context-Aware Bookmarking System

5.2.1 Interaction Model and Mechanism

The SmartPause prototype was developed as a high-fidelity conceptual system designed to support cognitive continuity in digital reading. Rather than implementing a fully functional application, the prototype simulates a lightweight system architecture that models the user's disengagement intent and delivers structured interventions. Specifically, the interaction flow is organised into five cognitively aligned stages: (1) detecting user disengagement or task exit, (2) prompting continuation to a nearby natural breakpoint, (3) inviting note-taking upon reaching the breakpoint, (4) saving the note and line-level reading position, and (5) restoring both contextual cues when the user returns. While no real-time sensors or adaptive tracking mechanisms were used, the system assumes intent through user-initiated pause or exit actions. The prototype was evaluated through structured interaction scenarios and a narrated video walkthrough (H. Lee & Hacioglu, 2023)[18] that demonstrated the core features to participants during the study. Unlike reactive, sensor-based bookmarking systems (e.g., Pan et al., 2011), SmartPause proactively guides users to pause at meaningful points based on content structure and includes lightweight note-taking prompts to externalise memory. The prototype's interaction flow is illustrated in Figures 5.2 and 5.3, which visualise the sequential user experience—from initial bookmarking and pause detection to note-taking and context restoration.

5.2.2 Interface Features

5.2.2.1 Precise Bookmarking with Line-Level Precision

The design improves traditional e-book bookmarks by allowing users to bookmark specific lines within a page. Line-level marking itself is well established in mainstream e-readers such as Amazon Kindle (Amazon, n.d.)[19] and Apple Books (Apple, n.d.-a)[20];

[18] End-of-Section Reminder, Hyowon Lee, Youtube. https://www.youtube.com/watch?v=oVohBF6yLy4
[19] Amazon Kindle. https://www.amazon.com/kindle/
[20] Apple Books. https://www.apple.com/apple-books/

its contribution lies in integrating it with the pause-and-resumption flow rather than using it primarily for annotation.

A slidable widget helps users mark the exact line where they stopped reading, ensuring precise resumption of the task. This feature reduces cognitive load, aiding users in re-engaging with the text without needing to recall where they stopped, thereby improving attention and task continuity. This interaction also reduces task resumption latency by providing exact visual and semantic continuity.

5.2.2.2 Encouragement to Pause at Natural Breakpoints

A nudge system encourages users to pause at natural breakpoints, such as section or chapter endings. As soon as the user tries to place the bookmark pointer mid-section, a

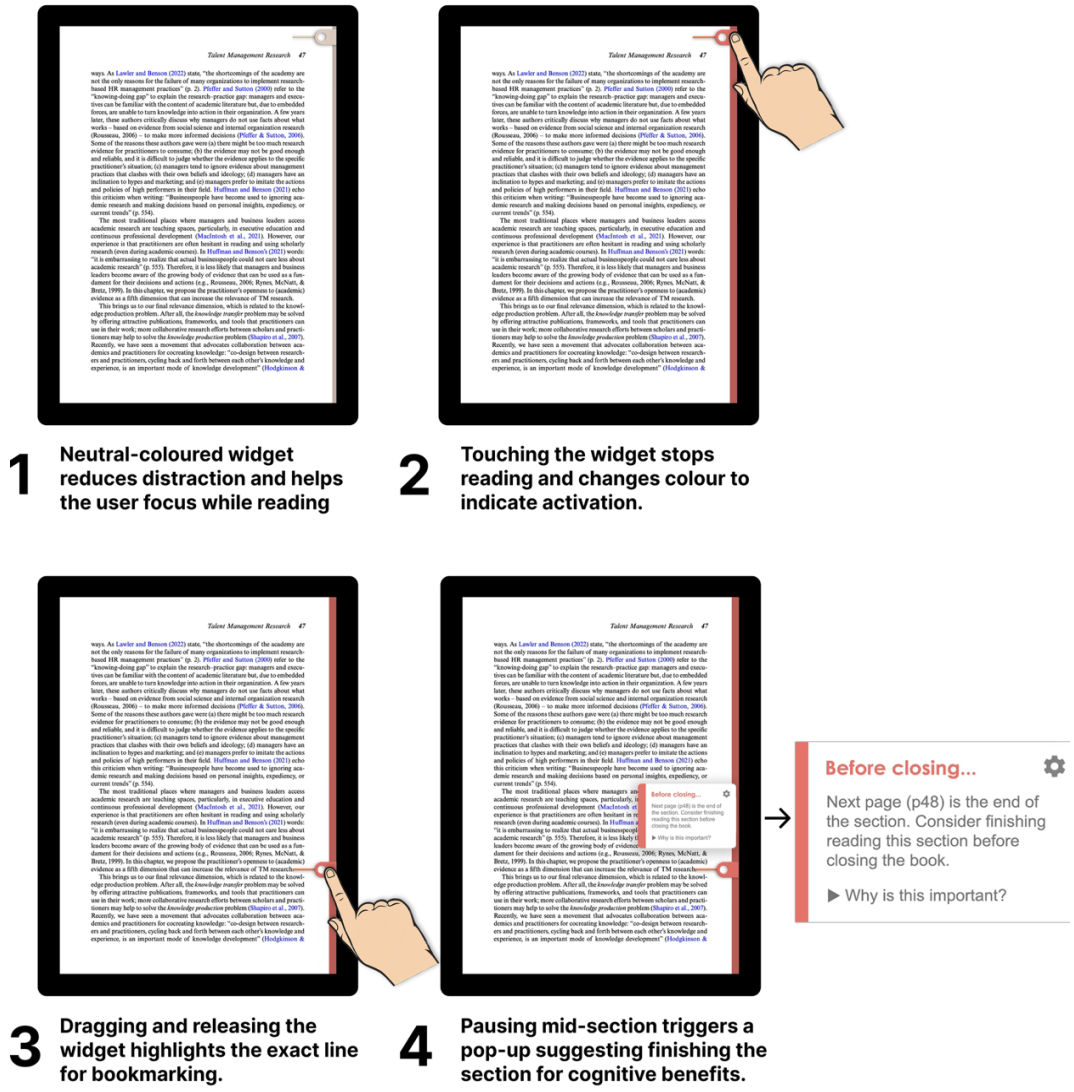


Figure 5.2: SmartPause prototype interaction flow (1/2) showing bookmarking and disengagement detection.

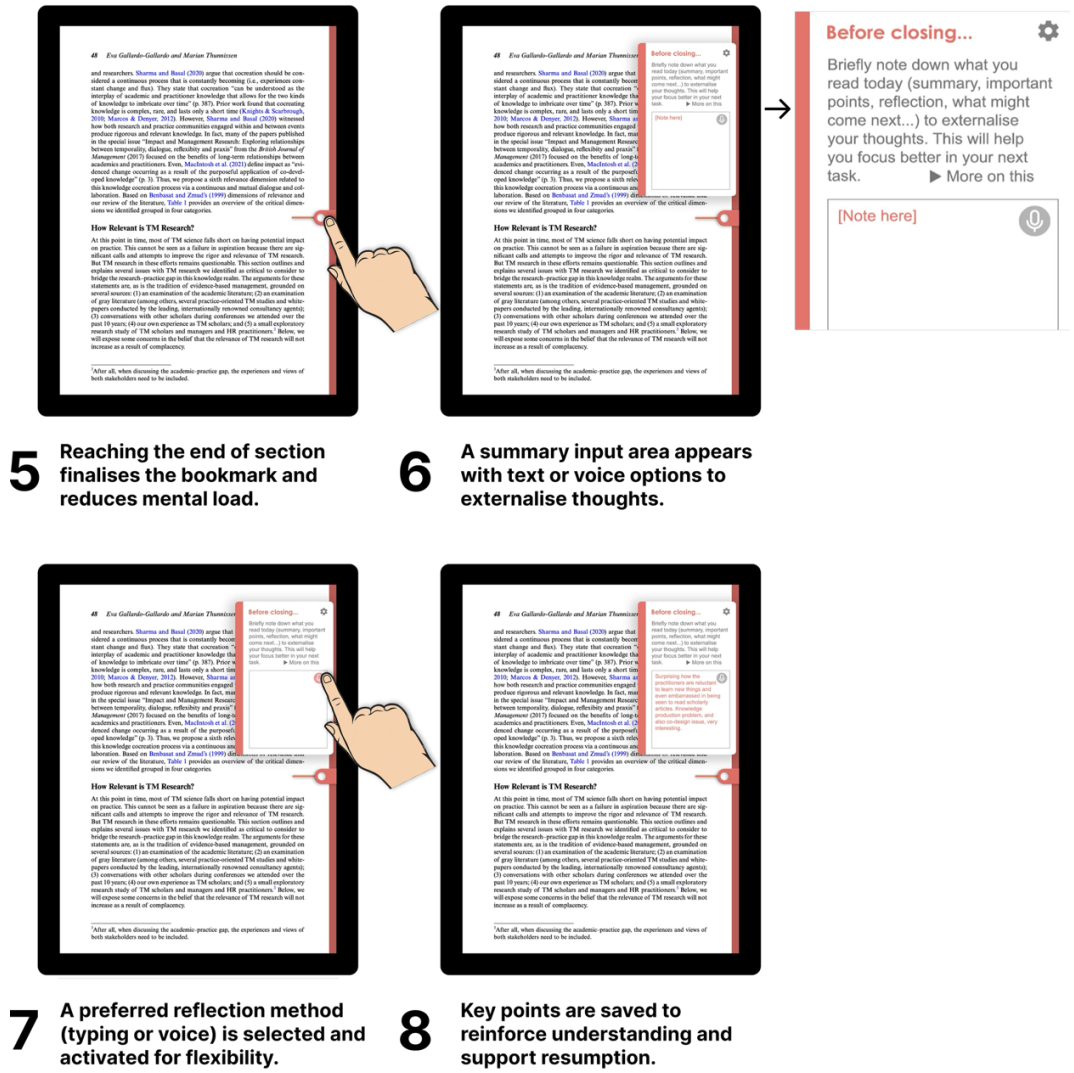


Figure 5.3: SmartPause prototype interaction flow (2/2), showing note-taking and context restoration on return.

small pop-up message appears next to the bookmark pointer, suggesting they continue reading to the next natural breakpoint (see Figure 5.3 (4)). The pop-up also includes a brief link explaining why this supports memory and task continuity.

5.2.2.3 Externalising Memories with Note-Taking Integration

Upon placing the bookmark pointer at a natural breakpoint, SmartPause prompts users to summarise their reading before exiting the task (see Figure 5.3(6)). This prompt is optional; users may decline it and continue without note-taking. They can type or dictate their thoughts using speech-to-text functionality. This externalises cognitive load and prepares users to resume reading with greater clarity. Mueller and Oppenheimer work (2014) provide empirical support for this design rationale, showing that generative note-taking, particularly when summarising or paraphrasing, leads to deeper processing and

better conceptual retention than verbatim transcription. This feature is informed by memory externalisation literature, suggesting that lightweight elaboration improves encoding and later retrieval. It also helps close the memory loop created by unfinished cognitive tasks, consistent with the Zeigarnik Effect.

5.2.2.4 Visual Continuity for Resumption

When users return, the exact line bookmarked along with the user's notes (see Figure 5.3(8)). is displayed. This ensures visual continuity, reducing the cognitive effort needed to recall the context of the previous session. This continuity mechanism reinforces the reader's mental model and improves task resumption by bridging the gap between sessions with both location and content cues, consistent with theories of goal resumption which emphasise the importance of contextual retrieval cues for suspended tasks (Altmann & Trafton, 2002).

These features were selected based on an extensive review of literature in cognitive psychology, interruption design, and task scaffolding, ensuring theoretical alignment rather than arbitrary inclusion.

5.2.3 Prototype Implementation

As the literature review and brainstorming progressed, the design of the bookmarking interaction was iteratively developed through a series of sketching exercises. Initial concepts were explored through pen-and-paper sketches, then refined as low-fidelity wireframes in Microsoft PowerPoint (Microsoft, n.d.)[21]. As the design matured, the wireframes were translated into high-fidelity visuals in Adobe Photoshop (Adobe, n.d.)[22]. The final visuals were sequenced into a set of slides and recorded as a 4-minute narrated video demonstrating the intended interaction flow.

5.3 Evaluation Method

5.3.1 Overall Evaluation Design

SmartPause was evaluated through two controlled experimental studies designed to assess the effects of breakpoint-aligned disengagement and, where applicable, lightweight externalisation through note-taking.

The first study used a between-subjects design to compare a control condition against two natural-breakpoint conditions (with and without note-taking), focusing on cognitive performance, workload, long-term memory retention, and perceived usability. The second study follows as a within-subjects pilot to reduce individual-difference effects and

[21] Microsoft PowerPoint. https://www.microsoft.com/en-us/microsoft-365/powerpoint
[22] Adobe Photoshop. https://www.adobe.com/products/photoshop.html

to isolate exit timing as the core intervention variable, while refining the protocol with affective-state assessment and longer recall delay.

Shared administration and apparatus details were consistent across studies: forms and questionnaires were administered online via an institution-managed account on Qualtrics (2024)[23] and the computerised Colour-Word Stroop task was administered using Inquisit Lab 6 (Millisecond, n.d.)[24] software. Participants completed all tasks on a MacBook Air laptop (M2, 2022, 16GB RAM) in full-screen mode to minimise distractions, and the study was conducted in a controlled, quiet environment. All analyses were conducted using Jamovi (2023)[25], an open-source statistical software.

5.3.2 Study 1: Between-Subjects (Primary Study)

5.3.2.1 Aim and Hypotheses

The following hypotheses aim to test whether SmartPause can optimise cognitive resources, enhance user experience, and demonstrate high usability during digital reading by aligning task interruptions with natural cognitive rhythms:

- **H1.1:** Exiting at a natural breakpoint will improve selective attention and processing speed in at least one of the natural breakpoint conditions (with or without note-taking), reflecting better attentional control and reduced interference.
- **H1.2:** Cognitive workload will be lower, and task engagement will be sustained, when users pause their reading at a natural breakpoint, in at least one of the natural breakpoint conditions (with or without note-taking).
- **H1.3:** Delayed recall will be higher in at least one of the natural breakpoint conditions (with or without note-taking), reflecting improved encoding and memory consolidation.
- **H1.4:** Participants will report high usability and positive engagement with the SmartPause prototype.

5.3.2.2 Participants

A total of 51 participants (aged 18-36, M = 25, 25 females, 26 males) were recruited for the study. Among them, 32 were native English speakers. Participants represented a diverse range of ethnic backgrounds, including EU citizens, as well as participants from Asia, Africa, and the Americas. All participants were at least high school graduates and

[23] Qualtrics. https://www.qualtrics.com/
[24] Inquisit, Millisecond Software. https://www.millisecond.com/download
[25] Jamovi. https://www.jamovi.org/

were currently enrolled in or had completed undergraduate education. Inclusion criteria required participants to have normal or corrected-to-normal vision, no history of attention or memory-related disorders, and fluency in English (native or advanced proficiency). The study received ethical approval from the university's Research Ethics Committee.

5.3.2.3 Experimental Design and Procedure

This study employed a between-subjects design, with participants randomly assigned conditions: Control Condition (Control, n = 17), Intervention Group 1 (IG1, n=16) and Intervention Group 2 (IG2, n = 16). The experiment aimed to investigate the effects of pausing at natural breakpoints and note-taking on cognitive performance and memory retention during a digital reading task.

- **Control Condition:** Participants read a 3-page passage, stopping at a predefined point before the section's conclusion.
- **Intervention Group 1 (IG1):** Participants read the same 3-page passage, but they were instructed to pause at the natural breakpoint (i.e., the end of a section), without any additional tasks.
- **Intervention Group 2 (IG2):** Participants followed the same procedure as IG1, but with the additional task of note-taking. After reaching the natural breakpoint, they were prompted to take notes on their reading by typing on the laptop.

Figure 5.4 illustrates the experimental procedure. Participants were first provided with a Participant Information Sheet and an Informed Consent Form. Following consent, they completed a pre-reading Stroop task to measure baseline selective attention and processing speed (Stroop, 1935). They were then asked to read the assigned passage (and take notes) under their group's condition. After the reading task, participants completed a post-reading Stroop task, the NASA-TLX questionnaire to assess perceived mental Workload (Hart & Staveland, 1988), and the Big Five Personality Test (BFI-2) to assess individual differences in personality traits (Smederevac et al., 2024). A demographics survey was also completed at this stage, followed by a recall test to measure memory retention based on the text they had read. Finally, participants watched the narrated SmartPause video and completed the System Usability Scale (SUS) questionnaire.

5.3.2.4 Materials and Measures

The reading material for the study was a 3-page passage with a Flesch-Kincaid reading score of 60, indicating moderate difficulty suitable for the participants' reading level (Kincaid et al., 1975; Wohlleben, 2016, pp. 56–59). The text met the following criteria:

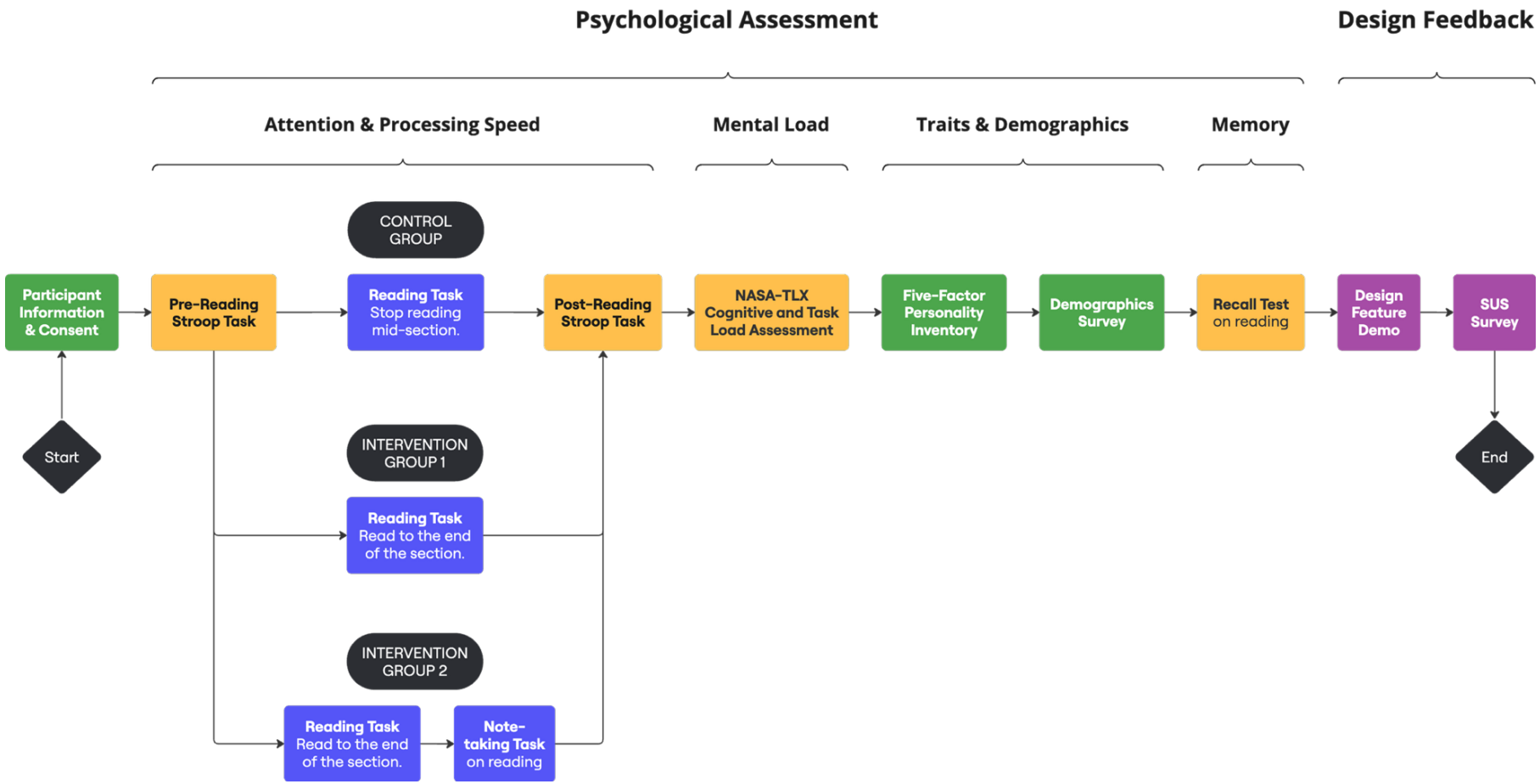


Figure 5.4: Experimental procedure for Study 1. Participants completed baseline and post-task cognitive assessments, a reading task under one of three conditions, and memory and workload evaluations. A SmartPause demonstration video followed the recall test, forming the basis for the SUS usability evaluation.

it was a standalone section that could be understood independently, the content was non-controversial and free of sensitive material, and the topic was accessible and of a similar level for all participants. The final 0.5 pages were blurred for all groups, interrupting reading at a fixed point and simulating the experience of being broken off mid-passage. The blur was then removed for the intervention groups so they could finish reading, while it remained for the control group.

To assess selective attention and processing speed, a Computerised Colour-Word Stroop task was administered using keyboard input both before and after the reading task. After completing the reading and Stroop tasks, participants filled out a seven-item NASA-TLX assessment questionnaire to gauge the cognitive load they experienced during the reading task. NASA-TLX was selected due to its widespread validation in measuring multidimensional cognitive load across reading and task-based studies (Hart & Staveland, 1988). The Big Five Personality Test (BFI-2) was used to assess participants' personality traits, particularly neuroticism. This assessment was included as prior studies have shown that neuroticism is associated with reduced attentional focus and shorter duration of attention on tasks (Mark, Iqbal, Czerwinski, Johns, & Sano, 2016), as well as impaired performance on tasks requiring inhibition and switching functions of working memory (Saylik et al., 2018).

A Recall Test, consisting of 12 multiple-choice, true/false, fill-in-the-blank, matching, and short-answer questions, was designed based on the first 2.5 pages of the text read by all participants. This test assessed their ability to recall specific details from the passage, serving as a measure of long-term memory retention.

Following the recall test, participants were shown a narrated demonstration video of the SmartPause prototype, which visually presented the system's intended features and interaction flow, including strategic pausing, note-taking, and resumption mechanisms. This video served as the basis for the subsequent usability evaluation, conducted using the System Usability Scale (SUS), a validated instrument for assessing user satisfaction and system usability (Brooke, 1996).

All materials, the demographics survey, Stroop task, the full reading passage, NASA-TLX, BFI-2, recall test, and SUS questionnaire, are available in Appendix E.

5.3.2.5 Data Analysis Approach

Paired t-tests and ANOVA were conducted to compare the effects of reading conditions on the dependent variables. The main and interaction effects of neuroticism were also examined as a personality trait and self-reported English proficiency (native vs. non-

native). The dependent variables analysed were Stroop Effect (selective attention and processing speed), NASA-TLX results and time-on-task during reading (both as indicators of mental load), recall test scores (long-term memory), and usability scores. For the Stroop Effect, three values for both reaction time and accuracy were calculated: pre-reading Stroop Effect, post-reading Stroop Effect, and the difference between them. Mental workload was measured using unweighted NASA-TLX scores and time-on-task as a behavioral proxy for cognitive effort. Recall test scores assessed long-term memory, with half credit awarded for inferred short answer responses. Usability scores were analysed based on feedback from the design concept video illustrating features (Section 5.2.1) in the e-book application.

Post hoc t-tests were conducted only when the omnibus ANOVA reached statistical significance, with *p*-values adjusted using the Benjamini-Hochberg (BH) procedure to control for multiple comparisons (Benjamini & Hochberg, 1995). Effect sizes were calculated using Cohen's *d* for *t*-tests and partial η^2 for ANOVA. They were interpreted based on Cohen's (1988) benchmarks: 0.2 = small, 0.5 = medium, and 0.8 = large, providing a measure of practical significance alongside statistical outcomes.

5.3.3 Study 2: Within-Subjects (Follow-up Study)

5.3.3.1 Aim and Hypotheses

The previously used Big Five Personality Inventory yielded inconclusive moderation effects and may lack granularity in explaining attentional disengagement. Thus, a within-subjects design was adopted here to control for individual differences and explore feasibility with a minimal design. Although this follow-up retained the same two core conditions as Study 1 (control condition and IG1), the within-subjects design positioned exit timing as the primary mechanism under test; time-on-task was therefore treated as a distinct behavioural outcome (continuation/engagement) rather than grouped under perceived workload, which was captured independently via NASA-TLX. In contrast to Study 1, affective state was assessed as an additional outcome, replacing usability as a primary focus.

Therefore, the following hypotheses were tested in this study:

- **H2.1:** Exiting at a natural breakpoint will improve selective attention and processing speed, reflecting better attentional control and reduced interference.
- **H2.2:** Perceived workload will be lower in the intervention condition.
- **H2.3:** Task engagement will be greater in the intervention condition, reflecting deeper involvement with the reading material.

- **H2.4:** Delayed recall will be higher in the intervention condition, reflecting improved encoding and memory consolidation.
- **H2.5:** Affective balance will be more positive in the intervention condition, reflecting a more satisfying disengagement experience.

5.3.3.2 Participants

A total of 14 participants (aged 20–38, M = 30.1; 10 males, 4 females) took part in the study. Participants again represented a diverse range of ethnic/national backgrounds, including European (Spanish, French, Italian, Irish/German), Asian (Chinese, Vietnamese, Bangladeshi, Iranian, Japanese), and African (Moroccan, Sudanese) backgrounds. Educational attainment was high (8 master's, 4 doctoral, 2 bachelor's). All participants reported fluent English, with 2 reporting native-level fluency, 11 advanced proficiency, and 1 proficient ability. Inclusion criteria were the same as in the previous study, and ethical approval was covered under the same university Research Ethics Committee approval. Two participants from Study 1 also took part in Study 2; given the minimal overlap, no meaningful carry-over effects are expected.

5.3.3.3 Experimental Design and Procedure

The procedure for Study 2 is outlined in Figure 5.5. While informed by an earlier between-subjects study that examined the full SmartPause interface, this follow-up study focused solely on exit timing by excluding the note-taking feature. It assesses the same cognitive measures and additionally measured affective state as specified in H2.5. The study employed a within-subjects design in which each participant completed both conditions in counterbalanced order to reduce individual variability.

As this study follows a within-subjects protocol, participants experienced both Control (early exit) and Intervention (completion at natural breakpoint) conditions in counterbalanced order to mitigate individual variability. Participants were randomly assigned to one of two counterbalancing groups. Group 1 completed the control condition with Task A and the intervention condition with Task B, while Group 2 experienced the reverse order of conditions.

Each block had the same sequence as illustrated in Figure 5.5. After providing consent and completing a demographics questionnaire, participants completed: (i) a pre-reading Stroop task to establish baseline attention, (ii) the reading task (control or intervention), (iii) a post-reading Stroop task, and (iv) the NASA-TLX and (v) SPANE-6 questionnaires to assess perceived workload and affective state respectively.

As a minor change from the previous study, a short practice Stroop phase was added before the main task to familiarise participants with the procedure and minimise learning effects in the results. The recall test was administered one hour after the second reading block. This delay was designed to assess longer-term memory consolidation more robustly than the 10–15 minute interval used in previous work.

The Big Five Inventory-2 (BFI-2) was excluded because this was a within-subjects study (personality traits were not expected to vary across conditions), and the System Usability Scale (SUS) was omitted because usability had already been assessed to a sufficient extent and was not a primary outcome of this study.



Figure 5.5: Experimental procedure for Study 2. Participants experienced both reading conditions in counterbalanced order, with cognitive and affective measures collected across blocks.

5.3.3.4 Materials and Measures

To better accommodate advanced but non-native English speakers, two texts of ~800-1000 words were selected (Appendix E.4), each with a relatively easier readability level (Flesch–Kincaid Reading Scores = 66.33 and 65.05; Kincaid et al., 1975). The texts were

selected from Secrets of the Octopus (Montgomery, 2024, pp. 14–16) and The Guest Cat (Hiraide & Selland, 2014, pp. 4–6). Text selection followed the same criteria as in the previous study, and passages were blurred 0.5 pages before the section end using the same approach.

For the Stroop task, NASA-TLX assessment, and recall tests, the same materials, instruments, and format were used as in the previous study.

As for the assessment of affective state, a shortened version of the Scale of Positive and Negative Experience (SPANE; Diener et al., 2010) was used (see Appendix E.7). This abbreviated "SPANE-6" included three positive and three negative items, selected for their relevance and brevity. The 6-item format reduced participant burden while preserving a balanced snapshot of emotional tone. Although the full 12-item SPANE is psychometrically validated, this compact version was used to capture key affective signals efficiently without overloading participants.

5.3.3.5 Data Analysis Approach

Paired-samples *t*-tests were conducted to compare the effects of the Control and Intervention conditions on the dependent variables. The dependent variables analysed were the change Stroop accuracy and reaction time between pre- and post- reading tasks (selective attention and processing speed), unweighted NASA-TLX scores and time-on-task during reading (as indicators of mental load and engagement/cognitive effort), SPANE-6 affect balance (affective state), and recall test performance (delayed memory retention). Affective state was calculated by subtracting SPANE-6 negative feelings score from the positive feelings score.

Descriptive statistics (means and confidence intervals) are reported alongside inferential results. Effect sizes were calculated using Cohen's *d* for paired comparisons, providing a measure of practical significance in addition to *p*-values. Given the small sample size, results are interpreted primarily in terms of effect-size patterns and exploratory trends rather than statistical significance alone. Outlier sensitivity was assessed qualitatively by inspecting individual change scores and checking whether conclusions depended on a small number of participants.

5.4 Findings

5.4.1 Study 1: Between-Subjects Findings

The analysis examined the effects of the interventions on post–pre changes in selective attention and processing speed, perceived mental workload, time-on-task, and memory retention; usability of the SmartPause concept was assessed separately (via SUS and

Table 5.1: Statistics for Stroop Task Performance, Perceived Mental Load, Time-on-task and Recall Metrics.

	Control Group		IG1		IG2		Overall	
	M	SD	M	SD	M	SD	M	SD
Pre Stroop RT	189.58	191.72	311.4	328.56	311.74	235.59	269.25	258.41
Post Stroop RT	197.15	146.05	199.33	187.82	200.19	230.84	198.86	186.51
Stroop RT Δ	7.57	168.44	-112.06	205.44	-111.55	322.36	-70.39	241.69
Pre Stroop Accuracy	0.04	0.06	0.06	0.17	0.04	0.07	0.05	0.11
Post Stroop Accuracy	0.01	0.05	0.03	0.12	0.02	0.04	0.02	0.07
Stroop Accuracy Δ	-0.03	0.1	-0.03	0.09	-0.01	0.08	-0.02	0.09
NASA-TLX Score	46.57	15.50	41.30	13.96	40.10	11.48	42.74	13.80
Time-on-Task	551.35	170.00	670.13	363.68	841.38	253.14	684.84	292.47
Recall Score	38.15	15.59	49.83	13.04	51.91	18.80	46.46	16.82

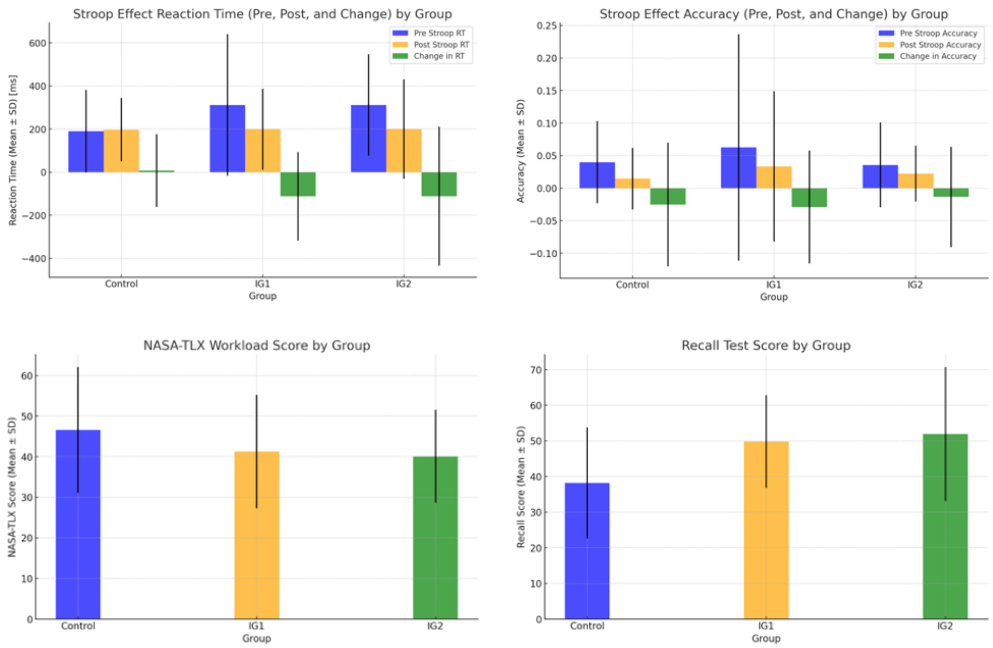


Figure 5.6: Stroop Effect Reaction Time, Accuracy NASA-TLX and Recall statistics across groups.

open-ended feedback) as an overall evaluation of the prototype rather than as a condition-dependent outcome. Throughout this section, Stroop RT Δ and Stroop Accuracy Δ refer to post–pre change scores (post-reading minus pre-reading) for Stroop-effect reaction time and accuracy, respectively.

Two of the original 51 participants were excluded: one due to undisclosed ADHD reported after the study, and one due to missing post-reading Stroop data caused by a software issue. Table 5.1 presents the descriptive statistics for each group and overall Stroop task performance, mental load, and recall metrics while Figure 5.6 provides a comparative visualisation of means with standard deviations across groups.

Table 5.2: Paired Samples t-Test Results for Pre- and Post-Stroop Task Changes

							95% Confidence Interval	
		t(df)	p	Mean diff	SE diff	Cohen's d	Lower	Upper
Reaction Time (ms)	Control	0.19 (16)	0.855	7.58	40.90	0.045	-79.04	94.18
	IG1	-2.18 (15)	**0.045***	-112.06	51.36	-0.545	-221.53	-2.59
	IG2	-1.38 (15)	0.187	-111.55	80.59	-0.346	-283.32	60.22
Accuracy	Control	-1.09 (16)	0.291	-0.03	0.02	-0.265	-0.07	0.02
	IG1	-1.34 (15)	0.201	-0.03	0.02	-0.335	-0.08	0.02
	IG2	-0.70 (15)	0.497	-0.01	0.02	-0.174	-0.05	0.03

Table 5.3: ANOVA Results for Between-Group Analysis of Pre-Post Stroop Effect Reaction Time, Accuracy Difference, Perceived Mental Load, Time-on-task and Recall Test Scores

	Sum of Squares	df	Mean Square	F	p	η^2
Stroop RT Δ (ms)	158211	2	79105	1.38	0.263	0.056
Stroop Accuracy Δ	0.00213	2	0.00107	0.141	0.868	0.006
NASA-TLX Score	393	2	197	1.03	0.363	0.043
Time-on-Task (s)	698435	2	349218	4.71	**0.014***	0.170
Recall Score (%)	1830	2	915	3.58	**0.036***	0.135

Table 5.4: Main and Interaction Effects of Language Level and Neuroticism on Cognitive Metrics

	Language Level (Main Effect)	Language Level (Interaction Effect)	Neuroticism (Main Effect)	Neuroticism (Interaction Effect)
Stroop RT Δ (ms)	F = 1.80 p = 0.186	F = 1.05 p = 0.360	F = 0.03 p = 0.867	F = 0.22 p = 0.801
Stroop Accuracy Δ	F = 0.723 p = 0.400	F = 1.84 p = 0.171	F = 0.50 p = 0.484	F = 0.05 p = 0.949
NASA-TLX Score	F = 7.64 **p = 0.008***	F = 0.84 p = 0.437	F = 0.56 p = 0.458	F = 0.61 p = 0.547
Recall Score (%)	F = 6.24 **p = 0.016***	F = 0.36 p = 0.701	F = 0.86 p = 0.358	F = 0.85 p = 0.436

5.4.1.1 Selective Attention and Processing Speed

For reaction time, IG1 showed a significant reduction (M = -112.06, SD = 205.44; $t(15) = -2.18$, $p = .045$, Cohen's $d = -0.545$). However, the between-group analysis using

ANOVA revealed no significant differences in reaction time or accuracy across the three groups ($F(2, 46) = 1.38$, $p = .263$, $\eta^2 = .056$), so this should be interpreted as partial support for H1.1 as shown in Table 5.3 and Figure 5.8. This suggests a within-condition improvement rather than a reliable between-condition effect.

Table 5.2 further details the paired t-test results for pre- and post-Stroop Effect changes, confirming the significant reaction time improvement within IG1. Figure 5.7 visualises these changes, illustrating how the pre- and post-reading Stroop Effect differed across conditions.

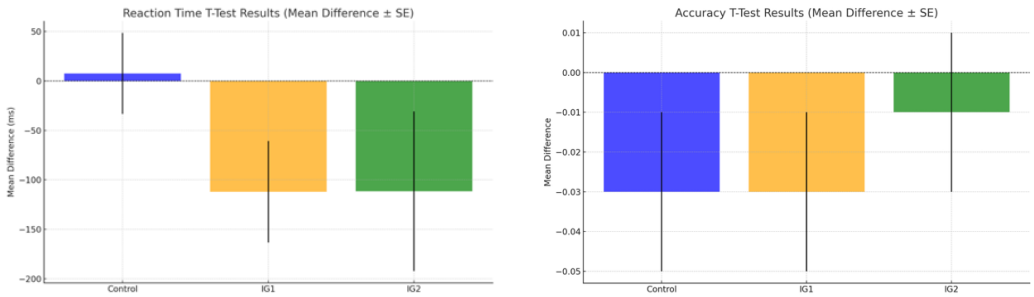


Figure 5.7: T-Test Results for Pre- and Post-Stroop Effect Changes

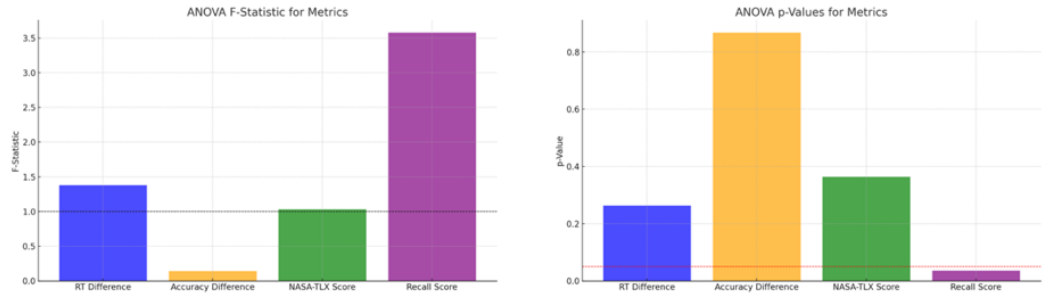


Figure 5.8: ANOVA Results for Between-Group Comparison of Reaction Time, Accuracy, and Recall Score

In terms of accuracy, IG1 showed a slight improvement, but the change was not statistically significant ($t(15) = -1.34$, $p = .201$, Cohen's $d = -0.335$). Similarly, the Control Group and IG2 showed no significant change either ($p > 0.05$). An ANOVA across the groups (Table 5.3) revealed no significant difference ($F(2, 46) = 0.14$, $p = .868$, $\eta^2 = .006$), suggesting that the interventions did not have a significant effect on accuracy. These results reinforce the idea that pausing at a natural breakpoint may facilitate faster processing but does not necessarily affect the accuracy of task performance.

Language proficiency and neuroticism were also examined for their effect on both reaction times and accuracy but neither showed a significant main effect or interaction ($p > 0.05$), as detailed in Table 5.4.

5.4.1.2 Perceived Mental Workload and Time-on-Task

The participants in intervention conditions particularly in IG2, reported numerically lower mental load compared to the control group. IG2's mean NASA-TLX score was 40.10 (SD = 11.48), while the control group's mean was 46.57 (SD = 15.5). An ANOVA revealed no significant difference ($F(2, 46) = 1.03$, $p = .363$, $\eta^2 = .043$), as shown in Table 5.3, indicating that the interventions did not produce a statistically reliable difference in perceived mental load.

To complement these subjective results, time-on-task during reading was examined as a behavioural proxy for engagement/cognitive effort. A one-way ANOVA revealed a significant difference in time-on-task across groups, $F(2, 46) = 4.71$, $p = .014$, $\eta^2 = .170$. Post hoc comparisons using the Benjamini-Hochberg correction showed that IG2 spent significantly more time on-task than the control group ($t(31) = –3.89$, $p < .001$, BH-adjusted $p = .002$, Cohen's $d = –1.35$), while differences between control and IG1 ($p = .234$) and between IG1 and IG2 ($p = .133$) were not statistically significant. These results suggest that the note-taking intervention was associated with longer on-task engagement, even though participants did not report increased mental effort.

The relationship between subjective and behavioural indicators was also assessed using Pearson correlation. The correlation between time-on-task and NASA-TLX scores was weak and non-significant, $r(47) = 0.216$, $p = .136$, suggesting that longer task duration did not correspond to higher perceived cognitive load. However, the trend differs across groups: IG1 and IG2 display a positive relationship between self-reported mental load and reading duration, while the control group shows little to no association, as visualised in Figure 5.9. Taken together, these findings provide only partial support for H1.2: while perceived mental load did not differ significantly across groups, behavioural indicators point to increased engagement in the note-taking condition.

5.4.1.3 Memory Retention

The ANOVA results revealed a significant effect of the interventions on memory retention ($F(2, 46) = 3.58$, $p = .036$, $\eta^2 = .135$), supporting H1.3 and indicating that the interventions meaningfully enhanced recall performance**.** Specifically, participants in the guided pausing and note-taking condition had the highest mean recall score 51.91 (SD = 18.8), followed by those in the guided pausing condition alone 49.83 (SD = 13.04). In contrast, the control condition showed a lower mean score 38.15 (SD = 15.59), suggesting that the interventions contributed to improved memory retention. Interruptions during reading have been shown to disrupt cognitive flow; however, these results indicate that

strategically timed pauses may serve as effective countermeasures, reinforcing memory retention processes.

Table 5.5: Pairwise t-test results for Reading Time-on-Task values with Benjamini-Hochberg correction and Cohen's d effect sizes

Comparison	t	df	p (raw)	P (BH-adjusted)	Cohen's d
Control vs IG1	–1.21	31	0.234	0.234	–0.423
Control vs IG2	–3.89	31	< .001	**0.002***	–1.35
IG1 vs IG2	–1.55	30	0.133	0.177	–0.547

Table 5.6: Pairwise t-test results for recall scores with Benjamini-Hochberg correction and Cohen's d effect sizes

Comparison	t	df	p (raw)	P (BH-adjusted)	Cohen's d
Control vs IG1	–2.33	31	0.027	**0.0435***	–0.81
Control vs IG2	–2.29	31	0.029	**0.0435***	–0.80
IG1 vs IG2	–0.36	30	0.718	0.718	–0.13

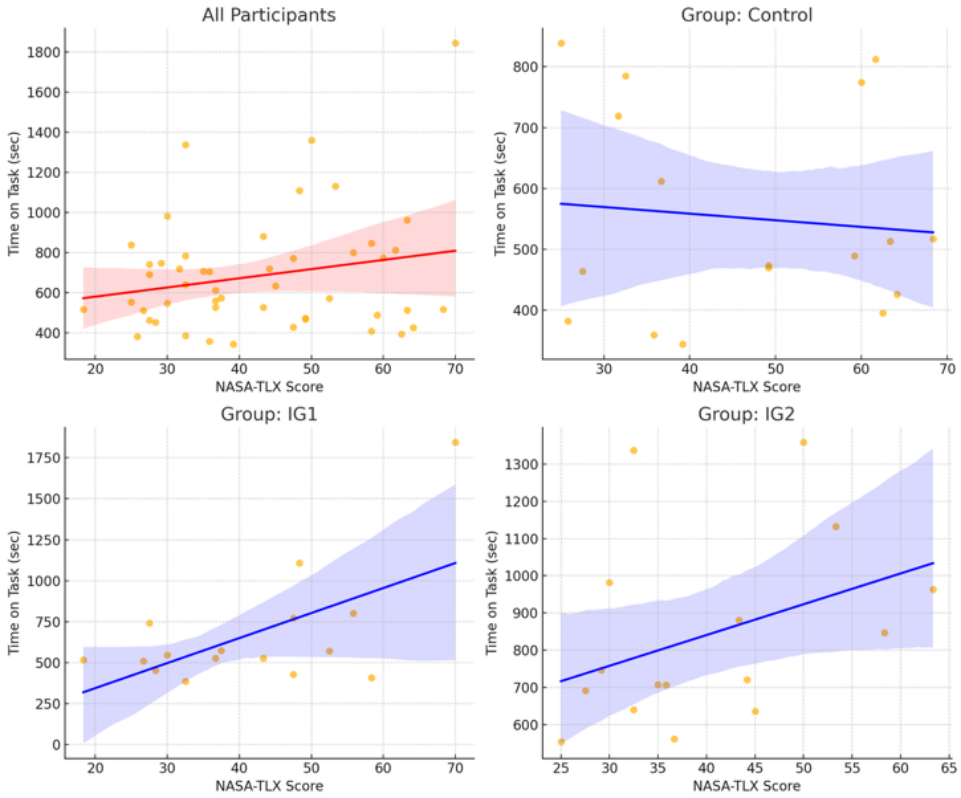


Figure 5.9: Correlation between NASA-TLX Scores and Reading Time-on-Task. Scatterplots with regression lines and 95% confidence intervals are shown for all participants and separately by group. IG1 shows the strongest positive trend, IG2 a moderate one, and the Control group displays no apparent relationship.

To examine specific group differences, post hoc independent samples t-tests were conducted and adjusted using the Benjamini-Hochberg procedure. The comparisons between the control group and both intervention groups remained statistically significant after correction (Control vs IG1: $p = .027$, BH-adjusted $p = .0435$; Control vs IG2: $p = .029$, BH-adjusted $p = .0435$), while no significant difference was found between IG1 and IG2 ($p = .718$, BH-adjusted $p = .718$), as detailed in Table 5.6.

Additionally, language proficiency significantly influenced recall performance, with native speakers outperforming non-native speakers. This finding highlights the impact of language proficiency on memory retention, suggesting that individuals with higher language proficiency may have an advantage in recalling details from the reading task.

5.4.1.4 Usability

Participants evaluated the usability of the system using the SUS questionnaire. The mean SUS score was 85.46 (SD = 12.18), which is considered excellent usability (Bangor et al., 2008). This score highlights the system's strong user satisfaction, though some participants suggested enhancing note-taking customisation for greater flexibility.

To complement the SUS scores, open-ended responses were analysed to gain deeper insight into users' subjective experiences. Participants generally found the system intuitive and easy to use, particularly valuing how the guided pause mechanism aligned with their natural reading rhythms. Thematic analysis of this feedback revealed several key perceptions (see Figure 5.10). The most frequently noted benefit was the alignment with existing pause habits. Many users also reported that note-taking supported memory retention, while a smaller group expressed a preference for disabling this feature in certain contexts, such as casual reading.

Additional themes included appreciation for the bookmark's line-level precision, general satisfaction with the feature's usefulness, and perceived benefits for users with attention or memory challenges. Some participants suggested improvements such as greater flexibility in prompting frequency or the ability to disable summarisation prompts. These responses highlight the need to accommodate varying user preferences through more customisable features.

The usability feedback aligns with the results observed in memory retention, suggesting that guided pauses and note-taking not only improve cognitive performance but also enhance user experience in digital reading environments. Figure 5.11 illustrates the distribution of SUS scores across participants, providing insights into individual variations in perceived usability.

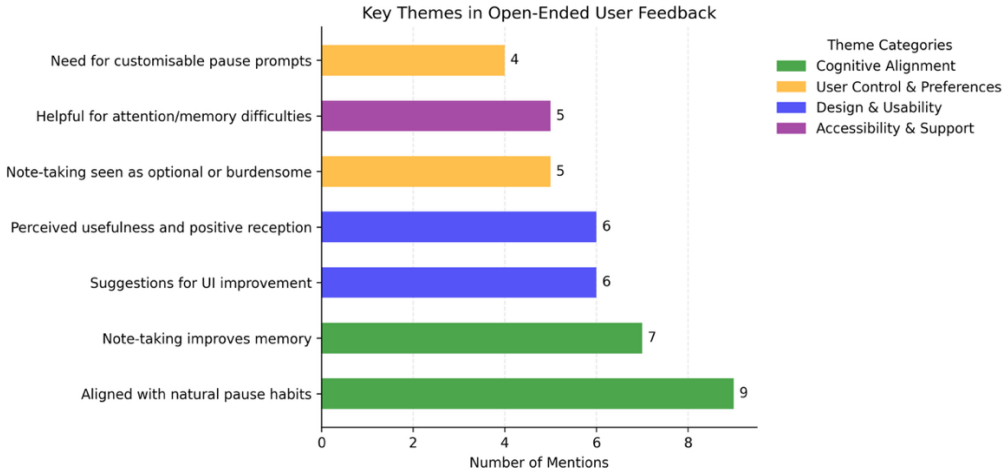


Figure 5.10: Key themes identified in open-ended usability feedback from participants. Responses were categorised into four groups: Cognitive Alignment, User Control & Preferences, Design & Usability, and Accessibility & Support. Each bar indicates the frequency of mentions per theme across all participants highlighting perceptions of SmartPause's value and usability features.

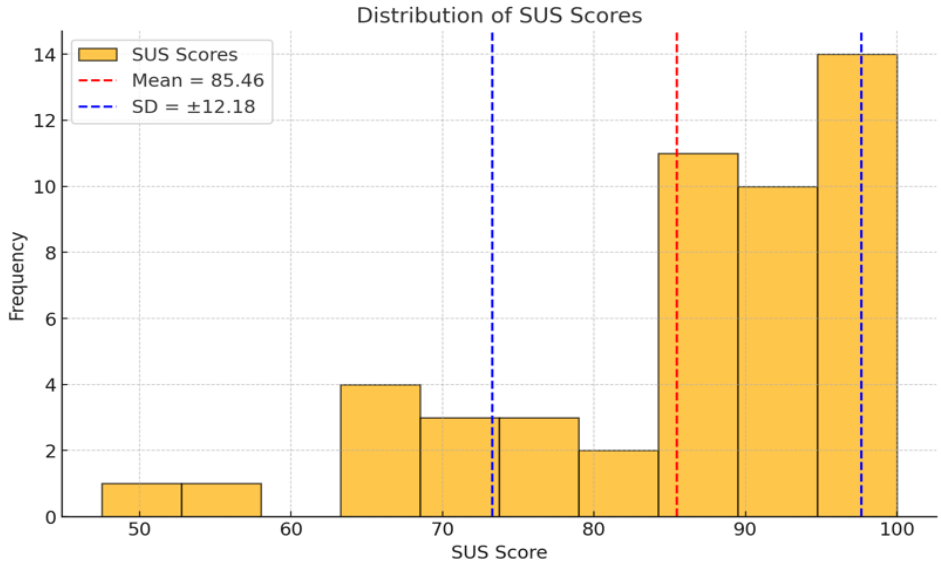


Figure 5.11: Distribution of SUS Scores Across Participants.

5.4.2 Study 2: Within-Subjects Findings

In the second study, post–pre change scores for selective attention and processing speed, perceived mental workload, time-on-task, memory retention, and affective state were analysed between the control and intervention conditions. Full descriptive statistics and effect sizes are presented in Table 5.7. While not statistically significant, as typical in small pilot samples, several measures revealed moderate effect sizes in the expected direction, offering preliminary support for the intervention's cognitive and affective benefits.

Table 5.7: Paired-sample t-tests for intervention vs. control n=14).

Measure	Control (M ± SD)	Intervention (M ± SD)	*t*	*p*	Cohen's *d*
Stroop RT Δ (ms)	3.13 ± 254.13	40.55 ± 159.43	-0.50	0.627	-0.133
Stroop Accuracy Δ	-0.04 ± 0.07	0.01 ± 0.06	-1.90	0.080	-0.51
NASA-TLX	42.62 ± 15.74	38.45 ± 12.79	1.25	0.234	0.33
Time-on-task (s)	408.29 ± 125.25	470.21 ± 141.36	-2.25	**0.042***	-0.60
SPANE-B	1.07 ± 5.72	2.86 ± 4.94	-1.18	0.259	-0.32
Recall Score (%)	40.27 ± 23.98	50.81 ± 23.00	-1.16	0.266	-0.31

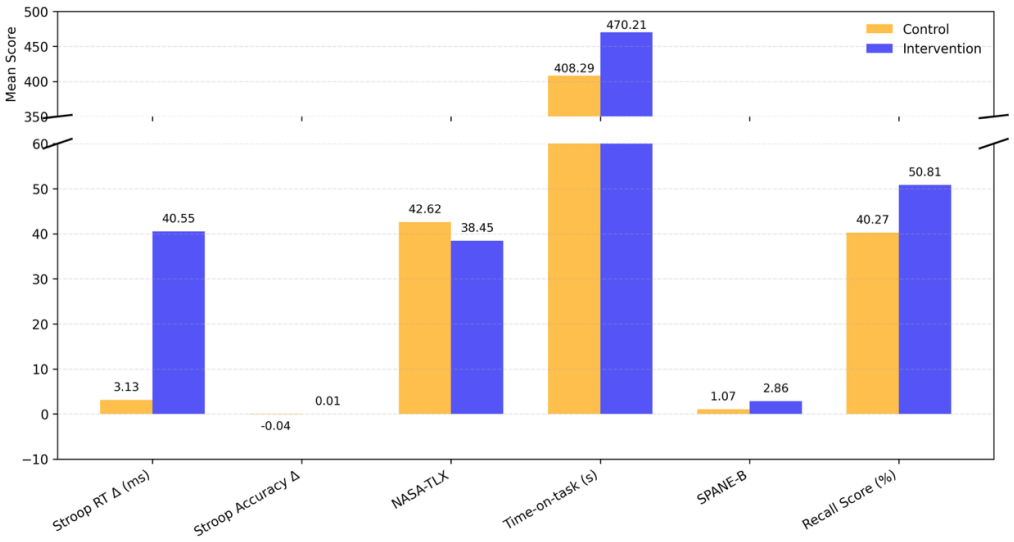


Figure 5.12: Mean performance across cognitive and affective outcomes by condition. A broken y-axis is applied only to Time-on-Task to enhance visibility of lower-value measures. Intervention reflects reading to a natural breakpoint; control reflects early exit mid-section**.**

Figure 5.12 summarises mean scores across all dependent variables, highlighting directional differences between control and intervention conditions. Notably, Stroop accuracy, time-on-task, and delayed recall all favoured the intervention condition, lending tentative support to hypotheses H2.1–H2.5. These trends are explored in the subsections that follow.

5.4.2.1 Selective Attention and Processing Speed

Participants demonstrated improved Stroop accuracy following the intervention condition (M = 0.01, SD = 0.06) but a decline after the control condition (M = –0.04, SD = 0.07), $t(13) = -1.90$, $p = .080$, $d = -0.51$. This moderate, trend-level effect aligns with H2.1, suggesting that exiting at a natural breakpoint may help preserve attentional control. These results echo findings from the earlier between-subjects study, where the

intervention group similarly showed improved accuracy compared to control. The within-subjects design strengthens this interpretation by controlling for individual variation in attention and multitasking resilience.

In contrast, Stroop response time did not differ meaningfully between conditions (Intervention: M = 40.55 ms, SD = 159.43; Control: M = 3.13 ms, SD = 254.13), $t(13) = -0.50$, $p = .627$, $d = -0.13$. Response time appeared highly variable across participants, consistent with previous findings suggesting that accuracy may be a more reliable marker of attentional modulation in this task context.

5.4.2.2 Perceived Mental Workload and Time-on-Task

Participants reported slightly lower mental workload (NASA-TLX) in the intervention condition (M = 38.45, SD = 12.79) than in the control condition (M = 42.62, SD = 15.74), $t(13) = 1.25$, $p = .234$, $d = 0.33$. This small effect supports H2.2, suggesting that readers may experience less mental strain when allowed to complete a semantically coherent unit before disengaging. This mirrors a similar non-significant pattern in the earlier study, where SmartPause prompts were associated with numerically lower workload scores.

Significantly higher time-on-task was observed in the intervention condition (M = 470.21s, SD = 141.36) versus control (M = 408.29s, SD = 125.25), $t(13) = -2.25$, $p = .042$, $d = -0.60$. While this increase is partly attributable to passage length, it also supports H2.3, indicating greater engagement when users are encouraged to read to a natural breakpoint. Notably, the increased duration was not accompanied by increased perceived workload, suggesting deeper involvement rather than cognitive overload.

5.4.2.3 Memory Retention

Participants scored higher on the delayed recall test following the intervention condition (M = 50.81%, SD = 23.00) compared to control (M = 40.27%, SD = 23.98), $t(13) = -1.16$, $p = .266$, $d = -0.31$. Though exploratory, this moderate effect aligns with H2.4 and extends findings from the earlier between-subjects study, where recall significantly improved under SmartPause. Here, even without note-taking prompts, simply exiting at a natural breakpoint appeared to support better memory retention—consistent with theories of task segmentation and semantic closure (Zeigarnik, 1927; Zacks *et al.*, 2007).

5.4.2.4 Affective State

Affective balance (SPANE-B) was more positive following the intervention (M = 2.86, SD = 4.94) than control (M = 1.07, SD = 5.72), $t(13) = -1.18$, $p = .259$, $d = -0.32$. This trend is consistent with H2.5 and prior qualitative feedback from the between-subjects study, where participants described SmartPause-style transitions as smoother and less

frustrating. These results suggest that even subtle design changes in disengagement timing may influence users' emotional experience of digital reading.

5.4.3 Summary: Findings from Both Studies

Across both studies, breakpoint-aligned disengagement was associated with more favourable outcomes overall, with the clearest and most consistent pattern observed for memory retention. Engagement, reflected in time-on-task, also tended to be higher in the intervention conditions, particularly when note-taking was included, whereas perceived workload showed only small or numerical differences rather than a robust condition effect. Effects on selective attention and processing speed were more mixed: Study 1 showed an improvement within the guided-pause condition but did not yield reliable between-group differences, while Study 2 trends favoured the intervention condition primarily on accuracy rather than reaction time. In Study 2, affective state also trended more positively following breakpoint-aligned disengagement. Separately from the condition-based outcomes, usability results indicated that the SmartPause concept was perceived as highly usable overall, supporting its viability at the prototype level. In summary, these results provided strongest support for the memory-retention hypotheses (H1.3/H2.4) and usability (H1.4), with partial or mixed support for attention/processing speed and workload/engagement hypotheses (H1.1–H1.2/H2.1–H2.3) and trend-level support for affect (H2.5).

5.5 Discussion: Implications for Cognitive Resilience and Design Knowledge

5.5.1 Cognitive Performance Findings and Interpretation

5.5.1.1 Memory Retention

The findings across both studies support the central claim that how users disengage from digital reading can shape cognitive continuity**,** particularly for memory. The most consistent outcome was the improvement in memory retention under breakpoint-aligned disengagement. This pattern is compatible with the idea that semantic closure reduces residual cognitive tension associated with incomplete activity, which otherwise competes for attention and undermines consolidation. In this sense, breakpoint-aligned stopping points may function as a cognitive "handover" that helps readers complete an internal unit of meaning before leaving, preserving what has been encoded and lowering the cost of later resumption. Well-placed pauses are known to reduce the cognitive effort required to resume tasks, aligning with this interpretation (Trafton et al., 2003).

The fact that memory benefits remained significant even when note-taking was removed in Study 2 suggests that *timing alignment alone can contribute to continuity*,

while reflective externalisation (when included) may amplify this mechanism or make it more robust in larger samples. Similar findings have been observed in various digital and non-digital contexts (e.g., lecture-based learning), where structured pauses and note-taking enhance memory retention, suggesting the potential for broader application of these techniques (Bohay et al., 2011; Mueller & Oppenheimer, 2014; Ruhl et al., 1990).

5.5.1.2 Engagement and Perceived Workload

Time-on-task, increased as expected, likely due to the slightly longer reading duration. However, higher time-on-task in the breakpoint-aligned conditions did not coincide with higher perceived workload. This dissociation suggests that longer reading duration should not be treated as "more strain" by default; instead, it may reflect sustained involvement or reduced friction when readers complete a coherent unit rather than stopping mid-flow.

Perceived workload showed only small or numerical shifts rather than a robust condition effect. This does not undermine the intervention rationale; rather, it clarifies that cognitive continuity benefits may occur even when users do not consciously experience reading as easier. For cognitive resilience, this is still valuable, as resilience is not merely about reducing effort; it is about preserving function under everyday disruption. If a design can support continued engagement without increasing subjective workload, it may strengthen users' ability to maintain continuity without requiring additional willpower or self-control.

5.5.1.3 Selective Attention and Processing Speed

Selective attention and processing speed outcomes were more mixed across the two studies, which is unsurprising given the sensitivity of Stroop measures to variability and the limited power of small samples. The pattern across studies, however, is still informative: breakpoint-aligned disengagement did not yield a stable advantage on response time, but it showed more promising trends for accuracy (Study 2) and within-condition improvement (Study 1).

One plausible interpretation is that breakpoint-aligned stopping points primarily protect attentional stability rather than accelerate speed, and that this protection may appear more clearly in accuracy or interference control than in reaction time. This aligns with the broader chapter framing: the intervention is aimed at reducing cognitive fragmentation at transition points, which may influence error-proneness and control more directly than raw speed.

5.5.1.4 Affective State

Study 2's affective trend suggests that breakpoint-aligned disengagement may influence not only cognitive outcomes but also how "smooth" the transition feels. Although this result should be interpreted cautiously (given the pilot scale and fixed text-to-condition assignment), it aligns with the idea that cognitively coherent stopping points reduce frustration and leave users with a more positive state after disengagement. In the context of everyday digital reading, where repeated micro-disruptions accumulate, even small affective improvements may matter because they can influence willingness to return, persistence, and perceived continuity over time.

Taken together, the results position breakpoint-aligned disengagement as a cognitive resilience mechanism that supports memory continuity most strongly, shifts engagement without increasing perceived workload, and may offer modest protection for attentional control, while also remaining usable and acceptable at the concept level. Rather than implying a universal performance boost across all metrics, the evidence suggests a targeted effect profile: *stronger for memory continuity and transition quality than for speed-based attentional outcomes.*

5.5.2 Implications for Design and Interaction

5.5.2.1 Designing for Disengagement

A central design implication is that interaction design should address disengagement, not only engagement. Digital reading tools typically treat stopping as a neutral user choice, offering minimal support beyond a static bookmark. The findings suggest that the timing of stopping is consequential and therefore a legitimate design concern. One promising direction is identifying natural breakpoints, i.e., moments of lower mental load and greater semantic closure, and recommending optimal pausing points, aligning with activity theory's emphasis on tools that support user goals and cognitive workflows (Kaptelinin, 2005). In this view, exit (or pause) timing becomes a mechanism for cognitive resilience rather than a purely behavioural variable, positioning disengagement as part of the interaction sequence that can be deliberately supported rather than treated as an endpoint.

5.5.2.2 Aligning with Cognitive Rhythms

SmartPause was intentionally designed not to interrupt arbitrarily, but to respond when users are already preparing to leave the task, such as pausing or attempting to exit. By aligning with users' cognitive rhythms and intentions, the system reduces the risk of disruption. This matters for cognitive resilience because it supports continuity without

imposing external control: it does not block exiting, enforce timers, or introduce an additional disruption; it reshapes the exit moment into a cognitively aligned transition. Transition points may be particularly vulnerable moments for working-memory representations and partially consolidated meaning are most fragile, so providing lightweight support at this moment can reduce loss without adding burden.

5.5.2.3 Rethinking Evaluation Criteria

These findings suggest a shift in how designers should evaluate reading interventions (and other continuity-sensitive tasks). If breakpoint-aligned designs reliably influence memory and perceived transition quality, then "success" should not be judged solely by comprehension-at-the-moment or speed metrics. Instead, evaluation should include continuity outcomes: delayed recall, ease of resumption, subjective smoothness of stopping, and behavioural engagement patterns.

5.5.2.4 Supporting Resumption

Although the current studies focus mainly on the exit moment, cognitive continuity also depends on successful resumption. Much like the "previously on" recaps used in episodic television, summaries at the point of return can remind readers of context before re-engaging with a text. User-authored notes are likely more effective for this purpose than auto-generated summaries, as they reflect the reader's own encoding and reactivate the same cognitive pathways formed during reading. This is consistent with evidence that self-generated notes outperform externally produced summaries for memory retrieval (Mueller & Oppenheimer, 2014).

5.5.2.5 Adaptive but User-Controllable

Real-world deployments hold promise, but they may also raise new challenges: emerging adaptive systems may introduce friction if they misjudge user intent or overstep the boundaries of user control. Automatically suggesting or enforcing pauses could feel intrusive if not properly personalised or explainable. Designing such features will require careful attention to transparency and timing to avoid undermining trust or increasing cognitive burden (Chalmers et al., 2003; Hollender et al., 2010). For this reason, cognitive-alignment features should be adaptive but user-controllable, with personalisation and explainability acting as safeguards against intrusiveness; if the support feels imposed, it risks becoming a new interruption.

5.5.2.6 Broader HCI Context

The findings contribute to a broader movement in HCI toward designing digital environments that support attentional control and minimise cognitive disruption without

enforcing rigid behavioural constraints. SmartPause aligns with this agenda by scaffolding the exit moment rather than restricting it. This is consistent with systems such as MyTime (Hiniker et al., 2016), which supports mindful transitions between apps by allowing users to reflect on their intent without blocking access, and with the Reflective Design approach (Sengers et al., 2005), which advocates for systems that make their assumptions visible and support user agency in moments of decision or disengagement.

These implications point to a need to update interaction design guidance to prioritise cognitive resilience, particularly preserving memory continuity and reducing fragmentation**.** More explicitly articulating these implications as actionable design knowledge would make them easier for practitioners to adopt in everyday systems. SmartPause contributes by demonstrating that exit timing is not merely a behavioural variable but an interaction-design variable that can be shaped in subtle ways to preserve continuity. In this way, the concept supports a cognitive resilience agenda in HCI: designing transitions that protect memory and cognitive performance in everyday digital practices, both when users leave a text, and when they return.

5.6 Limitations and Future Work

5.6.1 Methodological Constraints

Although the studies offer valuable insights, several limitations must be addressed. Stroop-based measures are susceptible to practice and learning effects, which may have influenced pre–post change scores despite the use of baseline comparisons. Study 1 adopted a between-subjects design to reduce fatigue and limit transfer across repeated cognitive measures, but this also introduced individual-difference noise that can mask condition-level effects. Study 2 mitigated this limitation with a within-subjects design, strengthening causal inference for exit-timing effects, and included a short practice phase to reduce task-familiarisation effects before the main Stroop blocks; yet it remained a small pilot and therefore underpowered for detecting modest effects reliably.

5.6.2 Ecological Validity and Generalisability

The reading tasks were conducted under controlled conditions, which limits ecological validity and may underestimate the role of cumulative interruptions in everyday reading (Czerwinski et al., 2004). Relatedly, Study 1 used a relatively short retention interval before recall testing, which restricts conclusions about longer-term consolidation. Study 2 extended the delay, but further work is needed to test whether the observed continuity benefits persist over longer timescales such as 24 hours or one week. Longitudinal and in-the-wild deployments will be essential to assess whether SmartPause improves real-

world resumption success, sustained reading habits, trust, and perceived cognitive wellbeing over time including, in assistive contexts and diverse user groups (Alnfiai et al., 2025).

In addition to these environmental constraints, content-level differences between passages can confound engagement and affective outcomes, particularly when texts differ slightly in length, complexity, or emotional tone. Additionally, passage assignment in Study 2 was not fully counterbalanced**,** meaning that the pairing between specific text and condition was not exhaustively rotated across participants such that each text appeared equally often in each condition (and in each order position)**.** As a result, recall and affect differences could partially reflect text properties rather than exit timing alone. Where perfect matching is impractical, future studies should therefore equalise reading materials more strictly and fully randomise text-to-condition assignment.

5.6.3 Individual Differences and Adaptive Support

Individual differences such as reading proficiency, working memory capacity, and interruption susceptibility were not systematically modelled in Study 1, even though these factors likely shape who benefits most from breakpoint-aligned support (Yuan & Zhong, 2024). Study 1 included personality measures but yielded inconclusive moderation, suggesting that more task-relevant constructs (e.g., multitasking habits, attentional control profiles, or reading goals) may be better candidates for future user modelling. Larger-scale within-subjects studies than Study 2 can test these moderators more robustly, controlling stable individual differences and providing sufficient statistical power.

5.6.4 Capturing Within-Session Behaviour

The current evaluation relied primarily on behavioural (time-on-task) and self-report (NASA-TLX, affect) indicators, which capture important aspects of experience but cannot reveal moment-to-moment attentional dynamics at transition points. Future work should incorporate more fine-grained measures such as eye-tracking, interaction logging, or physiological proxies to triangulate cognitive effort and disruption more directly during disengagement attempts. Beyond measurement, a key design challenge is reliable breakpoint detection in real reading environments, where section boundaries and “good stopping points” may be more fluid than in curated passages. Natural language processing including modern LLM-based approaches and user interaction patterns could support real-time breakpoint inference, but such adaptivity must remain transparent and user-controllable to avoid becoming a new source of friction or unwanted interruption. A promising direction is personalisation: SmartPause could learn users’ typical stopping

patterns and tailor nudge timing, granularity, and frequency to balance continuity benefits with autonomy and burden (Zoppis et al., 2025). Future prototypes may also compare minimal timing nudges against optional lightweight externalisation (e.g., brief notes or highlights) to clarify when reflective features amplify benefits beyond timing alone.

On the whole, these steps would move SmartPause from controlled evidence of mechanism toward robust, generalisable design knowledge for cognitive resilience in everyday digital reading.

5.7 Conclusion

This chapter presents SmartPause as a design response to a specific cognitive resilience challenge in everyday digital reading: the fragility of memory continuity at moments of disengagement. Rather than treating stopping as a neutral endpoint, SmartPause reframes it as an interaction moment where design can protect what has been encoded and reduce the cognitive cost of later resumption. The concept operationalises this reframing through breakpoint-aligned pausing and (in its fuller form) lightweight externalisation via note-taking (RQ2).

Across two controlled studies, the results showed a specific pattern of benefit. The strongest and most consistent pattern concerned memory retention, with breakpoint-aligned disengagement supporting better recall than mid-section exit. Study 1 showed improved recall in both breakpoint-aligned conditions and high perceived usability, with qualitative feedback indicating that the interaction fit participants' natural pausing rhythms. Study 2 strengthened the interpretive claim that timing alignment alone can carry continuity value by re-testing the breakpoint timing condition within-subjects and observing trends toward better recall and attentional accuracy. Together, these findings suggest that the cognitive resilience benefit is not primarily about making reading feel easier in the moment; rather, it is about supporting continuity at transition points.

Key insights from this study include:

- Aligning disengagement with natural task boundaries supports memory continuity.
- Preserving task context with lightweight externalisation at disengagement offers a way to reduce the cognitive cost of resumption.
- Cognitive support that explains its rationale can help users engage with it willingly.

- Reflective steps should remain optional and skippable, preserving user control over how and when cognitive support is used.
- Alternative input modes, such as voice dictation, may lower the effort of engaging with cognitive support at task boundaries.

Beyond reading, the chapter contributes to the thesis goal of cognitive resilience by showing that disengagement moments, when working memory is most fragile and partially consolidated meaning is easiest to lose, can be deliberately supported through interaction design. This reframing generalises to other continuity-sensitive digital activities (e.g., studying, writing, document reviewing, analytical work, or form completion, among others), where supporting *how users disengage* can strengthen their ability to sustain performance, return effectively, and retain meaning over time. The broader synthesis of these implications and their integration with the other design artefacts is addressed later in chapter 7.

Chapter 6

Design Study 3: ReasonScape for Reasoning and Critical Thinking in AI Assistant Use

This chapter presents ReasonScape, the third and final core design study of this thesis. While the preceding chapters focused on design support for attention (Attention Mode) and memory continuity (SmartPause), ReasonScape targets reasoning and critical thinking in AI-augmented judgement and sensemaking. When AI systems return outputs quickly, users can face higher cognitive load due to the high amount of information presented and may rely on the output too readily.

Contemporary conversational and generative AI systems significantly reduce the effort required to access information, explanations, and recommendations. These systems can improve efficiency and accessibility, but they can also prompt users to evaluate outputs superficially and accept them too quickly. Unlike conventional usability issues, these effects build gradually through repeated interaction with systems that favour quick, fluent outputs over deliberation and reflective judgement.

ReasonScape redesigns a familiar chat-style user-interface (e.g., ChatGPT or Gemini) in such a way that it guides reasoning and keeps users engaged in the process, rather than pushing them straight to an answer. It adds short pauses to facilitate reflection, guides users through the steps, and shows how their thinking evolves over time. This helps users to continue checking the AI's output just accepting them it too quickly.

Together with the preceding chapters, ReasonScape completes a set of three design investigations addressing attention, memory, and reasoning as interrelated components of cognitive resilience. By focusing on critical thinking within AI-augmented interaction, this chapter connects concrete interface interventions to broader questions of how

emerging AI systems can be designed to support, rather than undermine, human cognitive agency (i.e. users' active control over evaluation, justification, and final judgement when working with AI outputs).

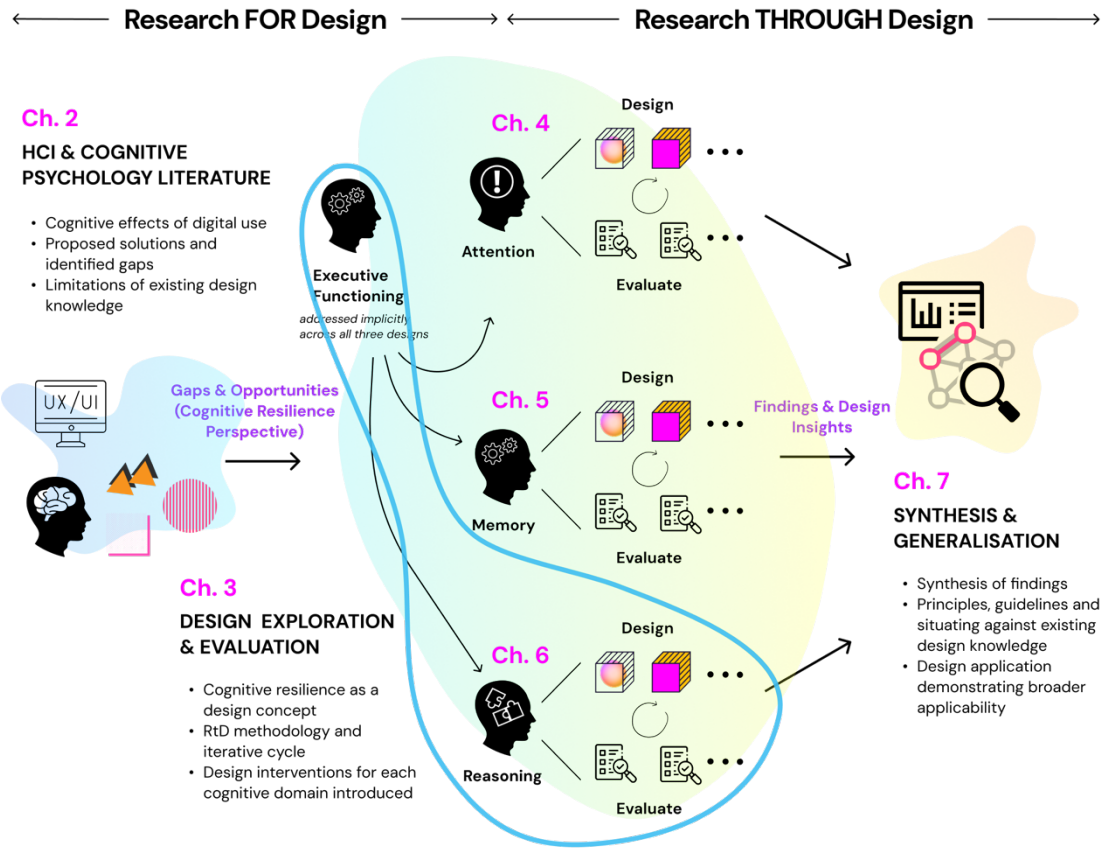


Figure 6.1: The ReasonScape design study within the research process (circled in blue).

Figure 6.1 illustrates the scope of this chapter within the overall methodology. The design study presented here has been disseminated through the following papers:

- Hacioglu, N., Leva, M.C. and Lee, H. (2025) 'AI That Makes You Think: Designing Systems for Guided Reasoning and Reflection'. *ACM CHI 2025 Workshop: Human-AI Interaction for Augmented Reasoning*, Yokohama, Japan.
- Hacioglu, N. B., Leva, M. C., & Lee, H. (2026). From answer-first to decision-first: An interaction pattern for creative judgment in AI chat. In *C&C '26: Proceedings of the 2026 Conference on Creativity and Cognition* (pp. 1280–1285).

6.1 Problem Focus and Design Opportunity

6.1.1 Effects of AI Chat Interaction on Reasoning and Critical Thinking

AI-augmented reasoning systems are widely used in information validation, automated argument analysis, and decision-making applications today. While these systems enhance

efficiency, research indicates that they can also contribute to cognitive overload by presenting users with excessive information at once**,** a phenomenon documented as affecting workplace decision-making (Buchanan & Kock, 2001). When working memory is overloaded, users have fewer cognitive resources available for evaluating new information (Sweller et al., 2011). As a result, AI-assisted users often default to accepting system outputs, relying on general heuristics about when to follow AI suggestions rather than engaging analytically with each recommendation (Buçinca et al., 2021; Danry et al., 2023).

Historically, cognitive science and HCI research have emphasised the importance of structured reasoning and deliberate reflection in learning and decision-making processes. Studies show that human cognition is context-dependent, meaning users rely on external tools and interfaces to offload cognitive effort (Risko & Gilbert, 2016). Traditional models of learning, such as Bloom's taxonomy (Bloom et al., 1956) emphasise the importance of active learning and self-reflection in problem-solving, both of which AI should facilitate rather than replace.

However, research suggests that higher confidence in AI capabilities can lead to diminished critical engagement, particularly in routine tasks, potentially eroding independent problem-solving skills (H.-P. Lee et al., 2025). Other research warns that deceptive AI systems can manipulate decision-making if users trust them uncritically (Danry et al., 2022).

6.1.1.1 Over-reliance and Automation Bias

Over time, over-reliance on AI responses can erode domain expertise and problem-solving abilities, as users gradually defer reasoning tasks to AI systems rather than applying their own analytical skills. Beyond short-term task performance, over-reliance raises concerns about longer-term cognitive consequences. Research on cognitive offloading suggests that repeatedly delegating cognitive work to external systems can reduce engagement in internal reasoning processes, particularly when users come to expect the system to "think for them" (Risko & Gilbert, 2016).

In open-ended sensemaking tasks, reduced critical checking can also weaken the evaluation of generated ideas, so that users accept plausible-looking directions without properly assessing them against alternatives, constraints, or trade-offs (Cropley, 2006).

Additionally, excessive reliance on automated systems can lead to automation bias, where users develop an uncritical trust in system recommendations despite evidence of errors. This tendency has been studied in automated decision aids in aviation and

monitoring systems (Parasuraman & Manzey, 2010; Skitka et al., 1999), and has been documented in fields such as healthcare and finance, where professionals may override their own expertise in favour of AI-suggested diagnoses or investment strategies (Goddard et al., 2012; Shukla & Shukla, 2023). Cecil et al. (2024) found across five experiments that people continued to follow incorrect AI advice even when the system's predictions were made explainable. Horowitz and Kahn (2024) found that users with a moderate background in AI relied on it the most, while those with minimal or extensive background relied on it more appropriately.

In chat-based AI systems, these effects are especially concerning because interactions are often frequent, low-friction, and embedded in everyday decision-making, increasing the likelihood that over-reliance develops gradually through repeated use rather than isolated failures.

6.1.1.2 Cognitive Overload

Alongside over-reliance, cognitive overload arises when AI systems present too much information for users to evaluate effectively. Many AI chatbots generate long, multi-paragraph responses that include background context, alternative viewpoints, and justifications in a single turn. While such responses may appear informative, they exceed the limited capacity of working memory (Sweller et al., 2011) and can lead users to shallow processing strategies, such as skimming, relying on surface cues, or deferring judgement to the system rather than engaging in deeper analysis (Buçinca et al., 2021).

Empirical work on decision-making with AI assistants further suggests that cognitive overload can interact with heuristic biases, increasing users' tendency to anchor on initial AI suggestions or framing effects (Gurney et al., 2023). These effects are particularly problematic in judgement and sensemaking tasks, where users must weigh uncertainty, compare alternatives, and justify decisions rather than simply retrieve factual information.

Recent evidence on cognitive debt strengthens these concerns by suggesting that repeated reliance on generative AI systems can lead to longer-term reductions in cognitive engagement, after AI assistance is removed (Kosmyna et al., 2025). Taken together, these findings indicate that AI-augmented reasoning systems may undermine critical thinking not only through momentary overload, but through cumulative shifts in how cognitive effort is allocated over time.

6.1.2 Existing Solutions

Existing solutions include both research prototypes and commercial systems, but they are still partial. Many of them focus on only one mechanism at a time (for example, question

framing, step-by-step prompting, feedback, structured representations, or pacing), instead of changing the overall chatbot interaction pattern.

6.1.2.1 Question-Based (Socratic) Support

One common approach in research prototypes is question-based (Socratic) support, where the system asks the user to justify, explain, or reconsider, rather than giving a direct conclusion immediately. Research suggests that framing explanations as questions can improve logical discernment and can reduce passive acceptance, especially when the system is designed to elicit reasoning steps from the user (Danry et al., 2023). This is also consistent with earlier work on self-explanation as a mechanism that supports deeper processing and learning (Chi et al., 1994). In current practice, similar question-led patterns appear in AI tutoring tools such as Khan Academy's Khanmigo (n.d.)[26] and in the guided learning modes of mainstream assistants: OpenAI's Study mode in ChatGPT (2026)[27], Google's Guided Learning in Gemini (Heymans, Maureen, 2025)[28] and Anthropic's Learning mode in Claude (2025)[29], all of which encourage step-by-step work instead of instant final answers.

In practice, these approaches are often implemented as a specialised tutor or an optional mode rather than as a systematic reconfiguration of chat interaction across tasks. Even when questions are used in mainstream interfaces, they can be superficial (for example, choice or navigation questions) rather than checkpoints that expose contradictions, test competing explanations, or require users to revise an initial judgement.

6.1.2.2 Feedback and Tutoring Loops

Some systems embed feedback and tutoring-like loops inside larger platforms**.** For example, Duolingo's "Explain My Answer"[30] gives immediate feedback after a user response, and it explains why an answer is correct or incorrect (Castillo, 2026). These features resemble intelligent tutoring systems (ITS) in a practical way: they respond to user input with feedback, and they guide users through smaller steps, which is consistent with tutoring loops described in ITS research (Ma et al., 2014). This approach is usually applied in instructional settings with bounded domains and pre-specified learning

[26] Khanmigo, Khan Academy. https://www.khanmigo.ai/
[27] Study Mode, OpenAI. https://openai.com/index/chatgpt-study-mode/
[28] Guided Learning, Google. https://blog.google/products-and-platforms/products/education/guided-learning/
[29] Claude for Education, Anthropic. https://www.anthropic.com/news/introducing-claude-for-education
[30] Explain My Answer, Duolingo. https://blog.duolingo.com/explain-my-answer-now-free/

objectives, not the open-ended contexts where chatbots are now used for everyday judgement and sensemaking (Graesser et al., 2005).

6.1.2.3 Structured Representations

Structured representations such as argument maps or debate trees make reasoning explicit. Argument mapping tools aim to externalise claims, evidence, and counterarguments, so users can inspect and compare reasoning rather than following one fluent narrative. For example, Kialo Edu[31] supports structured debate and is positioned as a tool for training critical thinking (Kialo Edu, n.d.). Educational material on argument mapping also highlights tools like Kialo as practical environments for making assumptions and argumentative structure visible (The Open University, n.d.). Such tools, though, typically sit outside mainstream AI chat interfaces, and they require users to translate conversational content into a separate reasoning workspace.

Across all these approaches, the combined problems described in Section 6.1.1 persist. Question-led prompting may increase engagement, but it can still sit on top of long, fluent outputs that create high information load and encourage shallow evaluation. Staged or step-by-step learning modes can reduce information volume per turn, but they do not always require users to challenge, verify, or justify conclusions across the interaction, so uncritical trust can remain. As a result, users can still encounter answer-first patterns in routine use, and support is often mode-based rather than integrated into the default chat workflow.

Taken together, the existing solutions are not sufficient to address the combined challenges identified in Section 6.1.1, though individual mechanisms such as questioning, scaffolding, structured representations, and pacing remain useful as precedents. The open question is how to integrate them into everyday chatbot use in a coherent and sustained way.

6.1.3 Knowledge Gap and Study Aim

The knowledge gap is at the interaction level: there is still limited design knowledge about how to integrate partial mechanisms into one coherent, end-to-end chat workflow that supports reasoning and critical thinking. As discussed above, existing solutions are often partial, situational, or separated from the default chatbot interface.

Without an integrated workflow, users may lose orientation about what is established, what is assumed, and what still needs checking, especially across long turns or repeated

[31] Kialo Edu. https://www.kialo-edu.com/

interactions. When this happens, users can shift from actively managing the reasoning process to passively following the system's flow, which increases the risk of premature acceptance.

More specifically, integration must address three needs within a familiar chatbot interface: (1) mitigating over-reliance and automation bias, (2) managing cognitive overload through pacing and information structuring, and (3) supporting users' ability to monitor and develop their reasoning process. While prior work shows the value of questioning and self-explanation for deeper engagement, it rarely combines these mechanisms with interaction pacing and longitudinal representations of cognitive progress in a single coherent chatbot experience.

Therefore, the study aim of ReasonScape in this thesis is to translate this framing into a concrete chat-based interaction concept and examine how it addresses the combined risks identified in the previous section through interaction structure, not content quality alone. This positions ReasonScape as an integrative design exploration: it treats "reasoning support" as a workflow problem (how the interaction unfolds), not only a prompting or explanation problem (what the system says).

6.2 ReasonScape: A Reasoning-Scaffolded AI Chat Interaction

6.2.1 Design Overview

ReasonScape is an interaction concept for chat-based AI that supports *reasoning* and *critical thinking* by reshaping how users move from a question to a justified direction, rather than optimising for fast answer delivery. It introduces selective, skippable reflection prompts, surfaces potential gaps in evaluation without claiming correctness, and maintains a lightweight trace of evolving rationale so users can revisit key commitments and shifts across turns. This is operationalised through (1) guided reasoning checkpoints, (2) targeted reasoning interventions, and (3) longitudinal reasoning tracking, as shown in Figure 6.2 and detailed in the following sections.

6.2.2 Interaction Model and Mechanism

ReasonScape's interaction-level framing builds on established views of AI as a system for augmenting human intellect rather than replacing it (Engelbart, 1962). It also draws on work showing that thinking is shaped not only by what happens in the mind, but also by interaction with external tools and representations, such as written information or interface elements (Clark & Chalmers, 1998; Hollan et al., 2000).

At a high level, ReasonScape replaces answer-first conversational patterns with a guided reasoning flow. This flow encourages users to pause and think and offers guidance

when needed, helping them stay involved in their own reasoning before, during, and after the AI provides input**.**

6.2.2.1 Guided Reasoning Checkpoints through Reflection Pauses

The first mechanism introduces guided reasoning checkpoints that ask users to pause and reflect before AI-generated insights are consolidated. Instead of receiving a complete explanation or recommendation straight away, users are asked to briefly articulate their current stance or line of reasoning. These checkpoints appear directly within the chat and are triggered at moments when users might otherwise move quickly toward accepting a fluent AI response.

This approach is grounded in research on self-explanation (Chi et al., 1994) and question-based AI prompts (Danry et al., 2023). By placing these prompts before AI responses are finalised, ReasonScape treats reflection as part of the reasoning process itself, rather than as something added afterwards. A slower pace of interaction enables more controlled information processing, supporting deeper understanding and helping mitigate cognitive overload.

6.2.2.2 Targeted Reasoning Interventions for Cognitive Gaps

In addition to general reflection pauses, ReasonScape introduces targeted reasoning interventions that are triggered only when signs of difficulty appear in the user's reasoning process. These interventions are only activated at moments where the interaction indicates that reasoning may be losing clarity or coherence during AI-supported judgement and sensemaking.

The aim is to make such patterns easier to notice and think through as they emerge. These may involve:

- *Biases*, where thinking is pushed in a certain direction without the user clearly noticing
- *Contradictions* and *inconsistencies*, where statements, assumptions, or conclusions do not fit together logically
- *Unexamined assumptions*, where claims are treated as true without being questioned
- *Weak* or *missing counterpoints*, where alternative views are not sufficiently considered
- *Shallow reasoning*, where the reasoning process lacks the necessary depth and explanation

- *Failure to explore what-if scenarios*, where conclusions are not assessed under alternative conditions
- *Loss of the big picture*, where attention focuses on details and the overall goal or context is overlooked

Importantly, these patterns are treated as interaction-level concerns rather than assumptions about the user's internal thinking; the design focuses on making potential gaps visible, not on diagnosing user reasoning. The prompts raise questions or highlight tensions, rather than offering corrections or instructions. Claims about correctness or optimality are avoided, keeping control with the user and framing the system as a tool for reflection rather than an authority. In that sense, the interaction aligns with what Hertwig & Grüne-Yanoff (2017) describe as a "boosting" stance: it strengthens users' reasoning capabilities without steering decisions toward predefined outcomes.

These interventions are also intended to counter automation bias. The system prompts interrupt answer-following at moments where users may defer too quickly to the AI, encouraging checking and revision before continuing (Parasuraman et al., 2000; Skitka et al., 1999).

6.2.2.3 Longitudinal Reasoning Tracking Across the Interaction

ReasonScape treats reasoning as a process that develops over time, rather than as a sequence of isolated chat messages. In many chat-based AI systems, earlier reasoning steps quickly fade as the conversation progresses. As a result, users can lose track of how they arrived at a certain point or which issues remain unresolved.

To address this limitation, the interaction model keeps track of key elements of the reasoning process across multiple turns. These elements include the main question at the start of the interaction, key points in the discussion**,** shifts in focus, and points where the system flags potential reasoning issues.

Longitudinal tracking is intended to support orientation during longer interactions. Instead of relying only on memory, scrolling or keyword search, users can see how their reasoning has progressed so far and how different parts of the conversation relate to each other. Users can also select specific points in the reasoning trace and jump directly to the corresponding part of the conversation. Such access makes it easier to understand the current state of the reasoning and what still needs attention.

Externalising the structure supports reflection on how thinking develops, shifts, or branches during the interaction. Maintaining continuity in this way allows users to reason more consistently during extended interactions and lowers the risk of information

overload. Users can track how their thinking develops, revisit earlier commitments, and integrate new information with prior discussion.

This is in line with research showing that external representations stay stable over time and give users persistent reference points that they can revisit and compare (Kirsh, 2010). Sensemaking research similarly shows that analysts use external representations to organise information and revise their interpretations as new evidence is collected (Pirolli & Card, 2005). A lightweight progress indicator summarises which categories of reasoning gaps have been addressed, and which remain open across the interaction.

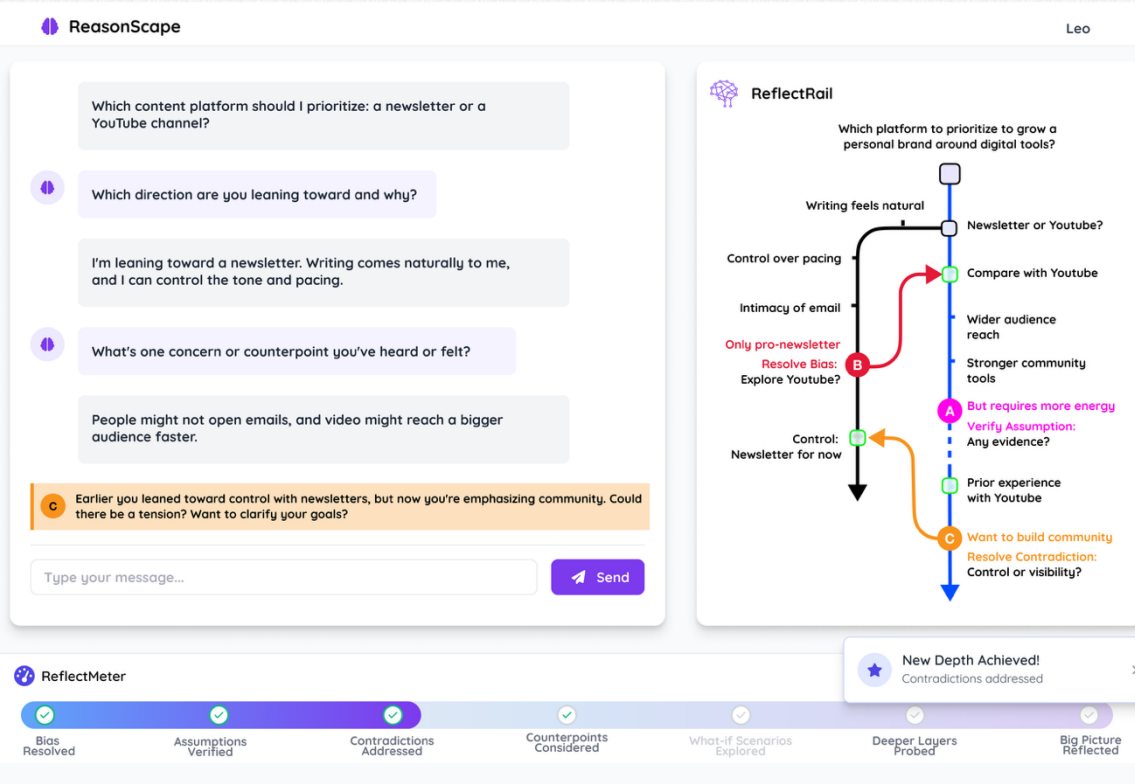


Figure 6.2: ReasonScape interface overview with an example chat flow. The layout combines a chat window (left) with embedded creative-judgement checkpoints and an in-line sensemaking intervention card (orange callout within the chat), alongside ReflectRail (right), which externalises the evolving rationale as a navigable trail. ReflectMeter (bottom) provides a persistent, lightweight status view of which gap categories are open or addressed.

6.2.3 Interface Features

ReasonScape implements the interaction model in Section 6.2.2 through three main interface components: (1) a restructured chat interaction, (2) ReflectRail, and (3) ReflectMeter. A familiar chat layout is maintained, while additional visual cues make it easier for users to notice and revisit key reasoning points, flagged issues, and overall progress during extended interactions. Figure 6.2 presents the full interface overview

including the placement of the main components in the layout (chat window, ReflectRail, ReflectMeter, and an example intervention card).

6.2.3.1 Restructured Chat Interaction

The chat is enhanced to support guided thinking, rather than fast and long answers. It keeps a familiar conversational format, but changes how the assistant produces responses and how reflection is added to the interaction. The interaction avoids multi-paragraph outputs with many details in a single turn and delivers responses in smaller units. This is accomplished either through (a) focusing on a specific aspect of the user's query at a time, or (b) providing a summary that captures the main points without minor details. Short reflection inserts are included in the flow, in the form of guided checkpoints and intervention cards, which request clarification or encourage reconsideration. This pacing reduces information and keeps the user actively involved, supporting comprehension by making it less likely that important reasoning steps are skipped.

Guided Chat Checkpoints (Reflection Questions). Guided checkpoints appear as short prompts placed inside the chat flow. Their purpose is to create small "stops" where the user makes their thinking explicit before the conversation continues. Checkpoints are intentionally brief, so they feel like part of normal chat, not a separate exercise (see Figure 6.2, left panel, upper portion of the chat window). Typical checkpoint prompts ask the user to:

- confirm or restate the main goal of the interaction
- state which option they currently lean toward and why
- name a concern, uncertainty, or counterpoint
- clarify what evidence, experience, or constraints are being used

These checkpoints support reasoning continuity by making intermediate judgements visible in the interaction, rather than leaving them implicit.

Cognitive Gap Intervention Cards. When the system flags a possible reasoning issue, it displays a compact intervention card inside the chat. The card is visually distinct from normal assistant text so it can be noticed during scanning **(**see Figure 6.2, left panel, mid-to-lower area: the orange-highlighted intervention card**).** Different types of reasoning gaps are also shown in different colours, providing a quick cue for the category of issue being raised. A short text label is included on the card, so interpretation does not depend on colour alone. In Figure 6.2 the contradiction-category card is marked with a "C" label and an orange highlight to signal a tension. The intervention does not "correct" the user. It highlights a gap or tension and invites reconsideration. A generic example is:

"Earlier you leaned toward A, but now you emphasise B. A tension may exist. Clarifying the goal could help."

Placing the card close to where the issue emerges helps the user revisit the relevant step while the context remains clear, without interrupting the interaction with long explanations or forced actions. (Figure 6.2)

6.2.3.2 ReflectRail: Longitudinal Reasoning Trail

ReflectRail is a visual trail that stays on screen and shows how the reasoning changes over time (Figure 6.2, right panel). It is designed to help users keep the big picture in longer chats, especially when the conversation becomes detailed and earlier steps are harder to recall.

ReflectRail summarises the interaction as a structured trail that includes:

- the starting question and the main goal of the interaction
- key points in the discussion (important steps rather than every message)
- direction changes into sub-questions or detail threads
- flagged reasoning issues attached to the point where they occurred (e.g., assumptions, contradictions, missing counterpoints)

The trail can show branching, so users are able to see where the discussion followed the main direction and where it moved into a side path. User can also select a point on the trail and jump back to the corresponding moment in the chat (e.g., in Figure 6.2, top-right, the ReflectRail shows the decision path with labelled nodes; selecting the red "C" node jumps the user back to the related point in the left chat panel, where the corresponding gap intervention is highlighted), reducing dependence on scrolling during revisiting.

6.2.3.3 ReflectMeter: Cognitive Gap Resolution Visibility

ReflectMeter is a lightweight progress indicator that remains visible across the interaction. It summarises which categories of reasoning gaps (as described in Section 6.2.2) have been addressed and which remain open.

ReflectMeter is not designed as a correctness score. It functions as a simple status view that helps users notice unfinished reasoning work **(**see Figure 6.2, along the bottom edge: the horizontal "ReflectMeter" strip shows gap categories such as Bias, Assumptions, Contradictions, Counterpoints, and What-if Scenarios, with visual states indicating addressed vs. still-open). For example, users can see when biases are not resolved or what-if scenarios have not been considered, or when an assumption check is not explored. When a category is not relevant to the current conversation, it can be visually reduced

(e.g., greyed out, as with "What-if Scenarios Explored" in the ReflectMeter, Figure 6.2) to avoid noise.

Once a gap category is fully addressed, the interface can show a short acknowledgement message (e.g., "All contradictions addressed"). This is the gamified element, but it is intentionally subtle. It is intended to encourage users to follow through on reflection, without turning the interaction into a scoring system.

6.2.3.4 Interaction Sequence Across Components

To show how the components operate together, the following eight-step sequence illustrates their combined operation:

1. **Initial query and opening checkpoint.** The user asks: *"Which content platform should I prioritise: a newsletter or a YouTube channel?"* An opening checkpoint prompt is presented in the chat to slow the interaction before extended guidance is provided. ReflectRail records the query as the starting node (initial goal).
2. **Preference articulation prompt.** The assistant asks: *"Which direction are you leaning toward, and why?"*
3. **Preference and rationale capture.** The user replies: *"I'm leaning toward a newsletter. Writing comes naturally to me, and I can control the tone and pacing."* ReflectRail adds a new node, branches into options (Newsletter / YouTube), and stores the user's reasons as short labels under the selected branch.
4. **Alternative consideration prompt.** The assistant asks: *"What would make YouTube the better choice for you? Name one benefit that the newsletter cannot provide."*
5. **Extended justification under the current preference.** The user answers while still defending the newsletter: *"YouTube might reach more people, but filming and editing would slow me down. A newsletter lets me publish consistently, and I can reuse the same ideas for videos later."* ReflectRail extends the *Newsletter* branch and records the additional reasons (time cost, consistency, reuse).
6. **Bias intervention and visible flagging.** A reasoning issue is flagged (one-sided evaluation with predominantly pro-newsletter points). A compact intervention card appears in the chat: *"Most points so far support the newsletter. To reduce one-sided reasoning, can you state one risk or limitation of starting with a newsletter?"* ReflectRail marks the relevant node with a visually distinct flag.

7. **Goal re-check through trace navigation.** The user selects the initial query node in ReflectRail to reread the goal, then returns to the flagged point to review what triggered the intervention.
8. **Gap resolution and status update.** The user resolves the bias prompt: *"A newsletter could grow slowly at the start, and it may be harder to reach new audiences."* ReflectRail marks the bias flag as resolved (e.g., greyed out) and creates a new node from that flag to show how the bias was resolved. ReflectMeter marks the bias check as completed and displays a short acknowledgement message (e.g., *"Bias addressed"*).

This sequence makes the pacing and interruption logic visible as steps that unfold through the interface, rather than remaining only as a written claim.

6.3 Evaluation Method

Two rounds of expert inquiry were conducted to evaluate ReasonScape and refine the design concept. Phase 1 gathered expert feedback from eleven participants during the ACM CHI 2025 workshop on AI-augmented reasoning (Yokohama, Japan, 26 April 2025), using a guided walkthrough to discuss the interaction mechanisms, interface components, and potential risks in real use. Phase 2 consisted of five ad hoc expert interviews conducted to verify the main points that emerged from Phase 1 and to assess implementation plausibility and likely constraints. There was no overlap between the experts in the two phases, i.e. there were total 16 individual experts who provided the feedback. Session protocols and the workshop poster are provided in Appendix F.

6.3.1 Phase 1: Expert Feedback (n = 11)

ReasonScape was first evaluated through expert feedback as a formative design assessment in the CHI 2025 workshop setting**,** where it was presented and discussed with researchers working on reflective and critical thinking support in human–AI interaction. The purpose was to understand how the proposed interaction pattern and interface components would be interpreted by researchers familiar with human–AI reasoning support, and what kinds of tensions or risks the design may introduce in real use. Feedback was used to refine the design concept and to support theoretical reflection in this thesis, especially around the trade-off between usability efficiency and interaction structures that encourage slower, more deliberate judgement.

The evaluation did not focus only on whether the system "improves reasoning". Just as importantly, it also aimed to surface broader design concerns, including the perceived supportiveness or intrusiveness of the interventions, the understandability of the system's

logic, the role of the visualisations in orientation, anticipated failure modes, and the positioning of agency and authority in the interaction.

6.3.1.1 Participants

Experts were recruited from workshop attendees (n = 11). They had relevant backgrounds in areas such as human–computer interaction, computer science, behavioural sciences, cognitive psychology, and learning sciences. Participants were a mixed group of early-career and more experienced researchers, predominantly from academia, with a smaller number from industry.

6.3.1.2 Materials

Experts reviewed ReasonScape using three artefacts: the workshop poster, interface visuals of the main components (restructured chat, ReflectRail, ReflectMeter), and a short scenario script used to demonstrate a concrete example interaction. There was no working prototype or interactive demonstrator system.

6.3.1.3 Expert Evaluation Sessions

A qualitative expert review approach was used because ReasonScape reorganises the workflow of chat-based AI. The aim was to test mechanism logic and interface interpretation, rather than measure performance outcomes.

Each session began with a brief framing of the system, followed by a guided walkthrough of the example scenario showing when checkpoints appear, when a gap card is triggered, and how ReflectRail and ReflectMeter update. Experts were then invited to comment on the broader design questions outlined above, with particular attention to whether the interventions felt supportive or intrusive, what failure cases they anticipated (for example, false positives, over-triggering, or user irritation), and how the design positioned agency and authority in the interaction. The sessions were held in the large room where the workshop posters were displayed, both during the dedicated poster session and afterwards, with each face-to-face session lasting approximately 15-20 minutes.

6.3.1.4 Data Analysis Approach

Feedback was captured as written notes during and immediately after each session and was supplemented with short quotations when experts gave precise wording that represented a broader point.

Comments were first grouped around the key parts of the system (checkpoints, gap interventions, ReflectRail, ReflectMeter), then interpreted as either benefits, frictions, risks, or design opportunities. Particular attention was given to “tension statements”

raised by experts (for example, cases where increased reflection support may reduce perceived speed or simplicity), since these directly relate to the thesis theme of cognitive resilience versus conventional usability priorities.

6.3.2 Phase 2: Ad hoc Expert Interviews (n = 5)

A second phase was conducted through separate ad hoc expert interviews to check the main points that emerged in Phase 1 and to sense-check feasibility considerations**.** This phase was not intended to generate many new themes. Instead, it focused on confirming whether the key concerns and perceived benefits were similar when discussed outside the workshop setting, and whether the overall design direction appears realistic. These interviews were conducted with experienced academic experts**.** Notes from this phase were integrated into the same synthesis as Phase 1, mainly as confirmation, clarification, or adjustment of earlier themes. Four interviews were conducted in person at the Faculty of Engineering and Computing, Dublin City University, on 24 September 2025, and one was held remotely via Zoom. All sessions used the same visuals presented in Phase 1, with each lasting approximately 20-25 minutes.

6.4 Findings

6.4.1 Phase 1 Findings: Expert Feedback (n = 11)

Phase 1 feedback highlighted how experts understood the value of ReasonScape and where they anticipated risks in real use. Experts responded to ReasonScape mainly as a change to the *interaction pattern* rather than a set of isolated UI features. The subsections below summarise the main themes by component.

6.4.1.1 Guided Reasoning Checkpoints (Reflection Pauses)

Experts largely viewed checkpoints as a low-effort way to slow “answer-first” chat and keep users engaged in the thinking behind responses. They described checkpoints as a pacing mechanism that invites users to briefly surface goals, key constraints and preferences, or uncertainty before the assistant continues. This was often described as a simple way to reduce superficial evaluation during fast chat interaction.

At the same time, the feedback stressed that effectiveness depends on calibration. Timing and wording were treated as critical as they can feel repetitive if checkpoints appear too often or when the user already feels clear. For this reason, they pointed out checkpoints should sound like natural clarification within the conversation, not like an extra step the user must complete.

Experts also pointed out a common situation where users may not act upon those and in this case, the checkpoint should remain optional, and the conversation should continue normally with the checkpoint treated as skipped.

Finally, they noted that contemporary assistants already ask short questions (e.g., clarification questions and preference checks). However, these prompts are usually designed to move quickly toward an answer. As a result, they often improve input clarity more than they support reasoning quality. ReasonScape was therefore seen as valuable because these familiar prompts were organised into a more intentional rhythm for reflection, while the conversation flow was still maintained.

6.4.1.2 Cognitive Gap Intervention Cards

Cognitive gap intervention cards were frequently discussed as one of most distinctive interruption mechanisms. Experts appreciated the intent in the design of gap card to surface open points in reasoning at the moment they emerge. They commented this mechanism could encourage a quick check rather than immediate acceptance of the first response and indeed reduce automation bias if properly implemented.

Concerns focused mainly on trust and on how the intervention would come across in tone. When issues are raised too often, or are not seen as relevant, the prompts may start to be ignored or become irritating, in a similar way to the reasoning checkpoints. Experts also warned that interventions should not be framed as judgement or correction, because this may be experienced as patronising and irritating. Cards were viewed as most acceptable when they raise a possible concern and invite a second look, without taking control away from the user.

Several practical cases were repeatedly raised. As in checkpoints, if a user does not resolve an intervention card, the chat should not be blocked or even stay in the chat window. Experts also discussed situations where multiple gaps appear close together. Presenting multiple issues can overwhelm the user's attention, suggesting that issues should be introduced selectively, and in a clear order of priority.

6.4.1.3 ReflectRail: Longitudinal Reasoning Trail

Experts appreciated that ReflectRail addressed a known limitation of chat interfaces, where earlier goals, decisions, and changes in direction can be missed. They found it useful especially in long chats, where reasoning steps quickly be forgotten as the conversation grows. The route style mapping was considered valuable for orientation, as the overview could be accessed without constant scrolling. Most of the participants

welcomed the direct navigation feature (through clicking the nodes) and mentioned it could make much easier to trace the reasoning back to earlier point.

On the other hand, they also noted that it may add visual clutter and recreate overload if the trail captures too much detail, while a trail that is too abstract may not worth using. This led to suggestions that ReflectRail should show only key steps and stay consistent over time, rather than listing every message. A clear distinction was also recommended between the main path and smaller side paths.

Experts also raised further considerations from different perspectives. Design-oriented comments emphasised that the trail should be immediately understandable, with nodes clearly tied to the chat. Without this clarity, the trail could become a second interface. Cognitive perspectives noted that the trail could reduce memory burden, but frequent switching between chat and the visual trace could also split attention. Feasibility-oriented comments warned that inaccurate or mislabelled steps in the trail could undermine trust. This reinforced the need to show only a small number of stable, key steps, and to provide a lightweight way to correct the trail when it misrepresents the conversation.

6.4.1.4 ReflectMeter: Cognitive Gap Resolution Visibility

ReflectMeter produced mixed reactions. Some experts viewed it as a way to keep track of what has been addressed and what still needs attention, without requiring a "correct answer". Overall, experts saw this gamification element as a good addition, since it supports completion in a simple and lightweight way.

However, there were also few concerns that meter-style visuals may be read as evaluation or judgement, regardless of how they are framed. This risk was seen as higher when the meter becomes the focal point of the interface and suggests that leaving any category incomplete is undesirable.

Feedback suggested that progress should be shown with minimal emphasis and that messages should be framed as supportive cues rather than a measure of performance. The meter should communicate what cognitive gaps are still present without turning it into a requirement to resolve or explore every one of them. Instead, it should support awareness of what has and has not been considered, while leaving the decision of what to address to the user.

6.4.1.5 Cross-cutting Finding: Reasoning and Critical Thinking vs. Efficiency

Across the different components, experts consistently highlighted the same underlying tension. ReasonScape deliberately adds moments of friction to encourage more reflective

judgement, yet chat interfaces are typically used with an expectation of speed and ease. They framed it as a central design challenge for the concept.

Existing design elements were identified as more likely to be accepted when it is paired with familiar design elements and implemented with restraint. They reported that ReflectRail could reduce the cognitive effort of reflection by providing a conversation overview and visualising reasoning steps, while ReflectMeter could make slower reflective steps feel more purposeful through light gamification cues. When combined with brief, optional prompts, these elements were described as a way to balance friction, keeping reflective support available without making the interaction feel interruptive, slow, or judgemental.

6.4.2 Phase 2 Findings: Ad hoc Expert Interviews (n = 5)

Phase 2 interviews largely confirmed the Phase 1 themes, but the emphasis shifted. Instead of discussing the desirability of the mechanisms in principle, experts focused on whether the concept seems realistic to implement. Overall, the design was described as feasible, but it needs careful tuning, so the system does not interrupt too often or fill the interface with too many flags.

One consistent point was that the system does not need perfect "reasoning detection" to be useful. Checkpoints and intervention prompts were seen as straightforward to deploy as interaction rules and UI patterns, as long as they remain lightweight and optional. ReflectRail and ReflectMeter were also considered buildable as live-updating summaries, but experts cautioned that usefulness depends on stability. If the trail or status view shifts wording, reshuffles earlier steps, or changes labels unpredictably during a long chat, trust may drop quickly because users cannot rely on what they see.

Two experts noted that false positives, where the system flags gaps that do not exist, can lead to *alert fatigue*, defined as users becoming less responsive to frequent or repeated low-value system feedback and ignoring it even when some prompts are helpful (Ancker et al., 2017). False negatives, where the system fails to flag gaps that do exist, reduce perceived value by not surfacing support when it is needed.

Related to this, experts stressed that "resolution" is hard to define in a robust way. A user may respond briefly just to move on, so marking an item as resolved can easily feel arbitrary. For that reason, phase 2 feedback supported conservative language and status cues that communicate "open" versus "addressed" without suggesting correctness.

Finally, all experts raised interaction costs as a practical limit. If each turn requires extra processing (checking for gaps, updating the trail, updating the meter), responses

may slow down and weaken the chat experience. Phase 2 feedback therefore reinforced the importance of restraint: prioritising only a small number of signals at a time and keeping updates simple enough to avoid noticeable latency.

6.5 Discussion: Implications for Cognitive Resilience and Design Knowledge

ReasonScape moves beyond the search for the "perfect" AI answer, focusing instead on how the layout of the conversation itself can better support human thinking. The design assumes that fast, polished answers contribute to judgement lapses by making it hard for users to scrutinise the missing, implicit, or illogical inferential steps linking premises to a conclusion. Rather than treating reasoning as a purely internal act, ReasonScape aligns with the view that external representations provide critical leverage for organising and coordinating thought (Kirsh, 2010). Therefore, it operationalises the aim of "augmenting human intellect", designed to help users manage the complex steps that link premises to conclusions (Chi et al., 1994; Engelbart, 1962). This aligns with reflective design in HCI, which argues that reflection can be supported by carefully placed breaks in otherwise smooth interaction, rather than crude interruptions, that surface implicit assumptions and encourage active meaning-making (Sengers et al., 2005).

6.5.1 Timing and Intervention in AI-Supported Reasoning

This study materialises these theories by introducing a chat workflow that surfaces reflective steps and logical gaps in real time, preventing them from being lost to memory or buried in long message threads. A key design implication is that "answer quality" alone cannot solve the problem of automation bias (Parasuraman & Manzey, 2010). Expert feedback reinforces this point, and ReasonScape's strength lies in how it disrupts the typical "answer-first" momentum. Rather than functioning as a collection of optional UI features, the system uses checkpoints to break this momentum and gap cards to reopen reasoning at moments of cognitive tension. This suggests that the when and how of user engagement are powerful but underused factors in mitigating the risks of fluent but flawed AI reasoning.

6.5.2 Calibrating Friction as a Design Resource

The findings suggest that friction can serve as a valuable resource, provided it is carefully calibrated to the user's needs. Phase 1 made the central problem clear: the "reflective pauses" built into the system conflicted with users' expectation of quick responses in chat assistants. This tension becomes productive when the design distinguishes between 'justified' pauses and 'noisy' interruptions. For these interventions to feel natural, they

must align with the rhythm of a dialogue and act as skippable conversational moves rather than corrections.

A practical way to calibrate friction is to begin with a light hint rather than an immediate label such as "assumption" or "contradiction." Friction can start as a subtle cue and become more specific only when needed. The system can first indicate that something may not fit, then surface the relevant parts of the dialogue, and only later name the gap type or introduce a stronger prompt if the user cannot progress or repeatedly bypasses the same tension. This staged approach can make the interaction feel less judgemental and reduce fatigue from frequent prompts. Importantly, such progressive disclosure encourages users to work through their own thinking before turning to the system for additional guidance. It also reflects everyday sensemaking, where people often register a vague tension first, then compare ideas, and only afterwards name the issue and organise the reasoning.

6.5.3 Supporting Structural Memory Through Visualisation

The findings also suggest that making information visible helps users keep track of their reasoning only when key steps in the interaction remain in a consistent place and can be revisited easily. This moves the design focus away from mere history-tracking and toward a model of "structural memory." In chat-based reasoning, users often suffer from narrative drift as the dialogue evolves, making it difficult to link early premises to current outputs. ReflectRail addresses this by providing a route-style visual metaphor that acts as a cognitive anchor, enhancing both orientation and learnability by offering a consistent map of the reasoning process. The insight here is that resilience design succeeds not by showing more information, but by sustaining selective continuity. Relying on consistent labels avoids the noise of frequent updates and provides the user with a stable mental hook. These anchors allow users to offload the cognitive burden of tracking progress (Kirsh, 2010) without exposing them to a secondary, competing stream of information.

6.5.4 Indicating "States" Rather Than "Milestones"

Phase 1 feedback highlighted a risk of misinterpretation in ReflectMeter's visual language. Since it adopts a conventional progress-bar format, it can inadvertently signal tracking and evaluation rather than open-ended reflection. Even when such meter-like elements are meant to be neutral, users may perceive them as implicit scores or requirements. Consequently, they might address reasoning interventions in a limited way simply to satisfy the system's visual demands, rather than based on the actual utility of the information. Designers should therefore present interaction cues as descriptive states

rather than milestones. This approach encourages reflective thinking and reduces the pressure for constant self-evaluation. In practice, this entails keeping the representation secondary, foregrounding only a small set of relevant categories, and categorising progress as 'still open' instead of 'addressed'. Framed this way, the system maintains user awareness while keeping agency with the user and ensures that unresolved categories are viewed as opportunities for further reflection rather than errors to be corrected (Hertwig & Grüne-Yanoff, 2017). This caution is also consistent with empirical findings that progress cues such as badges and leaderboards can shift users toward performance-oriented engagement and, over time, undermine intrinsic motivation (Hanus & Fox, 2015; Mekler et al., 2017).

6.5.5 Reliability, Trust, and Longitudinal Use

While Phase 2 interviews confirmed that ReasonScape can be implemented using interaction rules and lightweight summaries, the results also identified specific constraints on its real-world viability. The mechanisms are technically feasible, but their practical application depends on overcoming certain environmental or systemic limitations. The main concern was not whether the interface can be drawn, or the prompts can be written, but whether the system can remain reliable enough to avoid alert fatigue and trust loss over time. False positives and ambiguous resolution were described as the most likely reasons users would disengage, and stability across long chats was treated as a practical requirement for longitudinal tracking to remain usable. This shifts the implementation discussion away from “can it be implemented?” toward “can it be implemented in a way that stays credible during repeated use?”, which is closer to the thesis concern with cumulative cognitive effects.

6.5.6 Implications for Creative and Open-Ended Judgement

Finally, ReasonScape also suggests a broader opportunity for creativity and open-ended work. A common challenge in creative and sensemaking tasks is the tendency to converge too early. In these cases, a single narrative dominates before the user can weigh alternative perspectives or "what-if" scenarios. The combination of gap prompts (e.g., missing counterpoints, shallow reasoning, untested scenarios) and a visible thought trail can protect exploration by keeping alternatives and unresolved tensions visible long enough to be reconsidered. In this context, the system supports not only error avoidance, but also higher-quality judgement under uncertainty, an outcome that aligns with cognitive resilience as a long-term capacity rather than a momentary performance metric.

6.6 Limitations and Future Work

Since ReasonScape was an interaction concept rather than a functional prototype, evaluation centred on expert inquiry to examine whether the proposed logic and mechanisms were coherent. As a result, the evidence in this chapter is mainly interpretive: it reflects how researchers understood the mechanisms, where they anticipated value, and where they predicted risks.

While this evidence provides a basis for design knowledge, it does not yet account for actual behavioural changes. Potential benefits for automation bias and critical evaluation should be assessed in real-world settings. Therefore, the next phase of research should involve a user study centred on realistic judgment and task to validate these concepts. This would allow for an evaluation of immediate behavioural shifts and also the longer-term effects that emerge through repeated interaction with the system.

Another limitation is that several mechanisms rely heavily on the quality of detection and updates. The system can be built using interaction rules; however, the real-world value really depends on the credibility of its gap flags. In addition to detecting gaps accurately, it also needs to decide when a gap is truly addressed by the user. These are critical because it may misdirect or discourage users and ultimately erode trust in the system if the system cannot function in a credible way.

Additionally, there is a risk that live-updating key points and gaps will drift during long chats as the value of ReflectRail depends on consistent anchors. If the system constantly overrides its own history, users may lose their sense of orientation. This could also lead to latency considering the system may have to re-analyse the entire conversation and refresh the UI at every turn. Finding ways to lock the history could be a potential solution to this problem. For example, key nodes could be frozen once they are confirmed, ensuring that only the user can manually adjust a trace if it goes off track. Moreover, this limitation could diminish as model performance continues to improve in the future.

A significant constraint of the conceptual design presented and evaluated here is its dependence on visual structure, which limits its accessibility, particulary for individuals with colour-vision deficiencies and low vision. Providing alternatives to these visual modes may offer a pathway for such users without compromising the underlying interaction logic. Future studies could examine whether the system's benefits hold under alternative interaction patterns, including revised visual representations and audio-based cues.

6.7 Conclusion

This chapter presented ReasonScape as a design response to a cognitive resilience challenge in everyday AI assistant use: the tendency for fast, fluent, answer-first chat to weaken reflective judgement by making it easier to accept outputs without scrutinising the inferential steps that connect premises to conclusions. Rather than treating reasoning quality as something that can be solved by improving the content of AI answers alone, ReasonScape reframes the problem as an interaction-structure problem: how the conversation unfolds, where reflection fits, and how reasoning remains inspectable across turns. The concept operationalises this reframing through an integrated chat workflow that combines guided checkpoints, targeted cognitive-gap prompts, and longitudinal tracking via ReflectRail and ReflectMeter.

Across two rounds of expert inquiry, the results converge on a targeted interpretive profile. Phase 1 feedback emphasised that ReasonScape was understood primarily as a change in interaction rhythm rather than a bundle of isolated UI features: checkpoints and gap cards were seen as promising when they feel like skippable conversational moves that slow premature acceptance without becoming intrusive, and the tracking components were valued when they provide selective and stable anchors that prevent long conversations from drifting or collapsing into scrolling. At the same time, the feedback clarified the main risks that shape real-world acceptability: over-triggering can create alert fatigue, labels can feel judgemental if they are too direct, and multiple simultaneous gaps can overwhelm attention unless prioritised. Phase 2 interviews largely reinforced these themes while shifting attention to viability under repeated use: the concept was seen as realistic to build as interaction rules and lightweight summaries, but its credibility depends on maintaining stability over long chats, avoiding unreliable flags, and keeping interaction costs low enough that the experience still feels like "chat."

Beyond the specific prototype, the chapter contributes to the thesis goal of cognitive resilience by showing that reasoning support can be embedded in everyday AI interaction without restricting access or removing usefulness — by adjusting pacing, making gaps visible at the right time, and preserving a lightweight structural trace of what has been established and what remains open. This directly links to the thesis's wider aim of redesigning interaction contexts that can undermine cognition in repeated use (RQ1) by demonstrating an alternative interaction pattern that mitigates automation bias and overload pressures through interface-level mechanisms (RQ2), while also pointing

toward extensions of mainstream design thinking: calibrated friction, optional but persistent reflective scaffolds, and selective "structural memory" representations as legitimate usability trade-offs for protecting judgement over time (RQ3). The broader synthesis of these implications and their integration with the other design artefacts is addressed later in the thesis.

Key insights from this study include:

- Timing and placement of reflective interventions may support reasoning, beyond the quality of AI answers.
- Friction can serve as a calibrated design resource, used selectively to interrupt automatic processing.
- Stable visual anchors that externalise the interaction record show promise for supporting continuity more effectively than full history-tracking.
- Cognitive cues should be framed as collaborative rather than authoritative, supporting reflection rather than evaluation.
- Smaller reasoning units, rather than dense outputs, can support active evaluation rather than passive consumption.
- Skippable and reversible interventions preserve user control while still offering reasoning support.

Chapters 4, 5 and 6 have presented the three design studies of this thesis. Each examined a different cognitive process (attention in Chapter 4, memory in Chapter 5, and reasoning in this chapter) through a different interaction context (everyday browsing, digital reading, and AI chat), and each revealed design moves that recur across the three studies. Chapter 7 develops these recurring moves into generalisable design knowledge: it decomposes the three artefacts into their interaction components, identifies the mechanisms that appear across them, and consolidates these into a set of principles and guidelines for cognitively resilient design that can be applied beyond the specific cases studied here.

PART III

SYNTHESIS AND CONCLUSION

Chapter 7

From Synthesis to Generalisation: Design Principles and Guidelines for Cognitive Resilience

This chapter shifts the focus of the thesis from individual design studies to the synthesis and generalisation of design knowledge for cognitive resilience. While Chapters 4–6 presented three design investigations targeting attention, memory, and reasoning respectively, each study addressed a specific interaction context and a particular cognitive vulnerability. Taken together, these studies provide a basis for moving beyond context-specific findings and deriving more generalisable insights into how interaction design can sustain and regulate core cognitive processes. In doing so, this chapter addresses RQ3 by translating insights from the design studies into generalisable design knowledge for cognitively resilient interaction.

To achieve this, the chapter decomposes the three designs into a set of components, each capturing key interaction elements and their intended cognitive effects. It then applies cross-case analysis to identify interaction-level strategies by examining how these components address common cognitive challenges across contexts. These strategies are referred to throughout this chapter as Cognitive Resilience Support Mechanisms (CRSMs), which are identified and described in Section 7.1.3. CRSMs provide a basis for deriving design principles and actionable guidelines. Figure 7.1 illustrates this analytical process. These are further examined in relation to existing design and usability knowledge and extended through an additional design application to demonstrate their broader applicability. These contributions form a coherent set of design knowledge for cognitively resilient interaction that can be applied across different cognitive functions and interaction contexts.

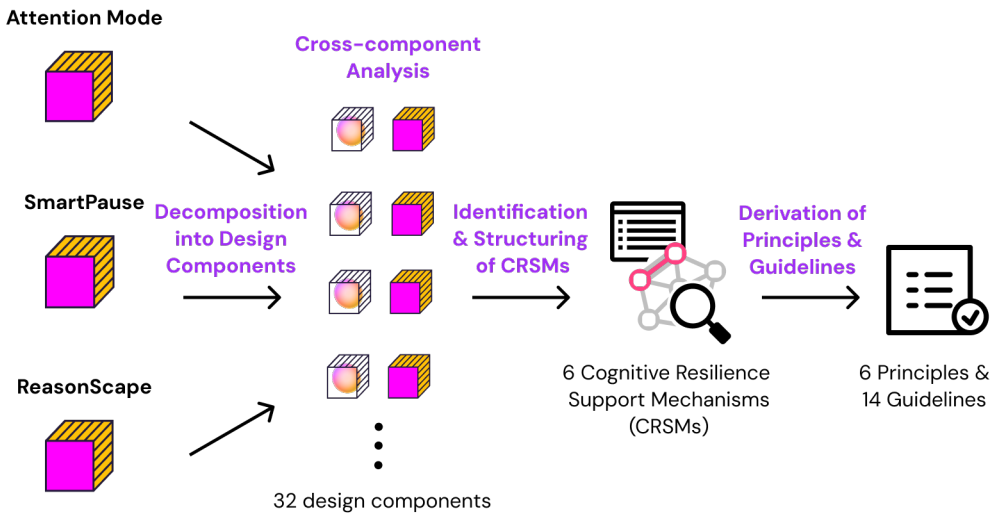


Figure 7.1: From design studies to principles and guidelines. Three design studies are decomposed into components, analysed across cases to identify and structure six CRSMs, from which six principles and fourteen guidelines are derived.

7.1 Decomposition and Cross-Case Analysis of Design Components

7.1.1 Decomposition of Designs into Components

The analysis is carried out at the level of individual interaction elements within the three design, drawing on the findings and discussion reported in Chapters 4, 5, and 6, in order to enable a structured examination across attention, memory and reasoning contexts, which together reflect core cognitive processes addressed in this thesis.

Each of the three designs is decomposed into a set of components representing distinct interaction elements (Table 7.1). Components here are defined as elements of the interaction characterised by the role they perform and the cognitive effects they are associated with. This includes interface features, interaction flows, feedback mechanisms, system cues, and constraints within the design (see Appendix G for full breakdown). For instance, in SmartPause, "Marking the precise reading position at pause" and "Linking notes to a specific reading position" are treated as separate components. While both are anchored to the reading position, they perform different roles and support different cognitive outcomes. In contrast, the pause state itself or the note-taking interaction as a whole is not treated as a single component, as it consists of multiple interaction elements combined.

Across the three design, a total of 32 components were identified, with 10 derived from Attention Mode, 8 from SmartPause, and 14 from ReasonScape. For each component, a consistent set of attributes was used to support analysis across designs. These included

the intended aim, the resulting cognitive outcome, the underlying design move, and the primary cognitive functions involved. Additional attributes, such as trade-offs and usability-related considerations, were also recorded to support later reflection. This approach enabled individual elements to show how these decisions play a role in relevant cognitive functions, while also influencing usability.

Table 7.1: Design components derived from the three design studies.

Design	ID	Components
Attention Mode	**C1**	Simultaneous activation of multiple distraction-reducing mechanisms via a single trigger
	C2	Cross-platform activation of distraction-mitigating features using a consistent interaction structure
	C3	Highlighting active sources of distraction and their cognitive impact
	C4	Adjustable levels of distraction mitigation
	C5	User-adjustable expansion of distraction-mitigating features beyond the default baseline
	C6	Removal of non-essential interface clutter
	C7	Suppression of notifications when Attention Mode is active
	C8	Restricting switching to other applications while Attention Mode is active
	C9	Immediate deactivation of Attention Mode
	C10	Visibility of active Attention Mode state
SmartPause	**C11**	Triggering support when disengagement occurs at non-natural breakpoints
	C12	Explaining the rationale for continuing to a natural breakpoint
	C13	Marking precise reading position at pause
	C14	Restoring surrounding reading context on return
	C15	Inviting lightweight summarisation
	C16	Allowing reflection to remain optional
	C17	Linking notes to reading position
	C18	Allowing voice-dictated reflections
ReasonScape	**C19**	Segmenting AI responses into smaller reasoning units
	C20	Guided reasoning checkpoints embedded in the chat flowC21: Intervention cards highlighting reasoning gaps
	C21	Intervention cards highlighting reasoning gaps
	C22	Placing reasoning interventions directly where issues emerge in the chat
	C23	Allowing users to revisit earlier reasoning points through the reasoning trail
	C24	Visual reasoning trail showing key reasoning steps and shifts
	C25	Representation of branching reasoning paths on visual reasoning trail
	C26	Visual reasoning trail highlighting flagged reasoning issues
	C27	Status indicator showing whether reasoning gap categories are addressed or unresolved
	C28	Acknowledgement when reasoning gap categories are addressed
	C29	Non-scoring feedback framing for reasoning interactions
	C30	Allowing reflective reasoning steps to be skipped
	C31	Framing reasoning guidance as suggestions rather than instructions
	C32	Integrated reasoning anchors linking chat, reasoning trail, and gap indicators

This decomposition provides a common basis for examining how components are configured across the three designs, enabling the identification of overarching themes in how interaction elements support cognitive processes across the designs.

7.1.2 Cross-Component Analysis

This analysis builds on the components identified in the previous section and examines how interaction elements are implemented across the three designs and how they contribute to supporting cognitive resilience. Drawing on inductive case research and cross-case analysis (Eisenhardt, 1989; Eisenhardt & Graebner, 2007), this approach enables insights to be developed through systematic examination across the designs.

Rather than organising the analysis strictly by cognitive function, components are examined in relation to multiple attributes captured in the component table, i.e., their intended aim, cognitive outcome, general design move, and usability tensions/contributions. It also makes it possible to examine how these approaches are implemented differently in relation to the demands of attention, memory, and reasoning.

Components are considered similar when they reflect the same underlying approach to supporting cognition, even if they are implemented differently across designs. One example is the move to preserve user control over cognitive resilience support. Attention Mode allows immediate deactivation, SmartPause includes optional reflection notes, and ReasonScape enables users to skip guided checkpoint messages and intervention cards. In each case the interaction element is different, but the underlying approach to supporting cognitive resilience without imposing constraints is shared.

Differences are examined through the same attributes, focusing on how components that share a general design move are implemented differently across designs. The externalisation of information illustrates this clearly. This happens at the point of disengagement in SmartPause, where users are prompted to note key ideas before exiting the reading task, reducing the effort required to reconstruct context later. In ReasonScape, a record of reasoning steps and flagged issues is externalised continuously through the ReflectRail, allowing users to monitor and revise their reasoning as it develops. The design approach is the same, but the cognitive demand shapes how and when it is applied. Across the three designs, six recurring interaction-level themes are identified, which are conceptualised as Cognitive Resilience Support Mechanisms (CRSMs), in the following section.

7.1.3 Identification of Recurring Interaction Mechanisms (CRSMs)

Components that exhibit similar underlying approaches are grouped together to form a set of Cognitive Resilience Support Mechanisms (CRSMs). Grouping is guided by the role each component plays within the interaction as primarily captured through general design move and cognitive outcome in the component table. For instance, "visibility of active Attention Mode state" (C10) and "status indicator showing whether reasoning gap categories are resolved or unresolved" (C27) are grouped together because both make aspects of the current interaction state visible to the user. "Marking the reading position at pause" (C13) is not included here, even though it also makes information visible, because its primary aim is to support memory continuity across task disengagement. The distinction reflects a focus on the cognitive role a component plays rather than the form it takes in the interaction.

Through this process, six CRSMs were identified as illustrated in Table 7.2. It shows how components across the three designs contribute to each mechanism. A number of components appear across multiple mechanisms. This reflects the fact that a single interaction element may support different aspects of cognitive resilience depending on how it is configured and used within the interaction. As a result, the mechanisms are not entirely independent, but are connected through shared components that support multiple roles within the interaction.

Each CRSM is briefly described below to clarify the basis for the grouping. *CRSM1* groups components that address why users may not engage with cognitive resilience support, by making it easier to activate, helping them see the value of doing so, and reinforcing continued engagement once started. In Attention Mode, bringing distraction controls into a single trigger and offering different levels made it easier for users to engage. In ReasonScape, expert reviewers pointed to low-effort framing of checkpoints and intervention cards as key to whether users would engage with reasoning support at all.

CRSM2 groups components that ensure cognitive resilience support is offered rather than imposed, preserving the user's ability to decide whether, when, and how to engage with it. This grouping reflects a pattern that surfaced across all three studies. Attention Mode participants wanted to exit without confirmation even after setting their own target duration. SmartPause kept reflection optional rather than required to avoid creating new friction. ReasonScape experts warned that prescriptive framing would feel patronising and likely be ignored.

CRSM3 groups components that make the user aware of factors affecting their cognitive performance within the interaction, both at a given moment and across the interaction as a whole. ReasonScape provided the strongest evidence here. Phase 1 expert reviewers saw the visibility of reasoning over time through ReflectRail and ReflectMeter as one of the most valuable parts of the design, while flagging that this value depended on stable anchors rather than dense or shifting displays. Attention Mode feedback also pointed to the value of clear status indication during focused use.

Table 7.2: Cognitive Resilience Support Mechanisms and related principles and design components

	CRSM	Principle	Component
Cross-cutting	**CRSM1 -** Engagement facilitation for cognitive resilience support	**P1 -** Reduce Barriers to Engaging with Cognitive Resilience Support	C1, C2, C3, C4, C5, C12, C18, C21, C28, C29
	CRSM2 - Autonomy preservation in cognitive resilience support	**P2 -** Preserve User Agency and Avoid Coercive Constraints	C9, C16, C21, C29, C30, C31
	CRSM3 - Representation of cognitively relevant state and risk	**P3 -** Make Cognitively Relevant State and Risk Visible	C10, C21, C23, C24, C25, C26, C27, C32
Domain-Specific	**CRSM4 -** Attentional interference reduction	**P4 -** Protect Attentional Continuity	C6, C7, C8
	CRSM5 - Memory continuity support	**P5 -** Support Memory Continuity at Task Breaks and Interruptions	C11, C12, C13, C14, C15, C16, C17, C18
	CRSM6 - Deliberate reasoning scaffolding	**P6 -** Scaffold Deliberate Reasoning	C19, C20, C21, C22, C27

CRSM4 groups components that protect attentional continuity by reducing direct exposure to sources of interruptions in the interaction environment, lowering the inhibitory effort required to maintain focus. Across the news website, e-book, and video streaming contexts of Attention Mode, removing clutter, suppressing notifications, and restricting application switching worked together to help users keep focus.

CRSM5 groups components that reduce the cognitive cost of leaving and returning to a task, by preserving the context and content the user would otherwise need to reconstruct from memory. This grouping comes from SmartPause's controlled findings: breakpoint-

aligned disengagement gave the most consistent improvement in delayed recall across both the between-subjects and within-subjects studies, and this benefit stayed even when the note-taking step was removed in Study 2.

CRSM6 groups components that help users engage more deliberately with information by slowing down the interaction and creating opportunities for more careful evaluation at points where shallow processing is most likely. ReasonScape's expert feedback supported this directly: checkpoints and intervention cards were described as ways to slow "answer-first" momentum and reopen reasoning at moments of cognitive tension, as long as the friction was tuned to feel like part of the conversation rather than a separate task. These mechanisms form the basis for their organisation across cognitive domains in the following section.

7.1.4 Structuring of CRSMs Across Cognitive Domains

The six CRSMs are organised into two groups: those that apply across multiple cognitive domains and those that are specific to a particular cognitive process.

Some mechanisms address concerns that are not specific to one cognitive function. These mechanisms are classified as cross-cutting because their underlying design moves remain relevant across attention, memory, and reasoning contexts. Others respond to demands that are particular to a specific cognitive process and would need significant adaptation to apply elsewhere. These are classified as domain-specific. This grouping is based primarily on the nature of the design move rather than on how many studies it appeared in. In some cases, judgement was needed. For example, offering increasing levels of support appeared mainly in Attention Mode but was classified as cross-cutting because adjusting the intensity of cognitive support is a concern that applies across attention, memory, and reasoning contexts, not only in managing distraction. This is reflected in CRSM1, which covers engagement facilitation more broadly across the three designs.

First three mechanisms are classified as cross-cutting (CRSM1, CRSM2, and CRSM3) as they address general conditions that apply across attention, memory, and reasoning contexts. The remaining three (CRSM4, CRSM5, and CRSM6) are classified as domain-specific, each responding to the particular demands of attention, memory, and reasoning respectively.

This grouping does not mean the mechanisms operate independently. Components can contribute to more than one mechanism, and mechanisms can work alongside each other within the same interaction. The grouping reflects the primary role each mechanism plays

in relation to cognitive processes, and provides the basis for deriving design principles and guidelines in the following section.

Table 7.3: Principles and guidelines for cognitive resilience. The table shows each principle alongside its associated CRSMs and the design components it draws on.

	Principle	Guideline	Component
Cross-cutting	**P1 - Reduce Barriers to Engaging with Cognitive Resilience Support**	**G1 - Minimise activation effort** Reduce the effort required to activate cognitive resilience support	C1, C2, C18
		G2 - Make cognitive consequences visible Make the cognitive consequences of behaviour visible to motivate engagement	C3, C12, C21, C28
		G3 - Reinforce engagement through lightweight motivation Sustain engagement through lightweight motivational mechanics	C28, C29
		G4 - Offer increasing levels of support Offer different levels of cognitive resilience support matched to task demands	C4, C5
	P2 - Preserve User Agency and Avoid Coercive Constraints	**G5 - Keep support reversible and optional** Ensure cognitive resilience support remains reversible and/or optional	C9,C16, C30
		G6 - Position support as collaboration not authority Position cognitive resilience support as collaborative aids rather than authoritative directives	C21, C29, C31
	P3 - Make Cognitively Relevant State and Risk Visible	**G7 - Make current cognitively relevant risks and state visible** Make the current cognitively relevant risks and interaction state apparent to the user to support self-monitoring without additional cognitive effort	C10, C21, C26, C27
		G8 - Externalise the accumulated cognitively relevant interaction record Externalise the accumulated interaction record to support review of the user's cognitive engagement over time	C23, C24, C25, C26, C32
Domain-Specific	**P4 - Protect Attentional Continuity**	**G9 - Suppress attentional interference** Remove or suppress sources of attentional interference during focused task engagement	C6, C7, C8
	P5 - Support Memory Continuity at Task Breaks and Interruptions	**G10 - Guide disengagement toward natural boundaries** Detect and signal cognitively costly disengagement points to guide users toward natural task boundaries	C11, C12
		G11 - Externalise task context to support resumption Preserve and externalise task context to enable resumption without cognitive reconstruction	C13, C14, C17
		G12 - Prompt externalisation at task boundaries Prompt lightweight externalisation at natural task boundaries	C15, C16, C18
	P6 - Scaffold Deliberate Reasoning	**G13 - Pace and structure information delivery** Pace and structure information delivery to support active evaluation	C19
		G14 - Interrupt automatic processing Interrupt automatic processing at moments of likely shallow evaluation	C20, C21, C22, C27

7.2 Design Principles and Guidelines for Cognitive Resilience

The six CRSMs identified in Section 7.1 provide the basis for a set of design principles and guidelines for cognitive resilience. Each CRSM is translated into a principle that states what the design should achieve and the rationale behind it. Under each principle, one or more guidelines are derived as actionable design directives that specify what designers should do to realise the principle in practice. Together, principles and guidelines form two levels of design knowledge: principles provide the orientation, guidelines provide the means. Each principle below is presented with a rationale explaining its design intent and empirical basis, followed by the guidelines that give it concrete design direction.

The principles are organised following the cross-cutting and domain-specific distinction established in Section 7.1.4. Table 7.3 provides an overview of all six principles, guidelines, and grounded-in components.

7.2.1 Cross-Cutting Principles and Guidelines

7.2.1.1 P1: Reduce Barriers to Engaging with Cognitive Resilience Support

Cognitive resilience support can only be effective if users engage with it. This principle therefore focuses on ensuring that the support itself does not become a barrier, so that activating, using, and disengaging from a feature requires minimal effort. Engagement with cognitive resilience support is hindered by barriers at multiple stages, and addressing only one is insufficient. At the point of activation, scattered controls and unfamiliar interaction patterns increase the effort beyond what users are willing to engage with. During interaction, the absence of visible benefit and lack of reinforcement can cause users to disengage before support has had any effect. A further barrier is the perceived cost of commitment: high-intensity modes can seem intimidating to first-time users and discourage engagement altogether. Therefore, cognitively resilient design must address all three: lowering the cost of entry, sustaining motivation through awareness and reinforcement, and offering increasing levels of support so users can start at a comfortable level and increase protection as needed.

According to research in behavioural science, individuals are sensitive to the level of effort that a protective behaviour demands. An increase in required effort can reduce the likelihood of engagement (Fogg, 2003). This is consistent with the tendency of people to favour options that require the least change or effort, even when alternatives would be more beneficial (Samuelson & Zeckhauser, 1988). This suggests that lowering activation cost is particularly important in cognitive resilience support where benefits are often not

immediate or obvious. For example, when SmartPause suggests continuing to the end of a section, this may not feel immediately useful to the user, as the benefit of improved recall only becomes apparent later. Similarly, activating Attention Mode might not show any noticeable cognitive benefit at the point of use.

This principle is reflected across all three studies. In Attention Mode, multiple distraction-reducing controls are combined into a single trigger, reducing activation effort. In SmartPause, voice dictation was introduced to lower the effort required at the point of disengagement. In ReasonScape, reflection checkpoints were kept lightweight to avoid becoming a barrier to continued engagement.

Related guidelines:

G1: Minimise activation effort. Activating cognitive resilience support should require minimal effort, and its controls should be consistently accessible across platforms and contexts.

G2: Make cognitive consequences of behaviour visible. The cognitive cost of an interaction should be visible at the moments that matter most, such as at first use, during engagement, or while the behaviour is occurring. This helps users understand what the support addresses and makes them more likely to engage with it.

G3: Reinforce engagement through lightweight motivation. Non-evaluative cues such as completion acknowledgements or lightweight gamification elements should be used to sustain engagement without creating performance pressure.

G4: Offer increasing levels of support. Different levels of support should be available so users can engage at an intensity that matches their current task demands. Starting at a lighter level of engagement lowers the barrier to first use and makes it less likely that users avoid support altogether**.**

7.2.1.2 P2: Preserve User Agency and Avoid Coercive Constraints

When users are limited in what they can do or pushed to reflect, it can quickly feel controlling. In Attention Mode, participants wanted to exit the mode immediately even after setting their own target duration. For ReasonScape, expert reviewers warned that prescriptive framing would feel patronising and be ignored. This can lead to frustration and lower engagement with the system, which goes against the aim of P1. For this reason, this principle emphasises that users should remain in full control of cognitive resilience features: restrictions need to be easy to turn off, reflection prompts optional, and advice presented as suggestions rather than rules.

Research on psychological reactance suggests that when users feel their freedom is limited, they may resist or become less willing to follow what the system suggests (Brehm & Brehm, 1981). Hertwig and Grüne-Yanoff (2017) distinguish between nudging, which steers behaviour through the design of choice environments, and boosting, which aims to strengthen individuals' decision-making competences. Boosting fits better with cognitive resilience support, as the aim is not to force protective behaviour, but to help users develop the ability to choose it themselves**.**

This concern is grounded in both existing approaches and the three design studies. As discussed in Chapter 2, many of existing strategies rely on overly restrictive methods such as usage limits and app blocking or self-regulation. When the level of restriction is high, sustaining these strategies requires greater self-control. In contrast, lower and more distributed forms of support place less demand on self-control and require less upfront commitment. For instance, users were more willing to activate Attention Mode when they could exit immediately without confirmation, as this reduced the sense of commitment.

In ReasonScape, expert reviewers similarly pointed out that prescriptive framing of guidance cards can be counterproductive. It makes the interaction feel more controlling and increases the perceived effort required to engage. Therefore, sustained engagement with cognitive resilience support depends on preserving user agency while minimising the cognitive effort required for self-control.

Related guidelines:

G5: Keep cognitive resilience support reversible and optional. Protective constraints should be easy to exit, without confirmation. Any constraint or reflective step should be skippable and reversible. Completing a support interaction should not be required to continue the primary task.

G6: Position cognitive resilience support as collaborative, not authoritative. Interventions should be designed to support reflection rather than to instruct or evaluate the user. The way they are written and presented should show that the system helps the user's own thinking, rather than telling them what to do.

7.2.1.3 P3: Make Cognitively-Relevant State and Risk Visible

Users can only self-regulate their cognitive engagement if they have access to relevant information about their current interaction. To address this, cognitively resilient design should make relevant information about the interaction visible. Here, visibility refers to information being made available in a way users can perceive and act on, not just visual

presentation. When this information is absent, users have no basis for deciding whether to engage with support or change how they are interacting.

The importance of making system state perceivable to users is well established in usability research. Norman (2013) and Nielsen (1994a, 1994b) both emphasise that users need to see what is happening in a system in order to regulate their interaction with it. As discussed in Section 3.1.2, cognitively resilient design extends this beyond conventional interface state to include information about cognitive risk and progress.

Findings from the design studies show that this form of visibility supports self-regulation in ways conventional system status feedback does not. In ReasonScape, ReflectRail and ReflectMeter were designed to address the problem that users in extended AI interactions lose track of how their reasoning has developed, increasing the risk of premature acceptance and unnoticed reasoning gaps. Expert reviewers identified the visibility of reasoning over time as one of the most valuable aspects of the design.

Related guidelines:

G7: Make current cognitively relevant risks and state visible. The current cognitively relevant interaction state should remain visible throughout. Active cognitive risks should be flagged as they arise so users can recognise and address them promptly.

G8: Externalise the accumulated cognitively relevant interaction record. The accumulated record of cognitively relevant information should remain accessible without requiring users to retrace their steps. Throughout extended interactions, prior states, emerging risks, and progress should remain visible.

7.2.2 Domain-Specific Principles and Guidelines

7.2.2.1 P4: Protect Attentional Continuity

Attention does not break down only because users lose focus; the design of the interface plays an equally important role in determining how well sustained attention can be maintained. Therefore, the challenge is not only about user behaviour but also about interactions that continuously generate interference place an unreasonable burden on users' ability to self-regulate.

Irrelevant competing stimuli place demands on attentional filtering and cognitive control, increasing susceptibility to interference (Ophir et al., 2009). These costs can arise even when users do not act on such stimuli, as the mere presence of one's own smartphone has been shown to reduce available cognitive capacity (Ward et al., 2017). This principle therefore addresses the problem at the level of the interface rather than the user.

Attention Mode design illustrates how this can be addressed in practice. It aimed to reduce the attentional burden imposed by the interface itself by removing sources of interference, i.e., notifications, non-essential content and elements, and access to other applications, when users chose to focus.

Related guideline:

G9: Suppress attentional interference. During focused use, sources of interruption and stimuli that are irrelevant to the task should be removed or suppressed from the interface. This reduces the effort required to inhibit distractions and shifts more of the responsibility from the user to the design.

7.2.2.2 P5: Support Memory Continuity at Task Breaks and Interruptions

The cognitive cost of disengaging from a task depends heavily on the point at which disengagement happens. Interruptions or pauses at arbitrary points make it harder to resume a task later, compared to stopping at natural breakpoints (Altmann & Trafton, 2002; Bailey & Iqbal, 2008). Incomplete work often stays active in memory even after a task ends. Leroy (2009) calls this attention residue. The Zeigarnik Effect describes a similar pattern, where unfinished tasks create a lingering cognitive tension (Zeigarnik, 1938).

This concern is most acute in tasks that place sustained demands on working memory, such as reading, reasoning, or sensemaking, where a poorly timed break can significantly raise the effort needed to resume. Therefore, designing when and how users disengage from a task is as important as designing the task interaction itself.

The SmartPause design demonstrated that guiding users toward natural boundaries, preserving task context at exit, and prompting lightweight externalisation before disengaging each contributed to better memory continuity and task resumption. Both studies supported the value of aligning the timing of disengagement with natural task boundaries.

Related guidelines:

G10: Guide disengagement toward natural task boundaries. When disengagement occurs at a point likely to impose high memory reconstruction costs, this should be detected and signalled, guiding the user to the nearest natural boundary.

G11: Externalise task context to support resumption. Task position and surrounding context should be preserved at the point of disengagement. This allows users to resume without having to reconstruct where they were or rebuild their understanding.

G12 - Prompt lightweight externalisation at task boundaries. At natural task boundaries, users should have the option to briefly capture key thoughts or reflections before disengaging, through whatever input method requires least effort.

7.2.2.3 P6: Scaffold Deliberate Reasoning

Interactions that prioritise speed and ease of response may encourage users to accept outputs without sufficient evaluation (Kahneman, 2012; Tversky & Kahneman, 1974). Particularly when information is presented in large volumes, the conditions for careful assessment may be weakened, increasing reliance on shallow rather than more effortful processing (Eppler & Mengis, 2004; Hong & Kim, 2020; Sweller, 1988). This effect may be further reinforced by automation bias, as users may over-rely on automated outputs and reduce critical monitoring, even when errors are present (Mosier et al., 1996). As discussed in Chapter 6, these effects emerge gradually through repeated interaction with systems that prioritise speed and fluency over deliberation. Rather than steering users toward predetermined conclusions, cognitively resilient design should strengthen users' capacity to make their own judgments by creating conditions for reflection and reconsideration (Hertwig & Grüne-Yanoff, 2017). Expert reviewers of ReasonScape highlighted the value of slowing the interaction pace, surfacing reasoning gaps as they emerge, and keeping guidance suggestive rather than directive to support more deliberate reasoning.

Related guidelines:

G13: Pace and structure information delivery to support active evaluation. Deliver information in manageable units and introduce structured points for reflection at moments where users might otherwise move directly to acceptance, supporting active evaluation rather than passive consumption.

G14: Surface reasoning gaps as they emerge. Surface signs of shallow or incomplete reasoning at the point where they occur, so users can reconsider while the relevant context remains available.

7.3 Situating the Principles and Guidelines in Existing Design Knowledge

This section situates the principles and guidelines in relation to six bodies of practical design knowledge: Nielsen's (1993) five usability characteristics, Nielsen's (1994a, 1994b) ten heuristics, Norman's (2013) six principles, Shneidermann's (2018) eight golden rules, and the guidelines for human-AI interaction by Amershi et al. (2019) and Weisz et al. (2024). Each of these bodies of knowledge is primarily oriented toward task performance, and none addresses the effects of digital interaction on users' cognitive

capacities. The principles and guidelines developed in this thesis extend and qualify existing knowledge at specific points, and introduce new design directions where existing knowledge does not reach.

7.3.1 Examination of Existing Design Knowledge

7.3.1.1 Nielsen's Five Usability Characteristics

Nielsen (1993) defines five usability characteristics as measurable criteria for evaluating interactive systems. A full mapping of the principles and guidelines against each characteristic is provided in Appendix H.1. Across four of characteristics, learnability, memorability, errors, and satisfaction, the principles and guidelines are largely compatible. Learnability is strongly aligned, particularly through P1, which lowers barriers to first-time engagement. Memorability is strongly aligned through both P3, which reduces the effort of reconstructing prior interaction states, and P5, which addresses task resumption beyond interface familiarity. Errors is strongly aligned across P2, P3, P4, P5, and P6, each of which reduces the likelihood of cognitive mistakes at different points in the interaction. Satisfaction is more mixed: several guidelines contribute positively, while P3, P4, and P6 each introduce a partial tension through added interface elements and structured prompts.

The relationship with efficiency is more complex than with the others. P1, P2, and P4 show strong alignment through reducing activation steps, ensuring cognitive resilience support does not add unnecessary overhead, and removing distractions that increase cognitive effort during tasks. However, P5 and P6 directly conflict with efficiency by introducing deliberate delays and reflection steps. In each case, friction is the mechanism of cognitive protection. This thesis therefore proposes cognitive resilience as a sixth usability characteristic. While efficiency presents the most direct conflict, the sixth characteristic applies more broadly. It takes precedence over any existing characteristic when a design mechanism serves the goal of cognitive resilience rather than task performance.

7.3.1.2 Nielsen's Ten Usability Heuristics and Shneidermann's Eight Golden Rules

Nielsen's (1994a, 1994b) ten usability heuristics, and Shneidermann's (2018) eight golden rules are examined together as they address many of the same design concerns. Shneidermann's "design dialogs to yield closure" (R4) is the only rule without a direct Nielsen equivalent. A full mapping of the principles and guidelines against each heuristic and rule is provided in Appendix H.2.

The analysis shows that conflicts are concentrated in "flexibility and efficiency of use" (H7/R2) and "aesthetic and minimalist design" (H8), following the same logic as the efficiency conflicts discussed in previous section. P3, P5, and P6 conflict with both by introducing interface elements throughout the interaction, adding extra steps or slowing information delivery. Following H7/R2 and H8 directly would lead designers to remove these that the principles and guidelines deliberately introduce to support cognitive resilience.

The most direct single conflict is between "user control and freedom" (H3/R6/R7) and P4. G9 restricts application switching during focused use, directly limiting user freedom. This is resolved by G5 (P2): the restriction is immediately reversible and entirely voluntary.

Three heuristics and rules are extended into a cognitive domain that falls outside the original scope of both frameworks. "Visibility of system status" (H1/R3) is particularly extended by P3 and P5: rather than showing only what the system is doing, it is applied to making the user's own cognitively relevant state visible. "Error prevention" (H5/R5) is extended by P4, P5, and P6: rather than preventing interface slips, it is applied to preventing attentional failures, memory loss at task breaks, and reasoning errors. "Help users recognise, diagnose, and recover from errors" (H9) is extended by P2, P3, and P5: rather than recovering from interface-level errors, it is applied to a full cognitive error-recovery process.

"Recognition rather than recall" (H6/R8) is a partial exception. Reducing memory load is already a direct concern of both Nielsen and Shneidermann. P3, P5, and P6 do not extend this into a new domain but apply it to a more demanding context than interface navigation: helping users recognise prior cognitively relevant states, task context, and reasoning gaps without having to reconstruct them from memory. These guidelines apply to a broader class of problems than either heuristic/rule originally considered.

"Match with real world" (H2), "consistency and standards" (H4/R1), "help and documentation" (H10), and "design dialogs to yield closure" (R4) are not primary concerns of the principles and guidelines. H2 is partially addressed as P1, P2, P3, and P6 each frame support in terms grounded in users' own cognitive experience and natural rhythms, though not all dimensions of the heuristic are covered. H4/R1, H10, and R4 are not directly addressed by any principle, though G1, G2, and G10 provide indirect contributions.

7.3.1.3 Norman's Six Principles of Interaction Design

Norman's (2013) six principles - visibility, feedback, constraints, mapping, consistency, and affordance - are examined in relation to the principles and guidelines in Appendix H.3. Four of the six overlap directly with Nielsen and Shneidermann: visibility corresponds to H1/R3, feedback to H1/R3, constraints to H5/R5 and consistency to H4/R1. The relationships for these are already detailed in Appendix H.2 and discussed in Section 7.3.2.2, and are not repeated here.

Mapping and affordance are the only two principles not covered by these sets of design knowledge. Mapping is the more substantive of the two. Norman holds that the relationship between controls and their effects should be clear and natural. The principles and guidelines extend this into a cognitive domain: rather than mapping controls to functions, they map interaction behaviours to cognitive consequences. Affordance is only partially addressed, through P1's reduction of activation effort.

7.3.1.4 Emerging Human-AI Interaction Design Knowledge

P6 and its guidelines were developed in the context of ReasonScape, an AI-assisted reasoning tool, and AI-mediated interaction is an increasingly common context in which all six principles may need to be applied. It is therefore necessary to examine how the present principles and guidelines relate to design knowledge developed specifically for AI systems. Three bodies of knowledge are examined: Amershi et al.'s (2019) eighteen guidelines for human-AI interaction developed at Microsoft, Google PAIR's five principles from its People + AI Guidebook (2019), and Weisz et al.'s (2024) six design principles for generative AI applications. Unlike Nielsen, Shneidermann, and Norman, these are emerging bodies of knowledge that have not yet reached the same level of maturity or specificity. For this reason, no appendix mapping is provided as the guidelines and principles do not contain enough detail to support the depth of assessment applied in preceding sections.

Among guidelines proposed by Amershi et al., the only overlap that directly concerns cognitive resilience is with the guideline to remember recent interactions, which partially aligns with P4's concern with preserving cognitively relevant interaction records. Other overlaps exist around system transparency and user control, but these are general usability overlaps. A direct tension involves the "update and adapt cautiously" guideline: updating the experience automatically to adapt the user can risk disrupting memory continuity, conflicting with P5. A second tension may involve proactive assistance since contextually timed interruptions can undermine attentional continuity, conflicting with P4.

Similarly, Google PAIR's five principles are largely concerned with system development, safety processes, and general usability rather than cognitive resilience. "Treat safety as an evolving endeavour" could potentially extend to cognitive risks, though the principle as stated does not address this. The adapt with feedback principle shares the tension identified in Amershi et al.'s work.

Of the three bodies of knowledge examined, Weisz et al. (2024) is the most relevant to cognitive resilience, though it remains primarily focused on enabling effective and responsible use of generative AI rather than on the cognitive consequences of interaction. The strongest overlap is the strategy of "using friction to avoid overreliance": Weisz et al. recommend mechanisms that slow users down at key decision points to encourage critical review of outputs, which directly converges with P6's concern with preventing passive acceptance and supporting deliberate reasoning. A second strong overlap is the strategy of "visualising the user's journey": preserving and displaying interaction history supports continuity and reflection, aligning with P3. The most direct tension involves the strategy of "leveraging multiple outputs". In practice, multiple options can increase cognitive load and encourage shallow scanning rather than careful evaluation. It conflicts with P6 since users tend to quickly compare surface differences and select the first acceptable option rather than evaluating each one deeply. Another tension involves "teaching effective use". As users learn to use AI more efficiently, they may progressively offload thinking to the system and stop structuring their own ideas, exploring alternatives, or critically evaluating outputs, reducing the deliberate cognitive engagement the present framework seeks to preserve.

Across all three, the gap is the same. Each is concerned with making AI systems effective, safe, and appropriate to use. None addresses what AI interaction does to users' cognitive capacities over time. The present principles and guidelines do not replace these contributions but add a concern that is absent from all three: whether repeated AI interaction preserves users' capacity for attention, memory, and deliberate reasoning.

7.3.2 Towards a Design Framework for Cognitive Resilience

The principles and guidelines developed in this chapter, together with their situating in relation to existing design knowledge, constitute a design framework for cognitive resilience. The framework consists of the following components:

1. Six design principles and fourteen guidelines derived from three design studies addressing attention, memory, and reasoning.

2. A cross-cutting and domain-specific structure that determines which principles apply in a given design context.
3. A systematic mapping to existing design knowledge showing where the principles extend, qualify, or conflict with established usability and interaction design knowledge.
4. A proposal that cognitive resilience functions as a sixth usability characteristic that takes precedence when it conflicts with the existing five.
5. A decision aid for applying the framework alongside existing design knowledge in practice (Figure 7.2).

Understanding the cross-cutting and domain-specific distinction is important for applying the framework in practice. P1, P2, and P3 may be relevant across all design contexts, regardless of which cognitive function is being addressed. They are not alternatives to the domain-specific principles but conditions that remain relevant alongside them. For example, when P6 introduces deliberate friction to support reasoning, P1 also becomes relevant: the friction could itself become a barrier to engagement if activation effort is too high. P2 ensures the support does not feel coercive, and P3 ensures the cognitively relevant state remains visible. P4, P5, and P6 are selected based on which cognitive function is affected - attention, memory, or reasoning respectively. A design decision may involve more than one of these at the same time.

The sixth characteristic proposal, introduced in Section 7.3.1, gives the framework its position relative to existing design knowledge. Where a design mechanism serves the goal of cognitive resilience rather than task performance, cognitive resilience takes precedence over the existing five characteristics. The decision tree in Figure 7.2 operationalises this. It is a decision aid for applying the principles and guidelines to individual design decisions and features, and can be used iteratively throughout the design process. For each decision or feature, it first asks whether cognitive resilience is a priority, and if so, whether the interaction could undermine cognition. If both questions are answered positively, the designer identifies which cognitive function or functions are affected and applies the relevant principles and guidelines.

Any conflicts with existing design knowledge are then identified and resolved at the characteristic or guideline level. Characteristic-level conflicts most directly concern efficiency and satisfaction. Guideline-level conflicts most directly concern User Agency and Minimalist Design. Other conflicts may arise in specific design contexts, as indicated by the three trailing dots shown as (…) in Figure 7.2.



Figure 7.2: A decision aid for applying cognitive resilience principles and guidelines alongside existing design knowledge. D1–D3 denote decision nodes, A1–A2 denote action steps, and O1–O4 denote outcomes.

The framework is derived from three design studies and covers three cognitive functions. It is designed to be expandable. As more studies examine how specific

interaction behaviours affect other cognitive functions, additional principles and guidelines can be derived and incorporated. The decision tree can accommodate additional conflict types at both the characteristic and guideline level. The generalisability of the framework beyond the three studies is examined in the next section.

7.4 Design Application: A Cognitive Resilience Design for Social Media Feeds

The principles and guidelines developed in this thesis were derived from three design studies addressing attention, memory, and reasoning in specific interaction contexts. To examine whether they generalise beyond these contexts, this section presents one exploratory design application developed after the guidelines were finalised. The application is not empirically evaluated here. It serves as a generalisability probe, demonstrating how the decision tree in Figure 7.2 can be applied to a new design problem in a different domain. The example applies a set of cognitive resilience interventions to Instagram's feed interaction.

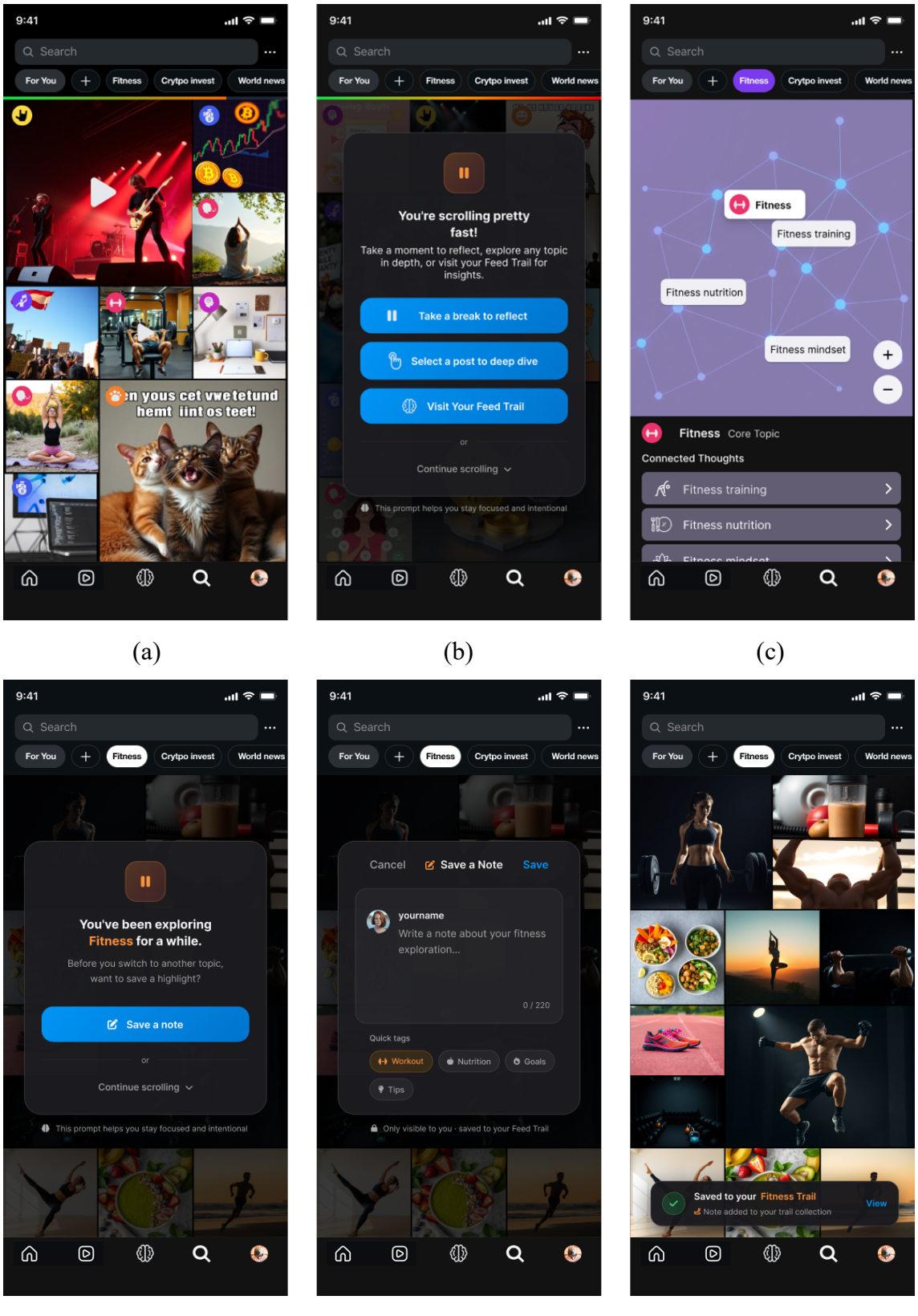
7.4.1 Design Context and Cognitive Concerns

Social media platforms are among the most widely used digital environments in everyday life. This application focuses on Instagram, one of the most widely used social media platforms (Kemp, 2025), selected because its interaction patterns raise clear cognitive resilience concerns. Infinite scrolling, autoplay, rapid content switching, and continuously updated feed structures have been associated with distraction, frequent attentional switching, and reduced sustained concentration in digital environments (Rosen et al., 2013; Shanmugasundaram & Tamilarasu, 2023; Yeykelis et al., 2014). In the case of short-form video feeds characterised by rapid context-switching, such interaction patterns have also been linked to memory-related costs (Chiossi et al., 2023). These effects arise from interface design choices that prioritise engagement and retention over cognitive well-being. As these patterns are common across social media platforms, the design interventions introduced here are applicable beyond Instagram to other platforms with similar feed-based interaction patterns.

7.4.2 Applying the Decision Tree

The decision tree in Figure 7.2 is applied here to the redesign of Instagram's (n.d.)[32] feed interaction. Each step of the tree is followed in sequence, from the initial priority decision through to conflict resolution action.

[32] Instagram. https://about.instagram.com/



(a) (b) (c)

(d) (e) (f)

Figure 7.3: Design interventions for a cognitively resilient social media feed. (a) topic icons on feed content; (b) scroll speed detection and reflection prompt; (c) Feed Trail map; (d) topic-based pause prompt; (e) save a note interface; (f) confirmation of note saved to Feed Trail.

Decision 1: ***D1. Is cognitive resilience a priority?***

For the purposes of this example, cognitive resilience is treated as a priority. In practice this decision may be driven by a designer's judgement, a regulatory requirement, or a company strategy. The reason does not affect how the remaining steps of the decision tree are applied.

Decision 2: ***D2. Could this affect cognitive functions negatively?***

Yes. As established in Section 7.4.1, the interaction patterns of Instagram's feed have been associated with negative effects on cognitive functioning.

Action 1: ***A1. Identify affected cognitive function(s) and apply relevant principles and guidelines***

Three cognitive functions are identified as affected. Attention is disrupted by infinite scroll and autoplay, which encourage continuous partial attention and remove natural points to stop. Memory is affected by rapid context-switching and fast-scanning, which have been linked to shallower encoding and weaker prospective memory. Reasoning may also be affected indirectly. When attention is fragmented and the pace of interaction is high, it becomes harder to slow down, compare options, and reflect. Executive functions, particularly inhibitory control, are also likely affected, though rather than being addressed directly, they are supported implicitly across the principles and guidelines applied throughout the design.

Since all three cognitive functions are affected, P4, P5, and P6 are all relevant as domain-specific principles. P1, P2, and P3 apply alongside them as cross-cutting principles. The redesign introduces five features. Each is described below with its principle and guideline mapping.

Topic icons on feed content. A small icon appears on each post in the feed indicating which topic cluster the content belongs to, for example Fitness, Finance, or World News (Figure 7.3a). This makes the user's content consumption visible in real time as they scroll, without requiring any action. P3 is applied here: the user can see what they are consuming and notice when they are moving across many unrelated topics in rapid succession.

Scroll speed detection and reflection prompt. The system monitors scrolling pace. When pace exceeds a threshold, a prompt appears: "You are scrolling pretty fast." As illustrated in Figure 7.3b, the user is offered four choices: take a moment to reflect, select a post see more content on the same topic, visit their Feed Trail (explained below), or close the prompt. P4 is applied through the detection of attentional fragmentation and the

introduction of a pause. P3 is applied through making the scrolling behaviour visible to the user. P6 is applied through the reflection option, which creates an opportunity for deliberate evaluation rather than impulsive continuation. P1 is reflected in the lightweight and non-blocking nature of the prompt, which imposes minimal activation cost. P2 is preserved by offering four choices including the option to dismiss and continue, keeping the user fully in control.

Topic-based pause prompt. When the user is about to switch to a new topic, the feed briefly pauses and shows a prompt: "You've been exploring Fitness. Before you switch to another topic, want to save a highlight?" The user can save a note, add it to their Feed Trail, or continue scrolling (Figure 7.3d–f). While the scroll speed prompt responds to how fast the user is scrolling, this prompt responds to a natural topic boundary, giving them a moment to consolidate before the context shifts. P5 is applied by creating a moment for externalisation at the point of topic transition. G11 is applied through preserving task context at the point of transition. G13 is applied through pacing information delivery at the topic level. P1 and P2 are preserved: the prompt is lightweight, non-blocking, and fully dismissible.

Feed Trail map. A dedicated page displays a visual map of topics the user has explored (Figure 7.3c). Each topic appears as a node, with connected subtopics branching from it. The size of each node grows based on the depth of engagement with that topic, for example time spent, interactions, and return visits, both within a single session and across sessions. The map grows as the user engages with content. P5 is applied through externalising the accumulated interaction record, making it possible for the user to see what they have engaged with and how deeply, without relying on memory. P3 is applied by making the pattern of consumption visible at the level of topics and depth rather than individual posts. P6 is applied through the map itself, which shows users how deeply and broadly they have engaged with topics, and may prompt them to reflect on whether they want to explore further.

Feed Trail icon in the bottom navigation bar. The Feed Trail icon is placed at the centre of the bottom navigation bar as a persistent item, giving users direct access to the map. P1 is applied here: the cognitive support is available with a single tap and does not require the user to locate it within settings or menus. As a practical consequence of adding this icon, the direct message icon was moved from the main navigation bar to make space. Removing the direct message icon from the main navigation bar reduces an opportunity

for task switching, which aligns with P4, though this decision was made due to a space constraint.

Decision 3 – *D3. Does the resulting design conflict with existing design knowledge?*

Yes. Three conflicts arise. The first conflict is with efficiency. Both the scroll speed prompt and the topic-based pause prompt introduce pauses that interrupt the interaction and add steps that conventional usability design would remove. The second conflict is with satisfaction. Prompts and pauses may reduce the immediate enjoyment of browsing. Users who open Instagram for relaxation may find them unwelcome. The third conflict is with User Agency. Both the scroll speed detection and the topic-based pause introduce system-initiated interventions that the user has not explicitly requested. The system is making a judgement about how the user is browsing.

Action 2 – *A2. Resolve conflicts at characteristic and/or guideline level*

The efficiency conflict is accepted. The deliberate pauses are the mechanisms through which attentional continuity and memory encoding are supported. The satisfaction conflict is partially resolved by introducing motivational elements. The Feed Trail map makes depth of engagement visible and potentially rewarding. Both prompts also offer choices rather than forcing behaviour, ensuring that the user can always dismiss and continue. The User Agency conflict is resolved through P2. All actions offered in both prompts are optional, prompts can be dismissed immediately, and no content is blocked or withheld. The interventions are informational rather than restrictive.

7.4.3 Implications for Generalisability

This application demonstrates that the principles and guidelines apply in a domain not covered by any of the three original design studies. The decision tree provided a structured path through an unfamiliar design context, from establishing cognitive resilience as a priority to identifying affected functions, applying principles and guidelines, and resolving conflicts. All three conflicts identified in Section 7.3 arose here and were resolved using the same logic.

The application also illustrates the cross-cutting and domain-specific structure in practice. P1, P2, and P3 appear alongside the domain-specific principles across the features, consistent with the structure described in Section 7.3.3. All five features were developed by applying the decision tree. The topic-based pause prompt emerged from a second iteration, when a gap in memory encoding support was identified during the first pass. This illustrates that the decision tree can be applied iteratively within the same design context.

7.5 Summary

This chapter addresses RQ3 by translating findings from three design studies into generalisable design knowledge for cognitively resilient interaction. The analysis began by decomposing the three designs into 32 components, each capturing a distinct interaction element and its cognitive effects. Cross-case analysis across these components identified six recurring interaction-level themes, conceptualised as Cognitive Resilience Support Mechanisms (CRSMs). Three of the six CRSMs address concerns that apply across all cognitive domains and are classified as cross-cutting. The remaining three respond to the specific demands of attention, memory, and reasoning respectively and are classified as domain-specific.

From these mechanisms, six design principles and fourteen guidelines were derived. The principles and guidelines were then situated in relation to existing design knowledge, including Nielsen's usability characteristics and heuristics, Norman's principles, Shneidermann's golden rules, and emerging AI interaction frameworks. The analysis showed that conflicts are concentrated around efficiency and minimalist design, while the framework largely extends rather than displaces existing knowledge. Cognitive resilience was proposed as a candidate sixth usability characteristic that takes precedence when it conflicts with the existing five.

A decision tree was introduced as a practical aid for applying the principles and guidelines to individual design decisions, and can be used iteratively throughout the design process. A design application to a social media feed demonstrated that the principles and guidelines generalise beyond the three original studies and that all three characteristic-level conflicts identified in Section 7.3 arose and were resolved using the same logic.

Chapter 8 reflects on the contributions of the thesis as a whole, discusses limitations, and identifies directions for future.

Chapter 8

Conclusion

Chapter 1 raised the concern that everyday digital interactions are often designed to maximise ease and engagement, while their long-term effects on cognition receive far less attention in interaction design. This thesis advances cognitive resilience as a design orientation in response to this concern. Within this orientation, core cognitive functions such as attention, memory, and reasoning are treated as capacities that need to be preserved through design, and not only as limited resources to be minimised. This chapter revisits the hypothesis and the three research questions introduced in Chapter 1 based on the evidence presented across Chapters 2 to 7. It presents the outcome of each research question, highlighting areas with stronger evidence as well as those where the findings remain tentative. Then it moves to the discussion of contributions, limitations, and future work.

8.1 Revisiting the Hypothesis and Research Questions

Each research question is revisited in turn below, followed by an assessment of the hypothesis:

RQ1. ***Which interaction contexts in everyday applications undermine core cognitive processes such as attention, memory, executive functions, and reasoning, when engaged with in the short term, on a repeated basis, or during continuous use?***

RQ1 was examined mainly in Chapter 2, through a review of 59 key studies spanning four cognitive domains and an archive of 163 media articles exploring how these effects were discussed in public discourse. The two sources highlighted several situations associated with cognitive disruption, especially notifications and interruptions, media multitasking, interruptions during digital reading, and interactions with AI assistants. Related issues included cognitive offloading and information overload. The same set of issues appears in both the academic literature and the public discourse, which suggests

a stable pattern of concern and not only effects observed under experimental conditions. They were then reaffirmed in the three design studies in Chapters 4 to 6, where each prototype responded to one or more of these in its specific interaction setting.

RQ2. ***How can these interaction contexts be redesigned to mitigate negative cognitive effects while maintaining usability and engagement, without relying on device, platform or application-level restrictions?***

RQ2 was addressed through the three design studies presented in Chapters 4 to 6:

- Attention Mode (Chapter 4) demonstrated a design approach in which a single in-app trigger removes several sources of distraction at the same time, and this approach was tested on a desktop news site, a tablet reading app, and a smartphone video player, where the SUS scores were in the excellent range on all three platforms.
- SmartPause (Chapter 5) was tested through two controlled studies in which pausing at natural breakpoints during digital reading was associated with better memory retention, while less consistent effects were observed for selective attention, perceived workload, and affective state.
- ReasonScape (Chapter 6) was developed as an interaction concept for AI chat in which reasoning is supported through the structure of the conversation and not only through the quality of the AI's outputs, and the feedback obtained from experts supported the overall logic of the concept while identifying calibration as the main implementation challenge.

The three interventions were all designed to operate within the existing application interface instead of relying on approaches like device-level restrictions or user self-regulation.

RQ3. ***What are the implications for existing design knowledge (principles, guidelines, and heuristics), and how can these be extended to support cognitive resilience in interaction design?***

RQ3 was answered in Chapter 7. The three design studies were decomposed into 32 components, which were analysed across cases to identify six Cognitive Resilience Support Mechanisms (CRSMs), and from these mechanisms, six design principles and fourteen guidelines were derived, with three of the principles being cross-cutting and three being domain-specific. The framework was then situated against existing design knowledge, including Nielsen's (1994a, 1994b) usability characteristics and heuristics, Norman's (2013) principles, Shneiderman's (2018) golden rules, and the AI interaction

guidelines from Amershi et al. (2019) and Weisz et al. (2024), showing where the framework extends, qualifies, or conflicts with each of these. As part of this framework, cognitive resilience was proposed as a candidate sixth usability characteristic that takes precedence when in conflict with the existing five, and a decision tree was developed for applying the principles and guidelines alongside existing design knowledge. The applicability of the framework beyond the three studies was examined through a design application to a social media feed (Instagram), which demonstrates transferability in the Research through Design sense and not as a claim of statistical generalisability.

Hypothesis. ***It is possible to design the interactions of everyday applications in such a way as to reduce or minimise negative consequences to users' cognitive abilities, including attention, memory, and reasoning, by preserving baseline cognitive functioning during both short-term and habitual interaction contexts***.

The findings of Chapters 4 to 6 support the hypothesis from Chapter 1. The hypothesis states that it is possible to design such interactions, and the question for the evidence is whether this possibility has been demonstrated in practice. The three design studies provide this demonstration in their respective domains, each evaluated through methods appropriate to its research aim and design maturity. Thus, the hypothesis posed in this thesis is supported.

The strength of evidence differs across the three domains. The clearest empirical support is for memory, through SmartPause's controlled experiments. Attention Mode provides usability evidence across three platforms, since attention itself was not measured directly. ReasonScape supports the hypothesis through expert evaluation of a conceptual design rather than a built prototype. This variation reflects the principle of matching the method to the question in Research through Design (Chapter 3, Section 3.3.5): evaluation methods were adapted to each artefact's research aim and design maturity instead of using a standardised approach across all three.

8.2 Contributions of the Thesis

8.2.1 Conceptual Contributions

This thesis makes four conceptual contributions. The construct of cognitive resilience is adapted from psychology, neuroscience, and ageing research and brought into the HCI context in Chapter 3 (Section 3.1.1). Before this work, the construct was used in other fields, but it was not available in a form that could be used to inform design decisions in HCI. Chapter 3 (Section 3.1.2) then introduces cognitively resilient design as a design

orientation, which is different from digital wellbeing, accessibility, and persuasive technology.

Two further conceptual contributions are made in Chapter 7. Section 7.1.4 presents an organising structure for the design knowledge developed in the thesis, in which principles are grouped into a cross-cutting category and a domain-specific category. Finally, Section 7.3.1 proposes that cognitive resilience can be considered as a sixth usability characteristic, which takes precedence over the existing five when it is in conflict with them.

8.2.2 Methodological Contributions

The first methodological contribution is the operationalisation of Research through Design for a construct that has no fixed benchmark in HCI (Chapter 3, Section 3.2). This demonstrates how Research through Design can be applied to investigate such constructs. The second is the use of mixed methods that are tailored to the design maturity of each artefact (Chapter 3, Section 3.3.3): controlled experiments for SmartPause, usability evaluation for Attention Mode, and expert review for ReasonScape. This approach shows how different evaluation methods can be combined within a single Research through Design programme, depending on the stage of each artefact.

The third methodological contribution is the cross-case decomposition method developed in Chapter 7 (Section 7.1). Through this method, 32 interaction components from the three design studies were grouped into six CRSMs. This offers an analytical pathway from individual design components to a shared set of mechanisms across artefacts, which was not previously available in this form in HCI.

8.2.3 Practical Contributions

The thesis presents three design instruments, Attention Mode, SmartPause, and ReasonScape, in Chapters 4, 5, and 6, which provide concrete instances of cognitively resilient design that other designers can build on. Chapter 7 then provides the design knowledge layer of the thesis, with six design principles and fourteen guidelines (Section 7.2) and a decision tree (Figure 7.2) for applying these alongside existing design knowledge from Nielsen (1994a, 1994b), Norman (2013), and Shneiderman (2018). Before this thesis, designers did not have a structured vocabulary for cognitive resilience, nor a procedural way to combine it with established design knowledge.

The framework's applicability beyond the original three studies is examined through a design application to a social media feed (Instagram) in Chapter 7 (Section 7.4), which demonstrates transferability in the Research through Design sense. Parts of this work have

been disseminated through six peer-reviewed publications listed in Chapters 4, 5, and 6, in venues such as HCI International, INTERACT, BCS HCI, CHI, and Creativity & Cognition conferences.

8.3 Limitations

8.3.1 Scope Choices

The scope of the thesis was bounded by a set of choices established at the design stage of the research and discussed in detail in Chapters 1 and 3.

Long-term cognitive effects were not directly measured, as stated in Chapter 1, Section 1.6. The three studies were single-session, and the persistence of the effects over time remains an open question for future work.

The work is also limited to the interaction layer of digital applications, and does not cover content moderation, algorithmic design, infrastructure, hardware, or business models. These layers may also influence cognitive resilience but were not within the scope of this work.

Beyond this, the findings of the thesis are presented as design insights and not as clinical or diagnostic claims. Cognitive effects are described at the behavioural, usability, and self-report levels, and no claims are made about neural mechanisms or clinical outcomes.

A further scope choice concerns the cognitive domains covered. The thesis examines attention, memory, and reasoning. Executive functions were treated as an implicit, cross-cutting concern, while creativity, decision-making, problem-solving, perception, and learning transfer were not part of the scope.

Finally, participants were adults with no known cognitive impairments (Chapter 3, Section 3.3.4). The effects of the proposed interactions on clinical populations, on older adults with cognitive decline, or on individuals with specific attention or memory difficulties remain open questions.

8.3.2 Empirical Constraints

Beyond these scope choices, there are also several constraints in the empirical work of the thesis. The studies varied in evaluation depth, from controlled experiments to usability evaluation and expert reviews. The consequences of this asymmetry have already been discussed in Section 8.1 and are not restated here.

The samples also varied in size across the three empirical evaluations. Attention Mode was evaluated with 18 participants in total across the formative and main rounds, ReasonScape with 16 experts (11 workshop participants and 5 ad hoc reviewers), and

SmartPause with 65 participants across the two studies. The first two were small, while SmartPause's first study used a moderate sample (N=51), large enough to detect a significant memory retention effect, but its follow-up study was smaller.

In addition to size, the samples also had limitations in terms of composition. The majority of participants were young adults based in Ireland, and English fluency was a requirement for all studies. Some individual differences were considered in the empirical evaluation, particularly in the SmartPause study. These included neuroticism and English proficiency tested for moderation effects, and a follow-up within-subjects design that controlled for between-participant variability. The analyses did not systematically control for other variables that may have been relevant, such as working memory capacity, attentional control, and media multitasking habits. Within the Research through Design approach of this thesis, the findings function mainly as design-oriented evidence. Statistical generalisation of these findings to broader populations is outside the scope of the present work.

Beyond this, the evaluations of the three artefacts were conducted in controlled settings, using prototypes and walkthroughs, and none of the artefacts was deployed in the field at this stage of the work. The measures used in the evaluations included behavioural task performance, self-report data, usability ratings, and expert feedback. Other types of data, such as eye-tracking, interaction logs, and physiological recordings, were not collected in the present work. Therefore, the studies could not fully capture the cumulative effects of everyday interruptions, multitasking demands, and user fatigue.

A further constraint is that only one design artefact was developed for each cognitive domain. Within-domain replication, such as a second memory artefact alongside SmartPause or a second attention artefact alongside Attention Mode, was not possible within the time and resources of the doctoral programme.

Finally, ReasonScape was evaluated as a design concept and not as a built and functional system. The expert review used visual mock-ups and scenarios, and the behavioural responses of end users to a working version of the system remain to be investigated.

8.4 Future Research Directions

8.4.1 Longitudinal and Field Evaluation

The long-term effects of the three artefacts on cognition were not assessed within this thesis and remain an open question for future work. Future studies could test the artefacts in everyday digital settings over several weeks or months. This would show whether the

support provided by the designs continues to help users over time, rather than only during a single study session. For example, Attention Mode could be studied during everyday activities such as work, reading, or media use. SmartPause could be tested with longer gaps between reading and recall, and across repeated reading sessions. ReasonScape could be examined in repeated tasks where users work with AI to make judgements or interpret information. Such studies would also help to overcome the controlled-setting constraint described in the previous section.

8.4.2 Expanding the Cognitive Domain

The cognitive domains examined in this thesis (attention, memory, and reasoning) represent only a part of the cognitive processes that may be affected by everyday digital interaction. Other functions, including creativity, decision-making, problem-solving, perception, learning transfer, and metacognitive calibration, were identified as gaps in Chapter 2 and excluded from the present work as a scope choice. Even within the covered domains, the artefacts addressed specific sub-processes rather than the full range, and processes such as anticipatory attention, semantic and transactive memory, and inductive or analogical reasoning were not directly examined. As research continues to develop, future work could examine how digital interaction influences these less-covered processes, and whether the principles and guidelines proposed in this thesis can be extended or adapted to support them.

8.4.3 Broader Empirical Validation

The principles and guidelines were derived from three design cases and applied to one further design (Instagram) in Chapter 7, which limits the empirical basis for the framework. Further work in other domains, such as productivity tools, education, workplace collaboration, and AI-assisted decision-making, would help to clarify which of the proposed mechanisms are domain-specific and which are more general. Within-domain replication through additional artefacts for attention, memory, or reasoning would also strengthen the evidence base for each domain. Testing with more diverse user groups in terms of age, language, region, digital expertise, and AI literacy would also address the sample composition limitations described in Section 8.3.2.

8.4.4 Measurement of Cognitive Dimensions of UX

Conventional usability measures, such as task completion, errors, efficiency, satisfaction, SUS, and NASA-TLX, are still useful, but they are limited for evaluating cognitive resilience. Therefore, future research could develop evaluation methods that combine usability measures with cognitive, behavioural, and experiential indicators. These may

include eye-tracking, interaction logging, delayed recall, reasoning quality assessment, confidence calibration, and physiological indicators of cognitive effort.

These indicators should be selected carefully according to the cognitive process being studied, rather than applied as a fixed set of measures. This would also help to address the measurement constraints discussed in Section 8.3.2 and connect future work with the methodological objective introduced in Chapter 1, Section 1.4.

8.4.5 Adaptive and Personalised Support

Users may differ in cognitive capacities, skills, and preferences, such as working memory, attentional control, reading ability, AI literacy, and tolerance for friction. While the three artefacts offered some user-controlled customisation, such as adjustable levels in Attention Mode, optional note-taking in SmartPause, and skippable steps in ReasonScape, they did not adapt cognitive support to such individual differences. A further direction is to develop cognitive resilience support that adapts to such differences, while remaining transparent and under the user's control. This is important to ensure that adaptation does not become another form of behavioural influence. Such work would address the individual differences constraint described as a limitation and align with the autonomy concern reflected in P2 of the framework, which concerns user agency.

8.3.6 From Research to Education, Industry, and Policy

Beyond their use in this research, the principles and guidelines could also be applied in professional design practice and education. For example, they could be turned into cognitive resilience checklists, design audit tools, or curriculum material for HCI and UX programmes. The proposed criteria also connect to wider topics such as digital well-being, AI accountability, and humane technology. These topics go beyond the interaction layer of this thesis and would need to be addressed at the infrastructure and policy level as well. Taken together, these directions would help to position cognitive resilience as a practical design value alongside usability, accessibility, safety, and well-being in the design of everyday digital technologies.

8.5 Closing Reflection

This thesis began with the concern that the design of everyday digital systems gives more attention to ease and engagement than to their effects on users' cognition. The work here suggested that interaction design itself can address this, rather than leaving it as something users must manage on their own. The three studies on attention, memory, and reasoning, together with the framework that followed, are one way of approaching this. They are not a finished answer, and much of what they raise remains for future research. Over time,

cognitive resilience may come to sit alongside usability, accessibility, safety, and well-being as a design value worth taking seriously.

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APPENDICES

Appendix A

Archived Media Articles on Digital Technology and Cognition

This appendix lists the 163 media articles archived in *Digital Habits, Cognitive Shifts*, which informed the analysis of public discourse in Chapter 2, Section 2.3.

Table A.1. Archived media articles on digital technology and cognition (n = 163).

	News Title	Source	Date	Category	Theme
1	Parents' obsessive technology use may have serious long-term effects on babies and toddlers: study	New York Post	06/05/2025	Cognitive Impacts	Affective & Social-Cognitive Impairment
2	How using social media affects teenagers	Child Mind Institute	18/11/2024	Cognitive Impacts	Affective & Social-Cognitive Impairment
3	Study links higher screen time with poorer language skills in young children	News Medical	12/09/2024	Cognitive Impacts	Affective & Social-Cognitive Impairment
4	How bad is social media for kids? (it's pretty bad and here's why according to experts)	GoodtoKnow	24/05/2024	Cognitive Impacts	Affective & Social-Cognitive Impairment
5	How social media can negatively affect your child	Cleveland Clinic	15/01/2024	Cognitive Impacts	Affective & Social-Cognitive Impairment
6	Smartphones and social media are destroying children's mental health	Financial Times	09/03/2023	Cognitive Impacts	Affective & Social-Cognitive Impairment
7	Constant surveillance can reduce concentration, memory	The Hill	13/05/2025	Cognitive Impacts	Attention Degradation
8	Has too much screen time rewired your child's brain?	Breaking News Ireland	07/05/2025	Cognitive Impacts	Attention Degradation
9	Breaking the habit: Why hiding your phone won't stop the distraction	Tech Explorist	28/03/2025	Cognitive Impacts	Attention Degradation
10	Colman Noctor: Technology is reducing our children's attention spans	Irish Examiner	09/12/2024	Cognitive Impacts	Attention Degradation
11	What is 'brain rot'? Oxford word of the year 2024 shows just how long we spend on our phones	Yahoo Life UK	02/12/2024	Cognitive Impacts	Attention Degradation

12	How screen addiction is harming teen brains	The Educator Magazine	18/11/2024	Cognitive Impacts	Attention Degradation
13	Concentration? I don't know her: How we lost our collective ability to focus	Cosmopolitan UK	25/09/2024	Cognitive Impacts	Attention Degradation
14	Scroll, swipe, repeat: How social media is rewiring our attention span	The Varsity	15/09/2024	Cognitive Impacts	Attention Degradation
15	The attention span panic	The Atlantic	06/05/2026	Cognitive Impacts	Attention Degradation
16	Is TikTok cooking your brain too? Welcome to being a brainrotter	Verywell Mind	23/07/2024	Cognitive Impacts	Attention Degradation
17	Smartphones are the new cigarettes	MIT Technology Review	25/06/2024	Cognitive Impacts	Attention Degradation
18	Your brain explained: Why it's getting harder to pay attention	ABC News (Australia)	15/04/2026	Cognitive Impacts	Attention Degradation
19	If you think you can't focus for long, you're right	CNN	15/05/2024	Cognitive Impacts	Attention Degradation
20	Social media promotes reading level decline	The Tide	01/05/2024	Cognitive Impacts	Attention Degradation
21	Short-form content popularity suspected to dramatically lower attention span, focus in classrooms	The Campanile	04/04/2024	Cognitive Impacts	Attention Degradation
22	A psychologist explains the rise of 'popcorn brain'	Forbes	04/04/2024	Cognitive Impacts	Attention Degradation
23	Social psychologist finds smartphones and social media harm kids in these four ways	Daily Citizen	01/04/2024	Cognitive Impacts	Attention Degradation
24	What is popcorn brain? How being chronically online is killing focus	NewsNation	24/02/2024	Cognitive Impacts	Attention Degradation
25	What is 'popcorn brain'? How social media may be killing your attention span	New York Post	18/02/2024	Cognitive Impacts	Attention Degradation
26	Popcorn brain: Social media is killing our attention span, experts claim	Evening Standard	16/02/2024	Cognitive Impacts	Attention Degradation
27	'Popcorn brain' could be behind our dwindling attention spans	Metro	12/02/2024	Cognitive Impacts	Attention Degradation
28	Squirrel! Why attention spans seem to be shrinking and what we can do about it	Northeastern University News	23/01/2024	Cognitive Impacts	Attention Degradation
29	The big idea: are our short attention spans really getting shorter?	The Guardian	23/10/2023	Cognitive Impacts	Attention Degradation
30	Here's how screen time is scaling sleep deprivation in teens	World Economic Forum	07/09/2023	Cognitive Impacts	Attention Degradation
31	Children's attention span 'shorter than ever' since Covid crisis, say teachers in England	The Guardian	07/06/2023	Cognitive Impacts	Attention Degradation
32	Gen Z has a 1-second attention span. That can work to marketers' advantage	eMarketer	15/12/2022	Cognitive Impacts	Attention Degradation

33	‘A goldfish generation’: Are there any benefits to digital distraction	The Independent	11/03/2022	Cognitive Impacts	Attention Degradation
34	Are attention spans really collapsing? Data shows UK public are worried – but also see benefits from technology	King's College London News	16/02/2022	Cognitive Impacts	Attention Degradation
35	Short attention spans linked to social media distress	Curtin University News	09/11/2021	Cognitive Impacts	Attention Degradation
36	Impact of social media on our attention span and its drastic aftermath	Countercurrents	12/04/2021	Cognitive Impacts	Attention Degradation
37	Are we really in an attention crisis, or are digital technologies getting a bad rap?	ABC News (Australia)	17/08/2019	Cognitive Impacts	Attention Degradation
38	How to disrupt your brain’s distraction habit	Inc.	25/05/2016	Cognitive Impacts	Attention Degradation
39	‘I don’t think my brain should have gone through that’: five young people on their experience of smartphones as teens	The Guardian	27/06/2025	Cognitive Impacts	Executive Function Disruption
40	Screen time can benefit or harm young kids	The Conversation	25/06/2025	Cognitive Impacts	Executive Function Disruption
41	Chromebooks or cellphones: Which are the bigger classroom distraction?	Education Week	09/05/2025	Cognitive Impacts	Executive Function Disruption
42	Your phone may not be the problem when it comes to distraction, study says	CNN	03/04/2025	Cognitive Impacts	Executive Function Disruption
43	The human mind is in a recession	Financial Times	16/02/2025	Cognitive Impacts	Executive Function Disruption
44	Does TikTok really cause brain rot? New study links short video addiction to brain abnormalities	PsyPost	17/01/2025	Cognitive Impacts	Executive Function Disruption
45	Brain rot' is Oxford Word of The Year: The hidden toll of endless of scrolling	India Today	09/12/2024	Cognitive Impacts	Executive Function Disruption
46	Is doom scrolling really rotting our brains? The evidence is getting harder to ignore	The Guardian	09/12/2024	Cognitive Impacts	Executive Function Disruption
47	Are you being driven to distraction by technology?	RTÉ Brainstorm	04/12/2024	Cognitive Impacts	Executive Function Disruption
48	Is brain fog the price Gen Z pays for hustle and scroll life?	India Today	03/12/2024	Cognitive Impacts	Executive Function Disruption
49	7 effects of social media on mental health	TechTarget	02/10/2024	Cognitive Impacts	Executive Function Disruption
50	Why kids’ shows like ‘cocomelon’ hamper critical brain development	Forbes	17/05/2024	Cognitive Impacts	Executive Function Disruption
51	‘TikTok Brain’ is a real thing – it is eating away at your mind & making your children dumber, warn experts	The Sun	27/04/2024	Cognitive Impacts	Executive Function Disruption
52	Is social media rewiring our children's brains?	Today's Parent	25/04/2024	Cognitive Impacts	Executive Function Disruption
53	Jonathan Haidt wants you to take away your kid’s phone	The New Yorker	20/04/2024	Cognitive Impacts	Executive Function Disruption

54	How cell phones are killing our kids, and what we can do about it	CNN	16/04/2024	Cognitive Impacts	Executive Function Disruption
55	How to calm the anxious generation	Harvard Public Health Magazine	20/03/2024	Cognitive Impacts	Executive Function Disruption
56	Zuckerberg claims social media isn't harmful to mental health — here's what the science says	APA Psychology News	09/02/2024	Cognitive Impacts	Executive Function Disruption
57	Are smartphones bad for us? Five world experts answer	The Guardian	10/01/2024	Cognitive Impacts	Executive Function Disruption
58	Social media use is linked to brain changes in teens, research finds	The New York Times	03/01/2023	Cognitive Impacts	Executive Function Disruption
59	Rise in 'alert fatigue' risks phone users disabling news notifications, study finds	The Guardian	20/06/2025	Cognitive Impacts	Executive Function Disruption
60	CNN: AI's effects on the brain	MIT Media Lab	20/06/2025	Cognitive Impacts	Memory Decline
61	Digital technology: Friend or foe to the brain?	Medscape	29/04/2025	Cognitive Impacts	Memory Decline
62	Book examines how digital culture is affecting our memory	Cornell News	10/04/2025	Cognitive Impacts	Memory Decline
63	What relationship does technology have with memory?	The Boar	03/04/2025	Cognitive Impacts	Memory Decline
64	Are the Internet and AI affecting our memory? What the science says	Nature	05/02/2025	Cognitive Impacts	Memory Decline
65	I'm worried what online learning is doing to my child's memory	iNews	05/12/2024	Cognitive Impacts	Memory Decline
66	People in their 30s and 40s are facing an unprecedented wave of memory problems	Boston Globe	21/10/2024	Cognitive Impacts	Memory Decline
67	Can excessive smart phone use cause memory loss?	Times of India	12/10/2024	Cognitive Impacts	Memory Decline
68	Digital dementia: How too much screen time can cause memory problems?	Only My Health	28/08/2024	Cognitive Impacts	Memory Decline
69	End the phone-based childhood now	The Atlantic	13/03/2024	Cognitive Impacts	Memory Decline
70	Can excessive screen time cause "digital dementia"?	Healthline	02/02/2024	Cognitive Impacts	Memory Decline
71	Unveiling the effects of reels and TikTok on the brain	Medium (ASYCD)	10/08/2023	Cognitive Impacts	Memory Decline
72	Are Google and smartphones degrading our memories?	Harvard Gazette	21/10/2021	Cognitive Impacts	Memory Decline
73	AI and the danger of cognitive surrender	The Economist	30/04/2026	Cognitive Impacts	Memory Decline
74	Digital dependence 'eroding human memory'	BBC News	07/10/2015	Cognitive Impacts	Memory Decline
75	Google Effect: is technology making us stupid?	The Independent	16/07/2015	Cognitive Impacts	Memory Decline

76	Educators warn that AI shortcuts are already making kids lazy: 'Critical thinking and attention spans have been demolished'	New York Post	25/06/2025	Cognitive Impacts	Reduced Reasoning & Critical Thinking
77	ChatGPT may be eroding critical thinking skills, according to a new MIT study	Time	23/06/2025	Cognitive Impacts	Reduced Reasoning & Critical Thinking
78	A.I. will destroy critical thinking in K-12	The New York Times	14/05/2025	Cognitive Impacts	Reduced Reasoning & Critical Thinking
79	'Don't ask what AI can do for us, ask what it is doing to us': are ChatGPT and co harming human intelligence?	The Guardian	19/04/2025	Cognitive Impacts	Reduced Reasoning & Critical Thinking
80	Teachers warn AI is impacting students' critical thinking	Axios	30/03/2025	Cognitive Impacts	Reduced Reasoning & Critical Thinking
81	AI tools may weaken critical thinking skills by encouraging cognitive offloading, study suggests	PsyPost	21/03/2025	Cognitive Impacts	Reduced Reasoning & Critical Thinking
82	Are we getting dumber? How AI affects critical thinking	Fortune	20/03/2025	Cognitive Impacts	Reduced Reasoning & Critical Thinking
83	The case for using your brain — even if AI can think for you	Vox	10/03/2025	Cognitive Impacts	Reduced Reasoning & Critical Thinking
84	Students' use of AI spells death knell for critical thinking	The Guardian	02/03/2025	Cognitive Impacts	Reduced Reasoning & Critical Thinking
85	Using AI tools like ChatGPT can reduce critical thinking skills	New Scientist	13/02/2025	Cognitive Impacts	Reduced Reasoning & Critical Thinking
86	Study: Generative AI could inhibit critical thinking	Campus Technology	02/02/2025	Cognitive Impacts	Reduced Reasoning & Critical Thinking
87	Is doom scrolling really rotting our brains? The evidence is getting harder to ignore	The Guardian	09/12/2024	Cognitive Impacts	Reduced Reasoning & Critical Thinking
88	Brain rot' is Oxford's 2024 word of the year	Time	02/12/2024	Cognitive Impacts	Reduced Reasoning & Critical Thinking
89	Algorithms are making kids desperately unhappy	The New York Times	18/07/2023	Cognitive Impacts	Reduced Reasoning & Critical Thinking
90	Will A.I. harm Us? Better to ask how we'll reckon with our hybrid nature	Nautilus	05/09/2016	Cognitive Impacts	Reduced Reasoning & Critical Thinking
91	Study links technology use to lower risk of cognitive decline	Washington Post	26/05/2025	Solutions	Cognitive Training
92	Think technology is hurting your brain? Science says the opposite — but only if you do these 5 things	Real Simple	07/05/2025	Solutions	Cognitive Training
93	Older people who use smartphones 'have lower rates of cognitive decline'	The Guardian	14/04/2025	Solutions	Cognitive Training
94	Technology use may be associated with a lower risk for dementia, study finds	CNN	14/04/2025	Solutions	Cognitive Training
95	Are video games good for you? Your brain thinks so	Cleveland Clinic	02/12/2024	Solutions	Cognitive Training

96	Brain-training games remain unproven, but research shows what sorts of activities do benefit cognitive functioning	The Conversation	13/11/2024	Solutions	Cognitive Training
97	10 memory-boosting games and activities to keep your brain sharp	Everyday Health	04/10/2024	Solutions	Cognitive Training
98	Negative social media content has a greater impact on people struggling with mental health	El País (English)	21/12/2024	Solutions	Device / App Restriction
99	HMD delivers Android Digital Detox feature to stop you scrolling your life away	The Register	17/10/2024	Solutions	Device / App Restriction
100	Social media platforms should act before warning labels are required	Forbes	01/07/2024	Solutions	Device / App Restriction
101	TikTok sets 60-min limit to use for under-18	BBC News	01/03/2023	Solutions	Device / App Restriction
102	Apple investors urged action on ‘smartphone addiction’	BBC News	08/01/2018	Solutions	Device / App Restriction
103	TikTok is back — and it's harming kids 'at an industrial scale,' says psychologist	CNBC	24/01/2025	Solutions	Policy & Platform Reforms
104	TikTok's US reprieve comes as other countries limit social media use	VOA News	22/01/2025	Solutions	Policy & Platform Reforms
105	No devices for kids at meals and turn off the TV: Singapore issues stricter screen use guidelines	The Straits Times	22/01/2025	Solutions	Policy & Platform Reforms
106	What teens are saying about barring children under 16 from social media	The New York Times	16/01/2025	Solutions	Policy & Platform Reforms
107	Social-media bans won’t work — there are better ways to keep kids safe	Nature	14/01/2025	Solutions	Policy & Platform Reforms
108	Why we shouldn’t ban kids from social media	Vox	09/01/2025	Solutions	Policy & Platform Reforms
109	Australia is booting kids under 16 off social media. Some senators hope the US is next: 'Our lack of action is inexcusable.'	Business Insider	11/12/2025	Solutions	Policy & Platform Reforms
110	UK tech secretary backs away from social media ban for under-16s	Financial Times	02/01/2025	Solutions	Policy & Platform Reforms
111	My son joined an online cult. But social media bans for kids are not the answer	U.S. News & World Report	11/12/2024	Solutions	Policy & Platform Reforms
112	Australia bans kids under 16 from social media in bold move against big tech	Social Europe	09/12/2024	Solutions	Policy & Platform Reforms
113	No more social media for kids? Texas lawmakers discuss restricting students' digital spaces	Austin American-Statesman	09/12/2024	Solutions	Policy & Platform Reforms
114	Social media can harm children's mental health. The question now is whether a ban will help or make it worse	ABC News (Australia)	01/12/2024	Solutions	Policy & Platform Reforms

115	Here's why Australia is banning Social media for children, teens under age of 16	Tempo (Indonesia)	01/12/2024	Solutions	Policy & Platform Reforms
116	The story behind Australia's social media ban for kids – and how it started with a politician's wife	Irish Independent	29/11/2024	Solutions	Policy & Platform Reforms
117	Australia passes social media ban for children under 16	Reuters	29/11/2024	Solutions	Policy & Platform Reforms
118	Australia approves social media ban on under-16s	BBC News	28/11/2024	Solutions	Policy & Platform Reforms
119	Social media sites call for Australia to delay its ban on child use	The Journal (Ireland)	25/11/2024	Solutions	Policy & Platform Reforms
120	Australia hears bill proposing social media ban for under-16s	Silicon Republic	21/11/2024	Solutions	Policy & Platform Reforms
121	Australia wants to ban kids from social media. Will it work?	BBC News		Solutions	Policy & Platform Reforms
122	Social media ban for under-16s 'on the table' in UK.	BBC News	20/11/2024	Solutions	Policy & Platform Reforms
123	Q&A with Dr. Michael Silverstein: How social media can impact child health, and what to do about it	Brown University News	13/11/2024	Solutions	Policy & Platform Reforms
124	Australia vows to ban social media for children under 16	Sky News	07/11/2024	Solutions	Policy & Platform Reforms
125	How to get kids off social media: 2 tips from the surgeon general	Education Week	17/10/2024	Solutions	Policy & Platform Reforms
126	A possible downside to limits on teens' access to social media	KFF Health News	16/09/2024	Solutions	Policy & Platform Reforms
127	France must curb child, teen use of smartphones, social media, says panel	Reuters	30/04/2024	Solutions	Policy & Platform Reforms
128	New Florida law aims to get kids off social media. Will it work?	Education Week	27/03/2024	Solutions	Policy & Platform Reforms
129	Social psychologist says kids shouldn't have smartphones before high school	ABC News (US)	26/03/2024	Solutions	Policy & Platform Reforms
130	UN warns of risk of having smartphones in school	BBC News	26/06/2023	Solutions	Policy & Platform Reforms
131	Technology might be making education worse	Stanford News	10/04/2023	Solutions	Policy & Platform Reforms
132	Mobile addiction's phone-free Fridays to help pupils.	BBC News	24/05/2019	Solutions	Policy & Platform Reforms
133	A phone (that's not a phone) to help you stop using your phone	Wired	24/06/2025	Solutions	Self-Regulation
134	Easily distracted? How to improve your attention span	AP News	17/05/2025	Solutions	Self-Regulation
135	TikTok and AI are junk food — start dieting	The Times	12/05/2025	Solutions	Self-Regulation
136	How accountants can balance technology and critical thinking	Journal of Accountancy	01/04/2025	Solutions	Self-Regulation
137	Taking even a short break from your smartphone can boost your mood: Here's how long you need	NPR	24/02/2025	Solutions	Self-Regulation

138	The best dumbphones for a digital detox, tried and tested	The Telegraph	03/02/2025	Solutions	Self-Regulation
139	Phone-Free February is the best excuse to drop your apps and reconnect with real life	Upworthy	30/01/2025	Solutions	Self-Regulation
140	All in the mind? The surprising truth about brain rot	The Guardian	29/01/2025	Solutions	Self-Regulation
141	Digital detox: A manageable, 10-step guide	Health.com	26/01/2025	Solutions	Self-Regulation
142	Digital detox for leaders: Combating the cognitive toll of screens	Forbes	06/01/2025	Solutions	Self-Regulation
143	3 steps to make your digital detox work (even when it's over)	Psychology Today	27/12/2024	Solutions	Self-Regulation
144	Colchester students give up smartphones for 21 days in experiment	BBC News	11/12/2024	Solutions	Self-Regulation
145	3 Things You'll Notice During Your First 'Digital Detox' — By A Psychologist	Forbes	11/11/2024	Solutions	Self-Regulation
146	Social media is bad for youth mental health: Where do we go from here?	European Public Health Alliance	23/09/2024	Solutions	Self-Regulation
147	EE tells parents: don't give under-11s smartphones	BBC News	25/08/2024	Solutions	Self-Regulation
148	Social media's impact on our mental health and tips to use it safely	UC Davis Health	10/05/2024	Solutions	Self-Regulation
149	'I feel more connected with humanity': the club where phones are banned – and visitors pay for the privilege	The Guardian	08/05/2024	Solutions	Self-Regulation
150	How switching from a smart to a flip phone saved me	The Japan Times	18/03/2024	Solutions	Self-Regulation
151	I tried some hacks to make my phone less appealing. It got existential	The Guardian	15/01/2024	Solutions	Self-Regulation
152	Does ditching your phone for three days actually rewire your brain?	InsideHook	20/12/2023	Solutions	Self-Regulation
153	Social media: Children aged seven using it regularly	BBC News	12/10/2023	Solutions	Self-Regulation
154	How to do a digital detox without unplugging completely	Everyday Health	04/08/2023	Solutions	Self-Regulation
155	"Is it possible to digital detox?"	BBC Worklife	16/03/2023	Solutions	Self-Regulation
156	Media overload is hurting our mental health. Here are ways to manage headline stress	APA Monitor on Psychology	01/11/2022	Solutions	Self-Regulation
157	Tom Holland steps back from social media due to detrimental effects	BBC News	15/08/2022	Solutions	Self-Regulation
158	Digital detox? Why a holiday with no phone is utter twaddle	The Telegraph	18/03/2022	Solutions	Self-Regulation
159	4 reasons to do a digital detox	Cleveland Clinic	23/11/2021	Solutions	Self-Regulation
160	Constantly on your phone? Try these 7 tips to digitally detox at home	Harper's Bazaar	31/05/2019	Solutions	Self-Regulation
161	Do not disturb: How I ditched my phone and unbroke my brain	The New York Times	23/02/2019	Solutions	Self-Regulation

162	How to quit your tech: a beginner's guide to divorcing your phone	The Guardian	13/01/2018	Solutions	Self-Regulation
163	These simple steps will help you stop checking your phone so much	CNBC	03/01/2018	Solutions	Self-Regulation

Appendix B

Research Ethics Approvals

B.1 Attention Mode: Dublin City University Research Ethics Committee Approval Letter

Ollscoil Chathair Bhaile Átha Cliath
Dublin City University

DCU

Ms Naile Hacioglu
School of Computing

10th May 2023

REC Reference: **DCUREC/2023/080**

Proposal Title: **Attention Mode on Everyday Digital Applications**

Applicant(s): **Ms Naile Hacioglu, Dr. Hyowon Lee**

Dear Colleagues,

Thank you for your application to DCU Research Ethics Committee (REC). Further to notification review, DCU REC is pleased to issue approval for this research proposal.

DCU REC's consideration of all ethics applications is dependent upon the information supplied by the researcher. This information is expected to be truthful and accurate. Researchers are responsible for ensuring that their research is carried out in accordance with the information provided in their ethics application.

Materials used to recruit participants should note that ethical approval for this project has been obtained from the Dublin City University Research Ethics Committee. Should substantial modifications to the research protocol be required at a later stage, a further amendment submission should be made to the REC.

Yours sincerely,

DCU
Research & Innovation

Taighde & Nuálaíocht Tacaíocht
Ollscoil Chathair Bhaile Átha Cliath,
Baile Átha Cliath, Éire

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E research@dcu.ie
www.dcu.ie

Dr. Melrona Kirrane
Chairperson
DCU Research Ethics Committee

Note: Please retain this approval letter for future publication purposes (for research students, this includes incorporating the letter within their thesis appendices).

B.2 SmartPause: Dublin City University Research Ethics Committee Approval Letter

Ollscoil Chathair Bhaile Átha Cliath
Dublin City University

DCU

Naile Hacioglu
School of Computing

17th September 2024

REC Reference: **DCUREC/2024/154 (Notification Review)**

Proposal Title: Establishing Design Principles to Combat Over-reliance on Day-to-Day Technologies and Cognitive Decline

Applicant(s): Naile Hacioglu, Dr Hyowon Lee

Dear Colleague(s),

Thank you for your application to DCU Research Ethics Committee (REC). Further to its review by the committee and resting on the assumption of information accuracy and completeness, DCU REC is pleased to issue ethical approval for this research project. Please include reference to this approval in all materials used to recruit research participants.

Researchers are responsible for ensuring that the research project to which this ethical approval refers is carried out as specifically described in the application form. Should modifications to the research project be required at a later stage, researchers must submit a research amendment application form to REC for approval, prior to the implementation of modifications.

Please note that it is the responsibility of the PI to ensure that any other DCU compliance requirements relevant to the research project, such as those related to data protection, insurance, health and safety, or legal issues, are fully met in advance of initiating the project.

As part of DCU REC's ongoing monitoring process, a research progress report may be required. DCU REC will request this report from the PI as appropriate.

DCU REC wishes you every success in your research.

Yours sincerely,

DCU Research & Innovation

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Dr Melrona Kirrane
Chairperson
DCU Research Ethics Committee

Note: Please retain this approval letter for future publication purposes. Research students should include this letter as a thesis appendix.

Appendix C

Participant Information Sheets and Informed Consent Forms

C.1 Attention Mode: Participant Information Sheet and Informed Consent Form

DUBLIN CITY UNIVERSITY

Plain Language Statement

Research Study Title
Attention Mode on Everyday Digital Applications

Researchers
Naile Hacioglu, DCU School of Computing naile.hacioglu@mail.dcu.ie
Dr. Hyowon Lee, DCU School of Computing hyowon.lee@dcu.ie

Privacy Notice

- The Data Controller of this project is DCU, and the Data Processor is Google Drive.
- The identity of the DCU Data Protection Officer – Mr. Martin Ward (data.protection@dcu.ie Ph: 7005118 / 7008257).
- We will collect data in the form of text, audio, or video, whichever is/are preferred by you.
- Data will be retained for the purposes of data analysis and dissemination (journal papers and conference presentation) on DCU Google Drive. It will be destroyed once dissemination is completed, or after four years, whichever happens first.
- Data will only be accessed by Naile Hacioglu and Hyowon Lee.
- You have the right to lodge a complaint with the Irish Data Protection Commission if you feel necessary.
- You have the right to access your own personal data at any time. Please contact DCU Data Protection Unit.
- You can withdraw consent for the use of your data at any time.
- All data will be anonymised.

This project's aim is to develop to investigate a novel design concept idea named *Attention Mode* that can aid users in effectively directing their attention and potentially even enhance their ability to concentrate while they are using commonly used digital applications on their smart devices.

For the usability testing, you are expected to use application(s) on smart devices (i.e., PC, tablet, or smart phone) provided by researchers, use a few features guided by the instructions, and answer questions of researchers about their experience afterwards. During testing, you will use several features of an existent application while Attention mode is turned on and off. You will be given instructions on how to activate or disactivate it by the researchers. When it is turned on, certain User Interface (UI) features might change. If you agree to participate, you will be asked to use a smart device application such as internet browser, video streaming or messaging app for 5–10 minutes. You don't have to use any personal information to use these applications – it is anonymous. The confidentiality of the information which is provided can only be protected within the limitations of the law - i.e., it is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

It is entirely voluntary and anonymous for you to participate in the study. The signed consent form will be shredded once the research is complete. You may withdraw from the study at any point and without notice. Data will be destroyed once you withdraw and your participation in the study will come to an end. All your data being requested and processed is solely for the purpose of testing the functionality, usability, and benefits of the application. The personal data of interest to be processed is that of age, gender/sex, nationality, profession, education level, traits/habits. This data will be anonymised and will not include any information that could identify participants to others. Anonymised data will be used to write academic research that will be published in academic journals and discussed at academic conferences and retained until dissemination of PhD thesis is completed (30/09/2026 latest). Name and contact information (email and Irish phone number) will only be asked in case you would like to receive a gift card. It is required research because this information is necessary to place the gift card order by using our research budget. This data will not be matched with your research data and will be deleted as soon as the purchase is claimed.

In the event of a data breach or any other mishappening, you are entitled to lodge a complaint with the Irish Data Protection Commission, as is their right. You also retain the right to access your own personal data and can do so via contact with the DCU Data Protection Unit.

This research is funded by the SFI Centre for Research Training in Digitally Enhanced Reality (d-real).

If you have any queries, participants can contact the researchers via their email addresses above.

If participants have concerns about this study and wish to contact an independent person, please contact:

The Secretary, Dublin City University Research Ethics Committee, c/o Research and Innovation Support, Dublin City University, Dublin 9. Tel 01-7008000, e-mail rec@dcu.ie

DUBLIN CITY UNIVERSITY

Informed Consent Form

Research Study Title
Attention Mode on Everyday Digital Applications

Researchers
Naile Hacioglu, DCU School of Computing naile.hacioglu@mail.dcu.ie
Dr. Hyowon Lee, DCU School of Computing hyowon.lee@dcu.ie

Clarification of the purpose of the research
This project's aim is to develop to investigate a novel design concept idea named Attention Mode that can aid users in effectively directing their attention and potentially even enhance their ability to concentrate while they are using commonly used digital applications on their smart devices.

Confirmation of particular requirements as highlighted in the Plain Language Statement
Requirements may include involvement in interviews, completion of questionnaire, audio / video-taping of events etc. Getting the participant to acknowledge requirements is preferable, e.g.

Participant – please complete the following (Circle Yes or No for each question)

I have read the Plain Language Statement (or had it read to me)	*Yes/ No*
I understand the information provided	*Yes/No*
I understand the information provided in relation to data protection	*Yes/No*
Security and confidentiality of my personal information has been explained to me:	*Yes/No*
I have had an opportunity to ask questions and discuss this study	*Yes/No*
I have received satisfactory answers to all my questions	*Yes/No*
I am aware that my interview might be audiotaped and/or videotaped	*Yes/No*
My participation is completely voluntary	*Yes/No*
I may withdraw from the Research Study at any point.	*Yes/No*

Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project

Participants Signature: _____

Name in Block Capitals: _____

Witness: _____

Date: _____

C.2 SmartPause Study 1: Participant Information Sheet and Informed Consent Form

Participant Information Sheet

Research Study Title: Exploring User Interaction and Cognitive Performance in Digital Applications with Design Interventions

Researchers:
Naile Hacioglu, DCU School of Computing naile.hacioglu@mail.dcu.ie
Dr. Hyowon Lee, DCU School of Computing hyowon.lee@dcu.ie

Privacy Notice

- The Data Controller of this project is DCU, and the Data Processor is Google Drive.
- The identity of the DCU Data Protection Officer – Mr. Martin Ward (data.protection@dcu.ie Ph: 7005118 / 7008257).
- We will collect data in the form of text, audio, or video, whichever is/are preferred by you.
- Data will be retained for the purposes of data analysis and dissemination (journal papers and conference presentation) on DCU Google Drive. It will be destroyed once dissemination is completed, or after two years, whichever happens first.
- Data will only be accessed by Naile Hacioglu and Dr Hyowon Lee.
- You have the right to lodge a complaint with the Irish Data Protection Commission if you feel necessary.
- You have the right to access your own personal data at any time. Please contact DCU Data Protection Unit.
- You can withdraw consent for the use of your data at any time.
- All data will be anonymised.

What is this research about?
This research explores how different ways of interacting with digital content can impact user experience and cognitive performance.

Why have you been invited to take part?
You have been invited to participate because you meet the demographic criteria needed for this study, representing a diverse background in terms of age, country, and gender.

What will happen if you decide to take part in this research study?
If you decide to participate, you will engage in a series of tasks designed to measure various aspects of user interaction and cognitive performance. The entire session will take approximately 35-45 minutes.

What activities will you undertake?

1. Introduction: Review the Participant Information Sheet, provide Informed Consent, and share Demographic Information.
2. Reading Task: Read a text (2-4 pages) designed for the study.
3. Usability Survey: Evaluate the usability of the reading task and design interventions.
4. Other Assessments: Complete various cognitive and personality assessments.
5. Debriefing Session: Learn about the study's aims, procedures, and findings

What are the benefits of taking part in this research study?

While there may be no direct benefits to you, your participation will contribute to the development of better design strategies for digital applications, potentially benefiting future users.

What are the risks of taking part in this study?

This study is considered low risk. The tasks involved are similar to everyday digital application usage and carry no more risk than normal use of smart devices. There is no deception or abnormal physical effort required.

How will your privacy be protected?

Your participation is anonymous, and your data will not be linked to your identity. The signed consent form will be shredded once the research is complete.

Can you change your mind at any stage and withdraw from this study?

Your participation is voluntary, and you may withdraw from the study at any point and without notice. Data will be destroyed once you withdraw and your participation in the study will come to an end.

How will you find out what happens with this project?

You will be provided with a summary of the study's results upon request. This will give you an overview of the findings and how they might be used in future research and applications.

If you have any questions or wish to withdraw your participation, please contact the researchers via their email addresses above.

All your data being requested and processed is solely for the purpose of testing the functionality, usability, and benefits of the application. The personal data of interest to be processed is that of a first name, family name, age, gender, nationality, educational level, profession, email address.

In the event of a data breach or any other mishappening, you are entitled to lodge a complaint with the Irish Data Protection Commission, as is their right. You also retain the right to access your own personal data and can do so via contact with the DCU Data Protection Unit.

This research is funded by the SFI Centre for Research Training in Digitally-Enhanced Reality (d-real).

If participants have concerns about this study and wish to contact an independent person, please contact:

The Secretary, Dublin City University Research Ethics Committee, c/o Research and Innovation Support, Dublin City University, Dublin 9. Tel 01-7008000, e-mail rec@dcu.ie

Informed Consent Form

Research Study Title: Exploring User Interaction and Cognitive Performance in Digital Applications with Design Interventions

Researchers:
Naile Hacioglu, DCU School of Computing naile.hacioglu@mail.dcu.ie
Dr. Hyowon Lee, DCU School of Computing hyowon.lee@dcu.ie

Clarification of the purpose of the research:
The purpose of this study is to explore the effectiveness of various design features in digital reading applications. We aim to understand how these features impact user experience, cognitive load, and overall reading performance. By investigating different aspects of digital reading environments, we hope to gather valuable insights that can contribute to the development of more user-friendly and supportive digital reading tools. Your participation will help us identify best practices for designing digital reading applications that enhance comprehension, retention, and user satisfaction.

Instruction. Confirmation of requirements as highlighted in the Plain Language Statement Please Select Yes or No for Questions 1-8:

Q1. I have read the Participant Information Sheet (or had it read to me).

- ◯ Yes
- ◯ No

Q2. I understand the information provided.

- ◯ Yes
- ◯ No

Q3. I understand the information provided in relation to data protection.

- ◯ Yes
- ◯ No

Q4. Security and confidentiality of my personal information has been explained to me.

- ◯ Yes
- ◯ No

Q5. I have had an opportunity to ask questions and discuss this study.

- ◯ Yes
- ◯ No

Q6. I have received satisfactory answers to all my questions.

- ◯ Yes
- ◯ No

Q7. My participation is completely voluntary.

- ◯ Yes
- ◯ No

Q8. I may withdraw from the Research Study at any point.

- ◯ Yes
- ◯ No

I have read and understood the information provided in this form. My questions and concerns have been addressed by the researchers, and I have a copy of this consent form. By entering my name below and submitting this form, I consent to participate in this research project.

Please enter your name here:

Please enter today's date in the form of dd/mm/yyyy:

C.3 SmartPause Study 2: Participant Information Sheet and Informed Consent Form

Participant Information Sheet

Research Study Title: Exploring User Interaction and Cognitive Performance in Digital Applications with Design Interventions

Researchers:
Naile Hacioglu, DCU School of Computing naile.hacioglu@mail.dcu.ie
Dr. Hyowon Lee, DCU School of Computing hyowon.lee@dcu.ie

Privacy Notice

- The Data Controller of this project is DCU, and the Data Processor is Google Drive.
- The identity of the DCU Data Protection Officer – Mr. Martin Ward (data.protection@dcu.ie Ph: 7005118 / 7008257).
- We will collect data in the form of text, audio, or video, whichever is/are preferred by you.
- Data will be retained for the purposes of data analysis and dissemination (journal papers and conference presentation) on DCU Google Drive. It wil be destroyed once dissemination is completed, or after two years, whichever happens first.
- Data will only be accessed by Naile Hacioglu and Dr Hyowon Lee.
- You have the right to lodge a complaint with the Irish Data Protection Commission if you feel necessary.
- You have the right to access your own personal data at any time. Please contact DCU Data Protection Unit.
- You can withdraw consent for the use of your data at any time.
- All data will be anonymised.

What is this research about?
This research explores how different ways of interacting with digital content can impact user experience and cognitive performance.

Why is this research being conducted?
The study aims to develop insights into user interactions with digital content, which can inform better design strategies for future digital applications.

Why have you been invited to take part?
You have been invited to participate because you meet the demographic criteria needed for this study, representing a diverse background in terms of age, country, and gender.

What will happen if you decide to take part in this research study?
If you decide to participate, you will engage in a series of tasks designed to measure various aspects of user interaction and cognitive performance. The entire session will take approximately 45-60 minutes in two sessions with 1-hour between each.

What activities will you undertake?
First Session (30-45 minutes):
1. Introduction: Review the Participant Information Sheet, provide Informed Consent, and share Demographic Information.
2. Reading Tasks: Read two study-related texts (4 pages each) at different points during the first session.
3. Cognitive Assessments: Complete additional brief cognitive assessments on a laptop.
Second Session (10-15 minutes, 1-hour following the end of first session):
4. Cognitive Assessments: Complete brief cognitive assessments on a laptop.
5. Debriefing: Learn about the study's aims, procedures, and findings in the second session.

What are the benefits of taking part in this research study?
While there may be no direct benefits to you, your participation will contribute to the development of better design strategies for digital applications, potentially benefiting future users.

What are the risks of taking part in this study?
This study is considered low risk. The tasks involved are similar to everyday digital application usage and carry no more risk than normal use of smart devices. There is no deception or abnormal physical effort required.

How will your privacy be protected?
Your participation is anonymous, and your data will not be linked to your identity. The signed consent form will be shredded once the research is complete.

Can you change your mind at any stage and withdraw from this study?
Your participation is voluntary, and you may withdraw from the study at any point and without notice. Data will be destroyed once you withdraw and your participation in the study will come to an end.

How will you find out what happens with this project?
You will be provided with a summary of the study's results upon request. This will give you an overview of the findings and how they might be used in future research and applications.

If you have any questions or wish to withdraw your participation, please contact the researchers via their email addresses above.

All your data being requested and processed is solely for the purpose of testing the functionality, usability, and benefits of the application. The personal data of interest to be processed is that of a first name, family name, age, gender, nationality, educational level, profession, email address.

In the event of a data breach or any other mishappening, you are entitled to lodge a complaint with the Irish Data Protection Commission, as is their right. You also retain the right to access your own personal data and can do so via contact with the DCU Data Protection Unit.

This research is funded by the SFI Centre for Research Training in Digitally-Enhanced Reality (d-real).

If participants have concerns about this study and wish to contact an independent person, please contact:

The Secretary, Dublin City University Research Ethics Committee, c/o Research and Innovation Support, Dublin City University, Dublin 9. Tel 01-7008000, e-mail rec@dcu.ie

Informed Consent Form

Research Study Title: Exploring User Interaction and Cognitive Performance in Digital Applications with Design Interventions

Researchers:
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Clarification of the purpose of the research:
The purpose of this study is to explore the effectiveness of various design features in digital reading applications. We aim to understand how these features impact user experience, cognitive load, and overall reading performance. By investigating different aspects of digital reading environments, we hope to gather valuable insights that can contribute to the development of more user-friendly and supportive digital reading tools. Your participation will help us identify best practices for designing digital reading applications that enhance comprehension, retention, and user satisfaction.

Instruction. Confirmation of requirements as highlighted in the Plain Language Statement Please Select Yes or No for Questions 1-8:

Q1. I have read the Participant Information Sheet (or had it read to me).

- ◯ Yes
- ◯ No

Q2. I understand the information provided.

- ◯ Yes
- ◯ No

Q3. I understand the information provided in relation to data protection.

- ◯ Yes
- ◯ No

Q4. Security and confidentiality of my personal information has been explained to me.

- ◯ Yes
- ◯ No

Q5. I have had an opportunity to ask questions and discuss this study.

- ◯ Yes
- ◯ No

Q6. I have received satisfactory answers to all my questions.

- ◯ Yes
- ◯ No

Q7. My participation is completely voluntary.

- ◯ Yes
- ◯ No

Q8. I may withdraw from the Research Study at any point.

- ◯ Yes
- ◯ No

I have read and understood the information provided in this form. My questions and concerns have been addressed by the researchers, and I have a copy of this consent form. By entering my name below and submitting this form, I consent to participate in this research project.

Please enter your name here:

Please enter today's date in the form of dd/mm/yyyy:

Appendix D

Attention Mode Study Materials

D.1 Preliminary Feedback Session Protocol (Phase 1, n = 5)

This appendix documents the protocol used for the preliminary feedback sessions reported in Chapter 4, Section 4.3.1.

Materials used. The three prototypes (desktop news website, tablet e-book application, smartphone video streaming application), shown in Chapter 4, Figures **4.2–4.6.**

Session length. Approximately 20–30 minutes per participant.

Setting. One-to-one in-person sessions.

Procedure.

1. Brief introduction to the Attention Mode concept (~2 minutes).
2. Walkthrough of each of the three prototypes in turn (~5 minutes each), demonstrating how Attention Mode is activated and what changes when it is turned on.
3. Open discussion guided by the prompts below.

Discussion prompts.

- Does the purpose of Attention Mode come across clearly?
- Would you use this kind of feature on your own devices?
- Does turning Attention Mode on or off feel easy?
- Are the different levels (Beginner and Advanced) easy to understand?
- Should users be able to customise what each level does?
- Are there features that should not be removed when Attention Mode is active?
- Anything that feels missing or confusing?

Recording. Written notes were taken during and immediately after each session, used to refine the prototypes before Phase 2.

D.2 System Usability Scale (SUS) Questionnaire

Participant ID: _____ Date: ___/___/___

Attention Mode on Web Browser - System Usability Scale

Instructions: For each of the following statements, mark one box that best describes your reactions to the website *today*.

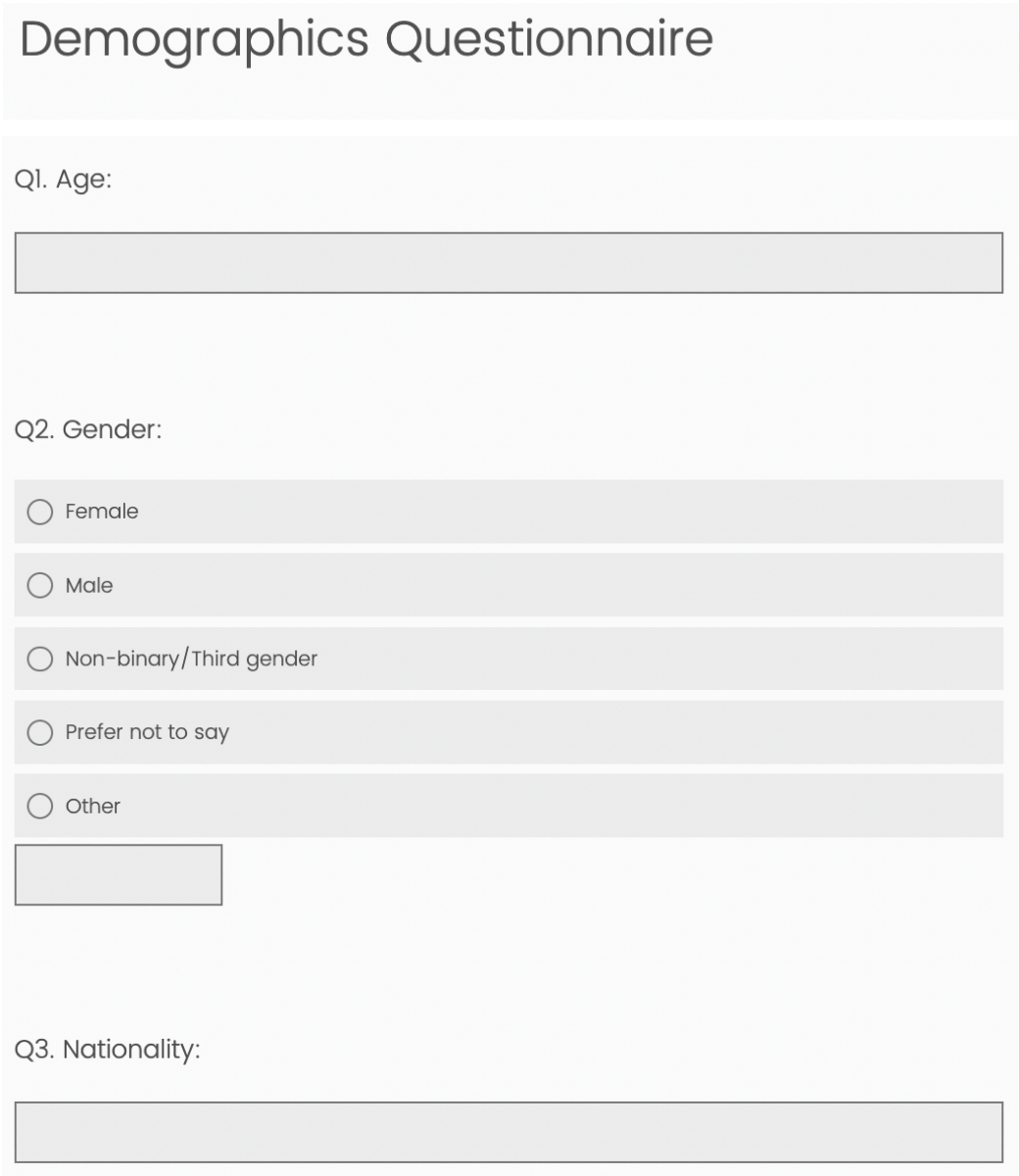
		Strongly Disagree				Strongly Agree
1.	I think that I would like to use this website frequently.	☐	☐	☐	☐	☐
2.	I found this website unnecessarily complex.	☐	☐	☐	☐	☐
3.	I thought this website was easy to use.	☐	☐	☐	☐	☐
4.	I think that I would need assistance to be able to use this website.	☐	☐	☐	☐	☐
5.	I found the various functions in this website were well integrated.	☐	☐	☐	☐	☐
6.	I thought there was too much inconsistency in this website.	☐	☐	☐	☐	☐
7.	I would imagine that most people would learn to use this website very quickly.	☐	☐	☐	☐	☐
8.	I found this website very cumbersome/awkward to use.	☐	☐	☐	☐	☐
9.	I felt very confident using this website.	☐	☐	☐	☐	☐
10.	I needed to learn a lot of things before I could get going with this website.	☐	☐	☐	☐	☐

Please provide any comments about Attention Mode on Web Browser (Laptop)

Appendix E

SmartPause Study Materials

E.1 Demographics Questionnaire



Q4. Highest degree or level of school completed:

- ◯ No formal education
- ◯ Some high school, no diploma
- ◯ High school diploma or equivalent
- ◯ Some college, no degree
- ◯ Associate degree
- ◯ Bachelor's degree
- ◯ Master's degree
- ◯ Doctoral degree
- ◯ Prefer not to say
- ◯ Other

Q5. What is your level of proficiency in English?

- ◯ Native-level: I speak, read, write, and understand this language as fluently as a native speaker.
- ◯ Advanced: I can speak, read, write, and understand this language very well, but I am not at a native level.
- ◯ Proficient: I can hold conversations and understand the language, but with some difficulty.
- ◯ Basic: I have limited knowledge and can communicate on a fundamental level.

E.2 Computerised Stroop Task: Stimulus Configuration

The computerised Colour-Word Stroop Task (Stroop, 1935) was used to assess selective attention and processing speed before and after the reading task in Study 1 and Study 2. The task was administered using Millisecond Software's *Color-Word Stroop – Keyboard* script running in Inquisit Lab 6.

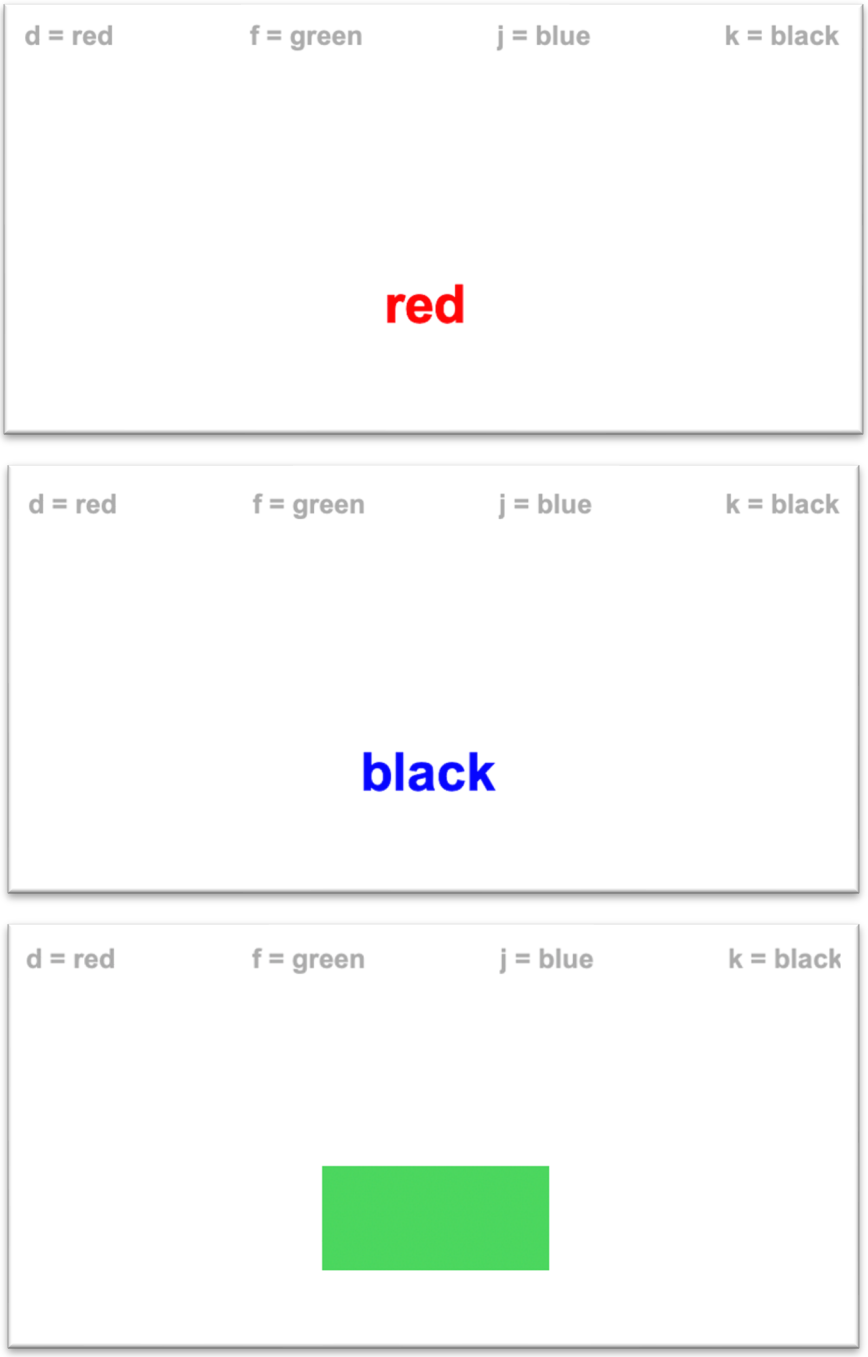


Figure E.2.1: Example stimuli used in the Stroop Task — one congruent (top), one incongruent (middle), and one control stimulus (bottom).

Stimuli. Four colour words (red, green, blue, black) were presented in one of four display colours, producing three trial types:

- *Congruent*: word and display colour match (e.g., *red* shown in red).
- *Incongruent*: word and display colour differ (e.g., *red* shown in blue).
- *Control*: a coloured rectangle with no word.

Trial structure. Each administration consisted of 84 randomly sampled trials: 4 display colours × 3 congruency types × 7 repetitions. Stimuli remained on screen until response. Inter-trial interval was 200 ms, with 400 ms of error feedback after incorrect responses.

Response mapping. Participants responded by pressing one of four keys: D (red), F (green), J (blue), K (black).

Practice phase. Study 2 (within-subjects) included a short practice Stroop phase before the main pre-reading block to reduce task-familiarisation effects (Chapter 5, Section 5.3.3). Study 1 (between-subjects) did not include a practice phase; this limitation is discussed in Chapter 5, Section 5.6.1.

Apparatus. All sessions were conducted on a MacBook Air (M2, 2022, 16 GB RAM) in full-screen mode in a quiet, controlled environment.

Outcome measures. Mean reaction time (ms) and proportion correct were extracted for each congruency condition. The Stroop Effect was computed as the difference between incongruent and congruent trials for latency, and between congruent and incongruent trials for accuracy. Pre–post change scores (Δ) were calculated by subtracting pre-reading values from post-reading values, as reported in Tables 5.2–5.7.

E.3 Study 1 Reading Passage (3-page text)

Source: Wohlleben (2016), [56-59] (Flesch–Kincaid Reading Ease: 60).

The full text of the passage is reproduced below for content reference and for verification of the recall test items in Appendix E.5. Figure E.3.1 shows the final portion as it appeared on screen, with the last 0.5 pages visually blurred. Figure E.3.2 shows the note-taking interface presented in the breakpoint + note-taking condition.

The Mysteries of Moving Water

How does water make its way up from the soil into the tree's leaves? For me, the way this question is answered sums up our current approach to what we know about the forest. For water transport is a relatively simple phenomenon to research —simpler at any rate than investigating whether trees feel pain or how they communicate with one another— and because it appears to be so uninteresting and obvious, university professors have been offering simplistic explanations for decades. This is one reason why I always have fun discussing this topic with students. Here are the accepted answers: capillary action[1] and transpiration[2].

You can study capillary action every morning at breakfast. Capillary action is what makes the surface of your coffee stand a few fractions of an inch higher than the edge of your cup. Without this force, the surface of the liquid would be completely flat. The narrower the vessel[3], the higher the liquid can rise against gravity. And the vessels that transport water in deciduous trees are very narrow indeed: they measure barely 0.02 inches across. Conifers[4] restrict the diameter of their vessels even more, to 0.0008 inches. Narrow vessels, however, are not enough to explain how water reaches the crown of trees that are more than 300 feet tall. In even the narrowest of vessels, there is only enough force to account for a rise of 3 feet at most.

Ah, but we have another candidate: transpiration. In the warmer part of the year, leaves and needles transpire by

1. capillary action: The rise of liquid in narrow spaces.
2. transpiration: The process of losing water through the surface of a plant.
3. vessel: A tube that carries liquids.
4. conifer: One of various types of evergreen tree.

steadily breathing out water vapor. In the case of a mature beech, the tree exhales hundreds of gallons of water a day. This exhalation[5] causes suction, which pulls a constant supply of water up through the transportation pathways in the tree. Suction works as long as the columns of water are continuous. Bonding forces[6] cause the water molecules to adhere to each other, and because they are strung together like links in a chain, as soon as space becomes available in the leaf thanks to transpiration, the bonded molecules pull each other a little higher up the trunk.

And because even this is not enough, osmosis[7] also comes into play. When the concentration of sugar in one cell is higher than in the neighboring cell, water flows through the cell walls into the more sugary solution until both cells contain the same percentage of water. And when that happens from cell to cell up into the crown, water makes its way up to the top of the tree.

Hmm. When you measure water pressure in trees, you find it is highest shortly before the leaves open up in the spring. At this time of year, water shoots up the trunk with such force that if you place a stethoscope[8] against the tree, you can actually hear it. In the north-eastern U.S. and Canada, people make use of this phenomenon to harvest syrup from sugar maples, which are often tapped just as the snow is melting. This is the only time of the year whenthe coveted sap[9] can be harvested. This early in the year, there are no leaves on deciduous[10] trees, which Means there can be no transpiration. And capillary action can be only a partial

5. exhalation: Breathing out.
6. bonding forces: Forces between molecules
7. osmosis: The movement of liquid through a cell's outer layer to equalise concentration.
8. stethoscope: A tool doctors use to listen to the heart and lungs.
9. sap: Nutrient-rich plant fluid.
10. deciduous: Trees that lose leaves yearly.

contributor because the aforementioned rise of 3 feet is hardly worth mentioning. Yet at precisely this time, the trunk is full to bursting. So that leaves us with osmosis, but this seems equally unlikely to me. After all, osmosis works only in the roots and leaves, not in the trunk, which consists not of cells attached one to the other but of long, continuous tubes for transporting water.

So where does that leave us? We don't know. But recent research has discovered something that at least calls into question the effects of transpiration and the forces of cohesion. Scientists from three institutions (the University of Bern; the Swiss Federal Institute for Forest, Snow, and Land- scape Research; and the Swiss Federal Institute of Technology in Zurich) listened more closely—literally. They registered a soft murmur in the trees. Above all, at night. At this time of day, most of the water is stored in the trunk, as the crown takes a break from photosynthesis and hardly transpires at all. The trees pump themselves so full of water their trunks sometimes increase in diameter. The water is held almost completely immobile in the inner transportation tubes. Nothing flows. So where are the noises coming from? The researchers think they are coming from tiny bubbles of carbon dioxide in the narrow water-filled tubes. Bubbles in the pipes? That means the supposedly continuous column of water is interrupted thousands of times. And if that is the case, transpiration, cohesion, and capillary action contribute very little to water transport.

So many questions remain unanswered. Perhaps we are poorer for having lost a possible explanation or richer for having gained a mystery. But aren't both possibilities equally intriguing?

END

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So many questions remain unanswered. Perhaps we are poorer for having lost a possible explanation or richer for having gained a mystery. But aren't both possibilities equally intriguing?

END

Figure E.3.1: Final portion of the passage as displayed in Study 1, with the last 0.5 pages visually blurred for all participants.

Instructions

- Write down important points, keywords, and any thoughts you have from the reading.
- It doesn't need to be organized and make sense for anyone else. This is only for your own reference and won't be reviewed by us.

Your Notes:

User ID:

Figure E.3.2: Note-taking form presented to Intervention Group 2 after reaching the natural breakpoint.

E.4 Study 2 Reading Passages (Texts A and B)

The full texts of both passages are reproduced below for content reference and for verification of the recall test items in Appendix E.5. Figures E.4.1 and E.4.2 show the final portions of Text A and Text B as they appeared on screen, with the last 0.5 pages visually blurred. Note-taking was not included in Study 2.

Text A

Source: Montgomery (2024), [14-16] (Flesch–Kincaid Reading Ease: 66.33).

1/4

From Monster to Superhero

I'd never met anyone like Athena before.

Though she was an adult, she was only about four feet (1.2 m) tall. She weighed a mere 40 pounds (18 kg). And she was unusual in several other respects. She could change color and shape, taste with her skin, drool venom, spit ink, and jet about by squirting water through a siphon[1] on the side of her head. Not to mention pour her baggy, boneless body through an opening the size of an orange. Her head wasn't even on top of her body, like mine. That spot was occupied by a body part known as the mantle[2], containing the organs of respiration, digestion, and reproduction. Her head was where you'd expect to find a torso[3]. And her mouth was in her armpit.

Athena was a giant Pacific octopus, an *Enteroctopus dofleini*.

We met at the New England Aquarium in Boston when senior aquarist Scott Dowd opened the heavy lid to her tank. Standing on a low step stool, I leaned over the water. The octopus changed from a mottled[4] brown to a bright red with excitement as she spilled her liquid body out of her rocky lair. "One of her glittering, silver eyes sought mine as her eight arms boiled up[5] to the surface to meet me. With Scott's permission, I plunged my hands and arms into the numbing, 47°F (8°C) salt water, and I let her engulf[6] my skin with her soft, questing[7], white suckers. She was both tasting and feeling me at the same time.

1 siphon: A tube-like structure that helps the octopus move by shooting out water.
2 mantle: The bag-like sac that sits above a cephalopod's eyes that contains its organs.
3 torso: The human body considered without head, arms, or legs.
4 mottled: Covered with areas of different colors that do not form a regular pattern.
5 engulf: To surround and cover something or someone completely.
6 questing: The activity of spending a long time searching for something that is difficult to find.

Most relationships don't begin with this degree of intimacy. Had a person begun tasting me at this early stage in our friendship, I'd have been alarmed.

And I realized, too, that not everyone would have liked being embraced by an octopus.

The water was cold, her skin was slimy, the creature I was touching was venomous—and I soon realized, as well, that when I got home later that day, I would have to explain to my husband why my arms were covered with hickeys[7].

But I was neither alarmed nor afraid. I was elated[8].

Athena didn't just welcome my company; she allowed me to touch her head. She had not allowed any visitor to do this before. And once we spent some time together, as she tasted me and I stroked her, she changed color again. She turned white beneath my touch—the color, I later learned, of an octopus who feels calm.

It was clear to me that during our encounter, we had shared an illuminating exchange. Athena, to my surprise, was just as inquisitive about me as I was about her.

"But aren't they monsters?" my human friend Jody Simpson asked me the next day as I described my encounter with Athena while we walked our dogs through the woods. Jody was a good friend to many animals. She shared her home with two poodles and a cat. She was an accomplished horseback rider. She loved feeding wild birds. But an octopus? How could you have any kind of communion[9] with

7 hickey: A temporary red mark on someone's skin, usually caused by suction.
8 elated: Extremely happy and excited.
9 communion: A close relationship with someone in which feelings and thoughts are exchanged

an octopus?

Indeed, centuries of Western literature have portrayed octopuses as oceangoing demons. "No animal is more savage in causing the death of man in the water," wrote Roman philosopher and commander Pliny the Elder around a.d. 77, "for it struggles with him by coiling round him and swallows him with sucker cups and drags him asunder[10]." Because they are so different from us, because some species can grow so large (several of the largest have topped 300 pounds [136 kg]), and because of their enormous strength (a single large sucker on a giant Pacific can lift more than 35 pounds [16 kg], and the animal has 1,600 of them), octopuses can frighten and confuse humans—or at least those humans who don't get a chance to know one.

Nearly two millennia after Pliny, filmmaker John Williams was still dissing[11] octopuses. "A man-eating shark, a giant poison-fanged moray, a murderous barracuda, appear harmless, innocent, friendly and even attractive when compared to the octopus," he wrote. "No words can adequately describe the sickening horror one feels when from some dark mysterious lair, the great lidless eyes stare at one…One's very soul seems to shrink beneath their gaze, and cold perspiration[12] beads the brow."

This is not what happened to me. I welcomed Athena's touch. Her slime coat was silky, like wet custard. Her skin was soft. The feel of her suction cups on my skin reminded me of little kisses. Athena's changing skin, her bridal-white

10 asunder: Into forcefully separated pieces
11 dis: To say or do something that shows a lack of respect for someone and is often intended to insult.
12 perspiration: Sweat

suckers, her alert gaze, her fluid grace: They all dazzled me with alien beauty.

I was mesmerized by her otherness. According to almost every basic classification of animal life, she and I were virtual opposites. She was a protostome—developing "as an embryo mouth first. I was a deuterostome, developing back-end first. She was an invertebrate, without bones. I was a vertebrate, scaffolded with a bony skeleton. She lived in water, I on land. She breathed water. I breathed air. The last time her kind and mine had shared a common ancestor, back half a billion years ago, everybody was a tube.

Yet I was also struck by an unexpected sameness. Despite the yawning[13] gap in our taxonomic classifications, it seemed possible that we could have a meeting of the minds. Perhaps we could even be friends.

And then, Athena began pulling me into her tank.

Equipped with hydrostatic muscles, more like those in our tongues than our biceps, an octopus of her size can, by some calculations, resist a pull 100 times her own weight. That would be 4,000 pounds (1,814 kg). I weigh 125 (57 kg). But again, I was not afraid. I felt no malice on her part. Her pull was insistent but gentle. I didn't worry she wanted to eat me. I was comfortably aware that her beak, located in her armpit, and its adjacent venom glands were nowhere near the arms that were pulling on mine. Her tenacious tug[14] was no threat. Instead, it was an invitation—one I was honored to accept.

END

13 yawning: used to describe a difference or amount that is extremely large.
14 tug: A sudden strong pull on something.

suckers, her alert gaze, her fluid grace: They all dazzled me with alien beauty.

I was mesmerized by her otherness. According to almost every basic classification of animal life, she and I were virtual opposites. She was a protostome—developing "as an embryo mouth first. I was a deuterostome, developing back-end first. She was an invertebrate, without bones. I was a vertebrate, scaffolded with a bony skeleton. She lived in water, I on land. She breathed water. I breathed air. The last time her kind and mine had shared a common ancestor, back half a billion years ago, everybody was a tube.

Yet I was also struck by an unexpected sameness. Despite the yawning[1] gap in our taxonomic classifications, it seemed possible that we could have a meeting of the minds. Perhaps we could even be friends.

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END

[1] yawning: used to describe a difference or amount that is extremely large.
[2] tug: A sudden strong pull on something.

Figure E.4.1: Final portion of Text A as displayed in Study 2, with the last 0.5 pages visually blurred.

Text B

Source: Hiraide & Selland (2014), [4-6] (Flesch–Kincaid Reading Ease: 65.05).

The Guest Cat

The little boy's triumphant[1] proclamation[2] must have been heard by the landlady inside the big house, for that evening we heard her talking in front of the neighbor's gate — "How'd you like to have a cat?"

The woman's dry voice was pressing. "It's just really too much for us," the voice went on, chatting blithely[3] about how cats infiltrated the premises from every corner, laying waste to the garden, raising a racket on the roof, and sometimes even leaving muddy paw prints inside the house.

The young housewife next door spoke in a voice both quiet and refined. One would think she would have been placed on the defensive, but after patiently listening to the eighty-year-old's pleas, it appeared she had no trouble holding her own. In all likelihood she could see the boy standing behind his grandmother and assumed he was praying for dear life. And in the end, it seems it was the old woman who lost out.

I remembered that just two years earlier when we'd signed the lease to rent the guesthouse from the old woman, there was a clause appended[4] to the agreement stating that no children or pets were allowed. Neither of us especially wanted a child at that point in our lives, even though we were on the verge of passing beyond our mid-thirties. And when it came to what are referred to as pets, neither of us especially liked cats, and the notion of owning a dog had

1 triumphant: Feeling or showing great success or victory.
2 proclamation: A public or official announcement.
3 blithely: Happily and without feeling or showing any worry, especially when there is a reason to be worried.
4 append: Attach or add to the end of something.

never even come up. So, you could say that based on the old woman's terms of occupancy, we were extremely well-suited renters.

There are a few cat lovers among my close friends, and I have to admit that there have been moments when that look of excessive sweet affection oozing from around their eyes has left me feeling absolutely disgusted. Having devoted themselves to cats' body and soul, they seemed at times utterly indifferent to shame. When I think about it now, rather than my not being a cat lover, it may simply have been that I felt a disconnect with people who were cat lovers. But more than anything, I'd simply never experienced having one around.

I had a dog once when I was a child. I felt my relationship with the dog was simple and frank. The tension felt through the leash between the one who obeys and the one who leads was refreshing.

I must have been right around the same age as the little neighbor boy when I was living with my family in a row house which acted as a residence for municipal workers, though the row houses looked more like tenements[5] in a slum[6] than public buildings. I had only just recently gotten the dog when somebody up and stole it. Most likely it was midafternoon on a Saturday or Sunday when my father noticed that the spitz[7], which had been tied up outside in front of the entry, was gone. "Dognappers[8] . . ." he

5 tenement: A large building divided into apartments, usually in a poor area of a city..
6 slum: A very poor and crowded area, especially of a city.
7 spitz: A type of dog that has a thick coat of hair.
8 dognapper: A person who steals a dog.

grumbled, then immediately began trying to counteract the event. He stormed out of the house, taking me along, and we raced around in every direction in search of the spitz, but there was no sign of either dog or dognapper. I remember clearly feeling that I shouldn't ask my father anything more about what had happened, seeing how he'd reacted when the dog went missing. My older sister insists I cried all night long, but I have no memory of that.

Although I myself did not especially like cats, my wife has an innate connection with all living things. From the time she was small, she would go out with her older brother to catch crawdads[9] and salamanders and keep them in an aquarium. She says she even hatched[10] butterflies of all kinds — they would fly around her room. She'd kept various kinds of birds, finches[11] and canaries, and had also raised chicks. She'd cared for baby birds that had fallen out of the nest as well and even nursed wounded bats back to health.

Even now she would turn on the TV to a nature program and could correctly name all of the animals, even rare species in faraway countries. In my wife's case, what I mean by not liking cats is something of an entirely different order than her husband's attitude, since all her life she had engaged with a variety of animals with the same level of interest. So, in other words, she did not have my sort of preference of dogs over cats. Once the cat had become the next-door neighbor's pet, it would often appear in the

9 crawdad: A small animal living in rivers that is similar to a lobster.
10 hatch: To (cause an egg to) break in order to allow a young animal to come out.
11 finch: Any of various types of small singing bird with a short, wide, pointed beak

garden in a new vermilion[12] collar, hung with a tinkling bell.

A simple wooden fence separated the yard of the main house and the little garden adjacent to the guesthouse — the two having originally been one. With its landscape of trees and little hills, pond and flower beds, the imposing garden of the main house was most agreeable to the cat. After first stepping into the guesthouse's small garden, the cat would set out on its own for the expanse[13] of the big house's yard.

Whenever the door to our small garden was left open, the cat was in the habit of peeking inside our house on its way to and from the main yard. The cat wasn't a bit scared of humans. But it was cautious — just a natural part of its behavior perhaps — and would gaze at us quietly with its tail standing straight in the air, yet it would never come inside. If we tried to pick it up outside, it would quickly run away, and if we tried to force it to let us hold it, it would bite. Aware of the ever-vigilant eye of the landlady, we made no real attempts to tame the cat.

These events unfolded between the autumn of 1988 and the beginning of winter, during the final months of the Showa Period[14].

END

12 vermilion: A bright red color.
13 expanse: A large, open area of land, water, or sky
14 Showa Period: A historical era in Japan during the reign of Emperor Hirohito (1926–1989).

garden in a new vermilion[12] collar, hung with a tinkling bell.

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These events unfolded between the autumn of 1988 and the beginning of winter, during the final months of the Showa Period[14].

END

12 vermilion: A bright red color.

13 expanse: A large, open area of land, water, or sky.

14 Showa Period: A historical era in Japan during the reign of Emperor Hirohito (1926–1989).

Figure E.4.2: Final portion of Text B as displayed in Study 2, with the last 0.5 pages visually blurred.

E.5 NASA-TLX


NASA-TLX Questionnaire
Q1. The NASA Task Load Index (TLX) survey is designed to assess the workload you experienced during the colour test you just completed.
Please use the sliders provided to rate each of the following six dimensions based on your experience.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Mental Demand: How mentally demanding was the task?
Very Low
Very High
Physical Demand How physically demanding was the task?
Very Low
Very High
Temporal Demand: How hurried or rushed was the pace of the task?
Very Low
Very High
Performance: How successful were you in accomplishing what you were asked to do?
Very Low
Very High
Effort: How hard did you have to work to accomplish your level of performance?
Very Low
Very High
Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?
Very Low
Very High

E.6 Big Five Inventory-2 (Study 1 only)

Big-Five Personality Questionnaire

Please enter the **Participant ID** provided by the researcher below:

Here are a number of characteristics that may or may not apply to you. For example, do you agree that you are someone who likes to spend time with others? Please mark one circle next to each statement to indicate the extent to which you agree or disagree with that statement.

Q1. Start each statement with "*I am someone who.....*"

	Disagree strongly	Disagree a little	Neutral, no opinion	Agree a little	Agree Strongly
1. Is outgoing, sociable.	○	○	○	○	○
2. Is compassionate, has a soft heart.	○	○	○	○	○
3. Tends to be disorganized.	○	○	○	○	○
4. Is relaxed, handles stress well.	○	○	○	○	○
5. Has few artistic interests.	○	○	○	○	○

	Disagree strongly	Disagree a little	Neutral, no opinion	Agree a little	Agree Strongly
6. Has an assertive personality.	○	○	○	○	○
7. Is respectful, treats others with respect.	○	○	○	○	○
8. Tends to be lazy.	○	○	○	○	○
9. Stays optimistic after experiencing a setback.	○	○	○	○	○
10. Is curious about many different things.	○	○	○	○	○

Q2. Start each statement with "*I am someone who.....*"

	Disagree strongly	Disagree a little	Neutral, no opinion	Agree a little	Agree Strongly
11. Rarely feels excited or eager.	○	○	○	○	○
12. Tends to find fault with others.	○	○	○	○	○
13. Is dependable, steady.	○	○	○	○	○
14. Is moody, has up and down mood swings.	○	○	○	○	○
15. Is inventive, finds clever ways to do things.	○	○	○	○	○

	Disagree strongly	Disagree a little	Neutral, no opinion	Agree a little	Agree Strongly
16. Tends to be quiet.	○	○	○	○	○
17. Feels little sympathy for others.	○	○	○	○	○
18. Is systematic, likes to keep things in order.	○	○	○	○	○
19. Can be tense.	○	○	○	○	○
20. Is fascinated by art, music, or literature.	○	○	○	○	○

Q3. Start each statement with "*I am someone who.....*"

	Disagree strongly	Disagree a little	Neutral, no opinion	Agree a little	Agree Strongly
21. Is dominant, acts as a leader.	○	○	○	○	○
22. Starts arguments with others.	○	○	○	○	○
23. Has difficulty getting started on tasks.	○	○	○	○	○
24. Feels secure, comfortable with self.	○	○	○	○	○
25. Avoids intellectual, philosophical discussions.	○	○	○	○	○

	Disagree strongly	Disagree a little	Neutral, no opinion	Agree a little	Agree Strongly
26. Is less active than other people.	○	○	○	○	○
27. Has a forgiving nature.	○	○	○	○	○
28. Can be somewhat careless.	○	○	○	○	○
29. Is emotionally stable, not easily upset.	○	○	○	○	○
30. Has little creativity.	○	○	○	○	○

Q4. Start each statement with "*I am someone who.....*"

	Disagree strongly	Disagree a little	Neutral, no opinion	Agree a little	Agree Strongly
31. Is sometimes shy, introverted.	○	○	○	○	○
32. Is helpful and unselfish with others.	○	○	○	○	○
33. Keeps things neat and tidy.	○	○	○	○	○
34. Worries a lot.	○	○	○	○	○
35. Values art and beauty.	○	○	○	○	○

	Disagree strongly	Disagree a little	Neutral, no opinion	Agree a little	Agree Strongly
36. Finds it hard to influence people.	○	○	○	○	○
37. Is sometimes rude to others.	○	○	○	○	○
38. Is efficient, gets things done.	○	○	○	○	○
39. Often feels sad.	○	○	○	○	○
40. Is complex, a deep thinker.	○	○	○	○	○

Q5. Start each statement with "*I am someone who.....*"

	Disagree strongly	Disagree a little	Neutral, no opinion	Agree a little	Agree Strongly
41. Is full of energy.	○	○	○	○	○
42. Is suspicious of others' intentions.	○	○	○	○	○
43. Is reliable, can always be counted on.	○	○	○	○	○
44. Keeps their emotions under control.	○	○	○	○	○
45. Has difficulty imagining things.	○	○	○	○	○

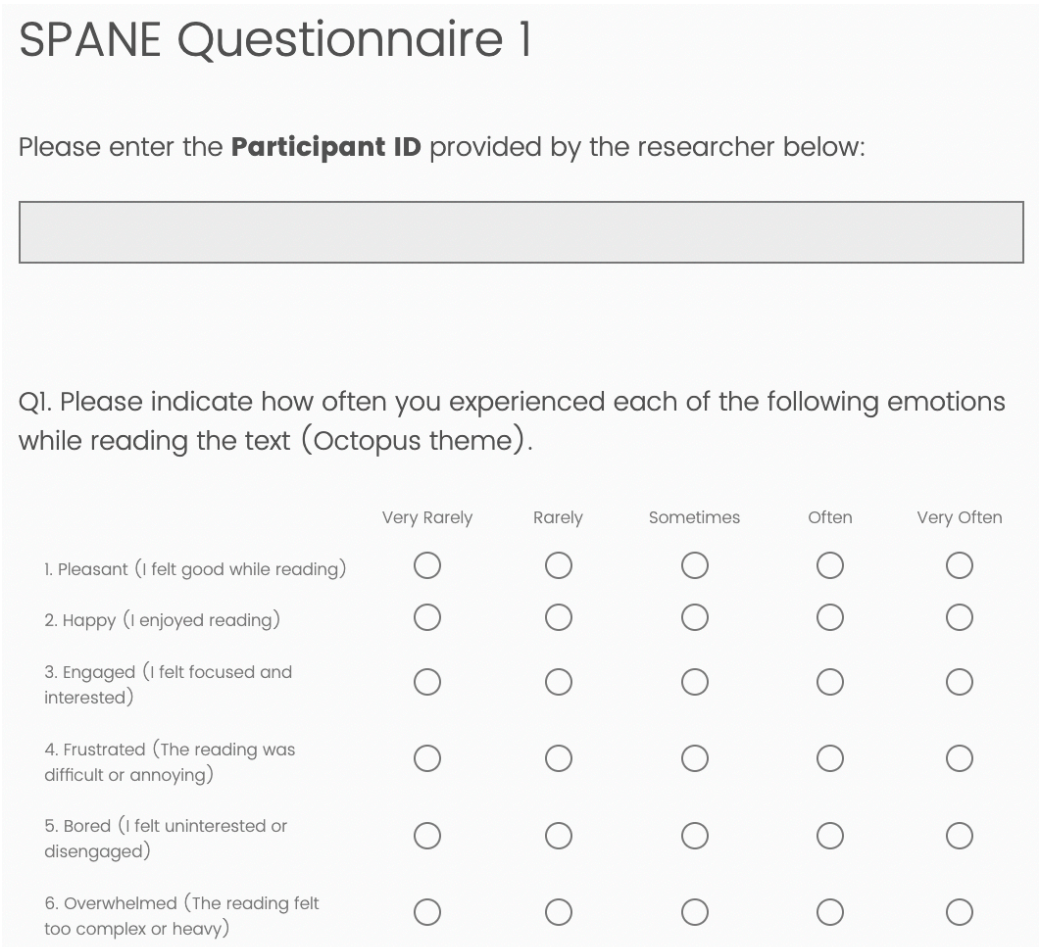
	Disagree strongly	Disagree a little	Neutral, no opinion	Agree a little	Agree Strongly
46. Is talkative.	○	○	○	○	○
47. Can be cold and uncaring.	○	○	○	○	○
48. Leaves a mess, doesn't clean up.	○	○	○	○	○
49. Rarely feels anxious or afraid.	○	○	○	○	○
50. Thinks poetry and plays are boring.	○	○	○	○	○

Q6. Start each statement with "*I am someone who.....*"

	Disagree strongly	Disagree a little	Neutral, no opinion	Agree a little	Agree Strongly
51. Prefers to have others take charge.	○	○	○	○	○
52. Is polite, courteous to others.	○	○	○	○	○
53. Is persistent, works until the task is finished.	○	○	○	○	○
54. Tends to feel depressed, blue.	○	○	○	○	○
55. Has little interest in abstract ideas.	○	○	○	○	○

	Disagree strongly	Disagree a little	Neutral, no opinion	Agree a little	Agree Strongly
56. Shows a lot of enthusiasm.	○	○	○	○	○
57. Assumes the best about people.	○	○	○	○	○
58. Sometimes behaves irresponsibly.	○	○	○	○	○
59. Is temperamental, gets emotional easily.	○	○	○	○	○
60. Is original, comes up with new ideas.	○	○	○	○	○

E.7 SPANE-6 Affective State Scale (Study 2 only)



SPANE Questionnaire 1

Please enter the **Participant ID** provided by the researcher below:

Q1. Please indicate how often you experienced each of the following emotions while reading the text (Octopus theme).

	Very Rarely	Rarely	Sometimes	Often	Very Often
1. Pleasant (I felt good while reading)	○	○	○	○	○
2. Happy (I enjoyed reading)	○	○	○	○	○
3. Engaged (I felt focused and interested)	○	○	○	○	○
4. Frustrated (The reading was difficult or annoying)	○	○	○	○	○
5. Bored (I felt uninterested or disengaged)	○	○	○	○	○
6. Overwhelmed (The reading felt too complex or heavy)	○	○	○	○	○

E.8 Study 1 Recall Test

Reading Recall Test

Please enter the **Participant ID** provided by the researcher below:

Multiple Choice Questions

For each questions Q1-Q4, select the option that best answers the question. Click on the circle next to your chosen answer.

Q1. What are the two commonly accepted explanations for how water is transported in trees?

- ◯ Capillary action and osmosis
- ◯ Capillary action and transpiration
- ◯ Osmosis and gravity
- ◯ Photosynthesis and suction
- ◯ I don't remember

Q2. Which process creates suction that pulls water up through the tree's transportation pathways?

- ◯ Capillary action
- ◯ Osmosis
- ◯ Transpiration
- ◯ Photosynthesis
- ◯ I don't remember

Q3. What recent discovery has led researchers to question traditional explanations of water transport in trees?

- ◯ Water evaporating from leaves even at night.
- ◯ Carbon dioxide bubbles found in the water tubes.
- ◯ Sugar levels in the tree reducing water movement.
- ◯ Leaves opening earlier in spring than expected.
- ◯ I don't remember

Q4. What does the author imply about the limitations of current scientific understanding of water transport in trees?

- ◯ We fully understand how water moves in trees.
- ◯ There are still mysteries surrounding water transport, and more research is needed.
- ◯ Trees don't actually need water transport mechanisms.
- ◯ Modern technology has provided all the answers we need.
- ◯ I don't remember

True/False Questions

For questions Q5-Q7, please indicate whether each statement is true or false by selecting the appropriate option.

Q5. Capillary action can explain how water moves up trees taller than 300 feet.

- ◯ True
- ◯ False
- ◯ I am not sure

Q6. Water pressure in trees is highest just before the leaves open in spring.

- ◯ True
- ◯ False
- ◯ I am not sure

Q7. The discovery of water movement at night challenges the traditional understanding that water only moves in trees during the day.

- ◯ True
- ◯ False
- ◯ I am not sure

Fill-in-the-Blank Questions

For questions Q8-Q9, type the correct word or phrase in the space provided to complete each sentence.

Q8. Transpiration occurs when trees release _ _ _ from their leaves and needles, creating suction to pull water upward.

Q9. The vessels in deciduous trees are about _ _ _ times wider than those in conifer trees, which affects how water moves through them.

Matching Question

For question Q10, drag the items on the left into the correct group on the right.

Q10. Match each process with its description:

Items

Transpiration

Capillary action

Osmosis

Water moves between cells to balance sugar concentration.
Water evaporates from leaves, creating suction.
Water moves up narrow tubes against gravity.

Short Answer Questions

For question Q11-Q12, provide a brief response to each question in the text box provided.

Q11. Why is osmosis unlikely to fully explain water movement in the trunk of trees?

Q12. What observation can be made when listening to a tree with a stethoscope during early spring, as described in relation to water transport?

E.9 Study 2 Recall Tests

Text A: Recall Test

Reading Recall Test

Please enter the **Participant ID** provided by the researcher below:

Multiple Choice Questions

For each questions Q1-Q4, select the option that best answers the question. Click on the circle next to your chosen answer.

Q1. Where did the author meet Athena, the octopus?

- ◯ At a marine research facility
- ◯ At the New England Aquarium
- ◯ While diving in the Pacific Ocean
- ◯ In a private home aquarium
- ◯ I don't remember

Q2. What unusual characteristic did Athena's body have compared to a human?

- ◯ Her head was located where a human torso would be
- ◯ She had a rigid exoskeleton instead of bones
- ◯ Her eyes were located on her tentacles
- ◯ She could breathe both in water and on land
- ◯ I don't remember

Q3. What colour did Athena turn when she became excited?

- ◯ Dark brown
- ◯ Deep blue
- ◯ Pale white
- ◯ Bright red
- ◯ I don't remember

Q4. What did the author realize when she first touched Athena?

- ◯ The octopus was trying to pull her into the water
- ◯ Athena was just as curious about her as she was about Athena
- ◯ The octopus was hostile and tried to bite her
- ◯ Athena immediately rejected her and swam away
- ◯ I don't remember

True/False Questions

For questions Q5-Q7, please indicate whether each statement is true or false by selecting the appropriate option.

Q5. The water in Athena's tank was warmer than room temperature.

- ◯ True
- ◯ False
- ◯ I am not sure

Q6. Athena had previously allowed visitors to touch her head before the author met her.

- ◯ True
- ◯ False
- ◯ I am not sure

Q7. The author had to explain to her husband why her arms were covered in marks after meeting Athena.

- ◯ True
- ◯ False
- ◯ I am not sure

Fill-in-the-Blank Questions

For questions Q8-Q9, type the correct word or phrase in the space provided to complete each sentence.

Q8. The author described Athena's suction cups as feeling like _ _ _ _ _ _ _ _ _ .

Q9. According to the passage, the octopus changed colour to _ _ _ _ _ _ _ _ _ _ _ _ when it felt calm.

Matching Question

For question Q10, drag the items on the left into the appropriate group on the right to match each person with their contribution or observation about Octopolis.

Q10. Match each anatomical feature of Athena with its correct function. Drag each item on the left to the correct description on the right.

Items	
Siphon	Contains organs for respiration, digestion, and reproduction
Suction cups	
Mantle	Used for jet propulsion by expelling water
	Allow tasting and feeling simultaneously

Short Answer Questions

For question Q11-Q12, provide a brief response to each question in the text box provided.

Q11. How did the author's friend react when she described her interaction with Athena?

Q12. Where was Athena's mouth located?

Text B: Recall Test

Reading Recall Test

Please enter the **Participant ID** provided by the researcher below:

Multiple Choice Questions

For each questions Q1-Q4, select the option that best answers the question. Click on the circle next to your chosen answer.

Q1. What was the landlady's complaint about the cats?

- ◯ They were scratching the furniture inside the house.
- ◯ They were stealing food from the kitchen.
- ◯ They were causing trouble in the garden and on the roof.
- ◯ She was allergic to them.
- ◯ I don't remember

Q2. What did the landlady try to convince the neighbour to do?

- ◯ Take in a cat.
- ◯ Move out of the neighborhood.
- ◯ Build a higher fence.
- ◯ Get rid of their dog.
- ◯ I don't remember

Q3. What was included in the rental agreement for the guesthouse?

- ◯ A rule prohibiting visitors.
- ◯ A strict curfew for tenants.
- ◯ A clause against children and pets.
- ◯ A requirement to take care of the landlady's garden.
- ◯ I don't remember

Q4. What was the narrator's attitude toward cats before having one around?

- ◯ They were indifferent but slightly disgusted by cat lovers.
- ◯ They had always wanted to own a cat.
- ◯ They loved all animals equally.
- ◯ They had a phobia of cats.
- ◯ I don't remember

True/False Questions

For questions Q5-Q7, please indicate whether each statement is true or false by selecting the appropriate option.

Q5. The guesthouse and the main house were originally part of the same property.

- ◯ True
- ◯ False
- ◯ I am not sure

Q6. The young housewife next door was easily pressured into taking the cat.

- ◯ True
- ◯ False
- ◯ I am not sure

Q7. The narrator's wife had little experience with animals before they moved into the guesthouse.

- ◯ True
- ◯ False
- ◯ I am not sure

Fill-in-the-Blank Questions

For questions Q8-Q9, type the correct word or phrase in the space provided to complete each sentence.

Q8. The narrator compared their relationship with their childhood dog to a balance between _ _ _ _ _ _ _ _ _ _.

Q9. The narrator felt a disconnect not with cats themselves, but with _ _ _ _ _ _ _ _ _ _. The fence separating the guesthouse and the main house was made of _ _ _ _ _ _ _ _ _ _.

Matching Question

For question Q10, drag the items on the left into the correct group on the right.

Q10. Match each object with its significance in the story.

Items	
The narrator's wife	Sought to shift responsibility but found herself entangled instead.
The little neighbour boy	Displayed an intrinsic connection with the world around her.
The landlady	Witnessed the unfolding events with quiet anticipation.

Short Answer Questions

For question Q11-Q12, provide a brief response to each question in the text box provided.

Q11. Why did the narrator hesitate to ask their father more about the missing dog?

Q12. How did the narrator know the cat had officially become a pet?

E.10 System Usability Scale (Study 1 only)

System Usability Scale Questionnaire

Please enter the **Participant ID** provided by the researcher below:

Q1. For each of the following statements, mark one circle that best describes your reactions to the End-of-section feature today.

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
1. I think that I would like to use this feature frequently.	○	○	○	○	○
2. I found this feature unnecessarily complex.	○	○	○	○	○
3. I thought this feature was easy to use.	○	○	○	○	○
4. I think that I would need assistance to be able to use this feature.	○	○	○	○	○
5. I found the various functions in this feature were well integrated.	○	○	○	○	○

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
6. I thought there was too much inconsistency in this feature.	○	○	○	○	○
7. I would imagine that most people would learn to use this feature very quickly.	○	○	○	○	○
8. I found this feature very cumbersome/awkward to use.	○	○	○	○	○
9. I felt very confident using this feature.	○	○	○	○	○
10. I needed to learn a lot of things before I could get going with this feature.	○	○	○	○	○

Q2. Please provide any comments about this feature:

Appendix F

ReasonScape Study Materials

F.1 Feedback Session Protocols

This appendix documents the protocols used for the two phases of expert evaluation reported in Chapter 6, Section 6.3. Phase 1 was conducted at the ACM CHI 2025 workshop on AI-augmented reasoning (Yokohama, 26 April 2025) with eleven participants. Phase 2 consisted of five ad-hoc expert interviews conducted between September and October 2025, four in person at the Faculty of Engineering and Computing, Dublin City University, and one remotely via Zoom.

Phase 1: Workshop Walkthrough Protocol (n = 11)

Materials used. Workshop poster (Appendix F.2), interface visuals shown he walkthrough scenario script as illustrated in Chapter 6, Section 6.2.3.

Session length. Approximately 15–20 minutes per participant.

Setting. Workshop poster session room (face-to-face).

Procedure.

1. Brief framing of ReasonScape (~5 minutes): overview of the problem (answer-first AI chat, automation bias, cognitive overload) and the design response.
2. Guided walkthrough of the example scenario (~5 minutes): showing when checkpoints appear, when a gap intervention card is triggered, and how ReflectRail and ReflectMeter update across the eight-step sequence.
3. Open discussion guided by the prompts below (~10 minutes).

Key discussion prompts.

- Do the checkpoints and gap cards feel helpful or annoying?
- Is it clear what the system is doing during the walkthrough?
- Are ReflectRail and ReflectMeter easy to follow?
- What could go wrong if people used this every day?

- Where do you see tensions between reflective support and conventional usability expectations?

Recording. Written notes were taken during and immediately after each session. Short verbatim quotations were captured where experts gave precise wording representing a broader point.

Phase 2: Ad-Hoc Expert Interview Protocol (n = 5)

Materials used. Same as Phase 1 (no working prototype).

Session length. Approximately 20–25 minutes per participant.

Setting. Four in-person sessions at the Faculty of Engineering and Computing, DCU; one remote session via Zoom.

Aim. To verify the main themes that emerged in Phase 1 and to sense-check implementation feasibility.

Procedure.

1. Brief framing of ReasonScape and reminder of the Phase 1 themes (~5 minutes).
2. Walkthrough of the example scenario (~5 minutes).
3. Focused discussion using the prompts below (~10–15 minutes).

Discussion prompts.

- Is the proposed interaction pattern realistic to implement with current technology?
- Which components (checkpoints, intervention cards, ReflectRail, ReflectMeter) would be hardest to implement reliably?
- How can the system decide when a flagged gap has actually been addressed, without that judgment feeling arbitrary?
- What would matter most for the system to remain usable across long or repeated conversations, for example, response speed, or keeping earlier summaries and labels consistent?

Recording. Written notes were taken during and immediately after each session, integrated into the same thematic synthesis as Phase 1.

F.2 Workshop Poster (CHI 2025)

AI THAT MAKES YOU THINK : DESIGNING SYSTEMS FOR GUIDED REASONING & REFLECTION?

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INTRODUCTION

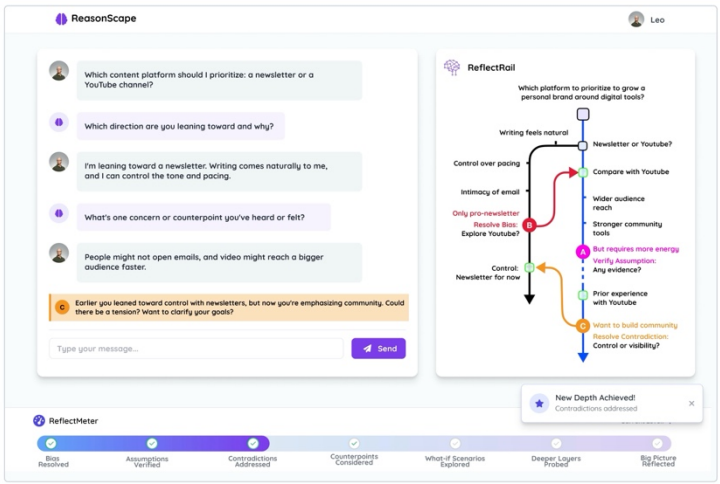
- Current AI-augmented reasoning systems often prioritize rapid, automated insights, potentially leading to cognitive overload and diminished critical thinking [1, 2].
- This work explores how AI can serve as a structured reasoning guide, actively shaping cognitive engagement through **guided reflection pauses**, **scaffolding reasoning skills**, and **tracking cognitive progress** [3].

COGNITIVE CHALLENGES

1. **Automation Bias and Over-Reliance:** Users may develop uncritical trust in AI-generated recommendations, reducing engagement in active reasoning [2, 4].
2. **Cognitive Overload:** Excessive information can overwhelm users, hindering deep engagement and leading to shallow processing [5].
3. **Shallow Processing:** Decisions are often made based on first impressions without considering assumptions or alternatives [6, 7].

These issues highlight a disconnect between AI's focus on efficiency and Engelbart's vision of systems that support and extend human reasoning [8].

DESIGN STRATEGIES FOR GUIDED REASONING & REFLECTION



1. Encourage metacognition through reflection pauses: AI prompts users to articulate their thinking before presenting suggestions. This reduces premature convergence and stimulates active engagement [9, 7].

2. Prompt users to explain their thinking: The system prompts users to reflect on assumptions, long-term outcomes, and opposing views—without requiring full-text inputs [10].

3. Visualize reasoning progress and patterns: A dedicated trail tracks the user's goals, reasoning shifts, and bias signals. By surfacing contradictions or conflicts (e.g., stated values vs. actions), users gain awareness of how their thinking evolves [11].

FUTURE WORK & QUESTIONS

- **Adaptive Prompting Logic:** How can AI systems dynamically tailor reflection prompts based on user behavior, cognitive load, or confidence levels—without creating friction or fatigue? [4]
- **Longitudinal Effects on Critical Thinking:** Can these design strategies foster lasting improvements in critical thinking and decision quality? [12]
- **AI-Supported Collaborative Reasoning:** How can structured reasoning tools extend beyond individual use to support collective thought processes, such as in team ideation, or multi-user deliberation? [13]

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Complete reference list with annotations available online:
Scan QR code to access all 13 citations and section mapping.

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Appendix G

Components Derived from the Three Designs

This appendix lists the 32 design components identified through the decomposition of the three core design studies: Attention Mode (C1–C10), SmartPause (C11–C18), and ReasonScape (C19–C32). Each component is described in terms of its intended aim, cognitive outcome, primary design move, trade-offs, usability tensions, and usability contributions.

Table G.1: Decomposition of the three design studies into 32 interaction components.

ID	Design	Design Component	Intended Aim	Cognitive Outcome	Design Move	Trade-off	Usability Tension	Usability Benefit	Cognitive Function
1	**Attention Mode**	**Simultaneous activation of multiple distraction reducing via a single trigger**	Reduce effort required to configure distraction-mitigating settings	Reduced decision load when entering a focused state	Bundle distraction-mitigating mechanisms	Possible mismatch between bundled protection and immediate needs	Flexibility and user control	Efficiency of use	**Executive Control (initiation):** Reduces the effort required to initiate a controlled focus state **Attention (sustained):** Immediately reduces need to actively resist interruption & switching
2	**Attention Mode**	**Cross-platform activation of distraction-mitigating features using a consistent interaction structure**	Reduce effort required to initiate a focused state	Reduced initiation cost for entering a focused state	Standardise access to distraction-mitigating features	May oversimplify context-specific needs	Flexibility across contexts	Consistency and standards	**Executive Control (initiation):** Reduces recall effort needed to engage control
3	**Attention Mode**	**Highlighting active sources of distraction and their cognitive impact**	Encourage continued use by increasing awareness of distraction effects	Improved monitoring of attentional risk	Make distraction sources and their cognitive consequences visible	May be ignored or normalised over time	Minimalist design	Informative feedback	**Metacognition (monitoring):** Improves monitoring by making threats to focus visible
4	**Attention Mode**	**Adjustable levels of distraction mitigation**	Match distraction mitigation intensity to task demands	Greater perceived control over attentional demands	Provide increasing levels of distraction mitigation	Increased configuration complexity	Simplicity / learnability	Flexibility of use	**Executive Control (allocation):** Provides options that reduce the need for rigid control over distraction **Attention (sustained):** Flexible mitigation levels help stabilise ongoing focus
5	**Attention Mode**	**User-adjustable expansion of distraction-mitigating features beyond the default baseline**	Enable flexible strengthening of distraction mitigation	Improved adaptability of attentional control to shifting priorities	Enable progressive expansion of mitigation scope	Increased configuration complexity; requires setup effort	Simplicity / learnability	Flexibility of use	**Executive Control (initiation):** Lowers the barrier to escalating mitigation when greater focus is required **Attention (sustained):** Stronger mitigation levels reduce interruption exposure, supporting more stable focus
6	**Attention Mode**	**Removal of non-essential interface clutter**	Reduce visual competition within the attentional field	Reduced distraction from non-task-relevant interface elements	Simplify the visual environment	Reduced access to secondary features or contextual information	Feature/content discoverability	Minimalist design	**Attention (selective):** Reduces competition between task-relevant content and non-essential interface elements **Executive Control (inhibitory control):** Reduces need to actively ignore irrelevant visual elements

7	**Attention Mode**	**Suppression of notifications when Attention Mode is active**	Prevent interruption events during focused activity	Reduced disruption of ongoing task engagement	Remove interruption sources during focused interaction	Delayed awareness of incoming messages or updates	User control and freedom	Minimalist design	**Executive Control (inhibitory control):** Reduces the need to suppress incoming notifications while focusing **Attention (sustained):** Eliminates interruption events that would break ongoing task engagement
8	**Attention Mode**	**Restricting switching to other applications while Attention Mode is active**	**Reduce task switching during focused activity**	Improved continuity of sustained attention during the task	Limit access to competing tasks during focused interaction	Reduced flexibility to access other applications	User control and freedom	None	**Executive Control (inhibitory control):** Encourages a deliberate decision about whether to continue the task or switch by requiring Attention Mode to be turned off before leaving the task **Attention (sustained):** Supports continuity of focus on the primary task by reducing impulsive task switching
9	**Attention Mode**	**Immediate deactivation of Attention Mode**	Avoid rigid restriction of interaction	Higher willingness to activate Attention Mode	Preserve reversibility of constrained interaction	Accidental toggling / exit	Error prevention	User control and freedom	**Executive Control (initiation):** Lowers hesitation to engage Attention Mode by ensuring users can easily exit the constrained state
10	**Attention Mode**	**Visibility of active Attention Mode state**	Make the active distraction-mitigation state visible to the user	Improved awareness of the current interaction state	Provide clear system status feedback	May be overlooked if too subtle, or contribute to visual distraction if overly prominent	Minimalist design	Visibility of system status	**Metacognition (monitoring):** Makes the current attentional environment visible to the user
11	**Smart Pause**	**Triggering support when disengagement occurs at non-natural breakpoints**	Signal when disengagement occurs away from meaningful content boundaries	Increased awareness of disengagement timing and reduced likelihood of stopping at non-natural boundaries	Intervene when disengagement occurs away from natural content boundaries	Slight delay in immediate exit	Efficiency of use	Informative feedback	**Metacognition (monitoring):** Signals when disengagement occurs away from a natural boundary, interrupting automatic exit and prompting awareness of disengagement timing
12	**Smart Pause**	**Explaining the rationale for continuing to a natural breakpoint**	Help users understand the cognitive benefits of continuing until a natural task boundary before disengaging.	Increased awareness of the benefits of stopping at natural boundaries, supporting motivation to follow the suggested breakpoint	Explain the cognitive benefits of disengaging at natural task boundaries	Adds a short explanatory step before exit	Efficiency of use	Informative feedback	**Executive Control (self-regulation):** Reduces the effort required to exert self-control to continue task until a natural breakpoint by explaining the cognitive benefits of doing so.

13	**Smart Pause**	**Marking precise reading position at pause**	Help users easily locate where they stopped reading	Reduced effort required to resume reading from the correct position	Provide explicit cues indicating the exact point of task interruption	Additional visual marker may slightly clutter the interface	Minimalist design	Visibility of system status	**Memory (offloading):** Offloads the need to remember the exact reading position, reducing memory load during task resumption and allowing attention to remain focused on the primary task
14	**Smart Pause**	**Restoring surrounding reading context on return**	Help users quickly reconstruct the text context and meaning when resuming	Easier task resumption and comprehension	Restore nearby content context to support task resumption	Additional content may momentarily increase visual complexity	Minimalist design	Recognition rather than recall	**Memory (retrieval):** Provides contextual cues that help reconstruct task meaning during resumption
15	**Smart Pause**	**Inviting lightweight summarisation**	Encourage users to briefly articulate the main idea before disengaging	Improved retention and consolidation of recently read content	Prompt brief reflection to consolidate meaning at task boundaries	Adds a short reflection step before exit	Efficiency of use	None	**Memory (encoding):** Supports consolidation of recently read information by prompting users to briefly summarise the main idea before disengaging
16	**Smart Pause**	**Allowing reflection to remain optional**	Preserve autonomy	Reduced resistance to reflection prompts and greater willingness to engage when beneficial	Offer reflection as an optional interaction rather than a required step	Users may skip reflection even when it could support learning or retention	None	User control and freedom	**Executive Control (self-regulation):** Supports voluntary engagement in reflection without imposing additional cognitive demands when users prefer to disengage
17	**Smart Pause**	**Linking notes to reading position**	Help users reconnect reflections with the specific part of the text they relate to	Improved recall of reflections and their associated reading context	Anchor reflections to the specific location in the task where they were created	Additional visual elements may slightly increase interface complexity	Minimalist design	Recognition rather than recall	**Memory (retrieval):** Provides location-based cues that support retrieval of reflections and associated task context
18	**Smart Pause**	**Allowing voice-dictated reflections**	Reduce effort required to capture reflections during disengagement	Increased likelihood of externalising reflections at breakpoints	Provide alternative input modalities to reduce effort of reflection capture	Modalities like voice input may not be suitable in all environments	None	Flexibility of use	**Memory (externalisation):** Reduces effort required to externalise reflections, supporting encoding of key ideas before disengagement
19	**Reason Scape**	**Segmenting AI responses into smaller reasoning units**	Reduce information overload in AI responses	Reduced cognitive load and improved comprehension during evaluation	Pace information delivery through smaller response units	Slower interaction flow compared to instant full responses	Efficiency of use	Minimalist design	**Working Memory (load management) → Reasoning:** Reduces information load to support deeper reasoning

20	**Reason Scape**	**Guided reasoning checkpoints embedded in the chat flow that prompt users to articulate goals, concerns, or constraints**	Slow premature commitment to AI suggestions and make reasoning explicit	More deliberate reasoning before accepting conclusions	Insert reflection pauses during reasoning flow	Adds interaction steps that may feel slower	Efficiency of use	Informative feedback	**Executive Control (inhibitory control) → Reasoning:** Prevents automatic acceptance of AI outputs by interrupting answer-following behaviour and requiring deliberate reflection before continuing
21	**Reason Scape**	**Intervention cards embedded in the chat flow that highlight reasoning gap)**	Reveal weaknesses or inconsistencies in reasoning	Improved awareness of gaps in the current reasoning	Surface reasoning gaps during interaction	May interrupt conversational flow	Efficiency of use	Help users recognise and diagnose errors	**Metacognition (monitoring) → Reasoning:** Prevents reasoning gaps from going unnoticed by making potential issues in the reasoning process visible during the interaction and prompting reconsideration before continuing
22	**Reason Scape**	**Placing reasoning interventions directly where issues emerge in the chat**	Enable timely reconsideration of reasoning gaps while context is visible	Earlier recognition and reconsideration of reasoning gaps	Embed reasoning interventions within the reasoning flow as issues emerge	Additional interface elements may increase visual complexity	Minimalist design	Visibility of system status	**Metacognition (monitoring) → Reasoning:** Prevents unnoticed reasoning breakdowns by surfacing issues at the moment they occur
23	**Reason Scape**	**Allowing users to revisit earlier reasoning points through the reasoning trail**	Support reconsideration and revision of earlier reasoning	Greater flexibility in revising earlier reasoning	Enable iterative revision of reasoning steps	May slow interaction as users revisit earlier steps and introduce additional interface elements that increase complexity.	Minimalist design	User control and freedom	**Executive Control (cognitive flexibility) → Reasoning:** Enables reconsideration of earlier reasoning by allowing users to revisit and revise prior reasoning steps.
24	**Reason Scape**	**Visual reasoning trail showing key reasoning steps and shifts across the interaction**	Maintain orientation during extended reasoning	Improved understanding of how reasoning evolves across the interaction	Externalise reasoning structure visually	Additional interface component may increase visual complexity	Minimalist design	Recognition rather than recall	**Metacognition (monitoring) → Reasoning:** Prevents loss of reasoning trace by making the progression of reasoning visible across the interaction, allowing users to monitor how their reasoning evolves.
25	**Reason Scape**	**Representation of branching reasoning paths on visual reasoning trail**	Enable comparison of alternative reasoning directions	Improved evaluation of alternative reasoning paths	Externalise alternative reasoning paths visually	May increase interface complexity	Minimalist design	Recognition rather than recall	**Reasoning (evaluation)**: Prevents narrow exploration of a single reasoning path by enabling comparison between alternative reasoning paths.

26	**Reason Scape**	**Visual reasoning trail highlighting flagged reasoning issues across the interaction**	Enable users to quickly locate where reasoning gaps occur	Maintained awareness of where reasoning gaps occur across the interaction	Visually mark reasoning gaps within the reasoning trail	Additional visual indicators may increase interface complexity	Minimalist design	Visibility of system status	**Metacognition (monitoring) → Reasoning:** Prevents users from overlooking reasoning gaps by keeping their location visible across the interaction, supporting more holistic evaluation of the reasoning process.
27	**Reason Scape**	**Status indicator showing whether reasoning gap categories are addressed or unresolved**	Help users track whether specific reasoning gap categories have been addressed	Improved awareness of unfinished reasoning work	Provide a visual summary of the status of reasoning gap categories	Additional interface element may increase visual complexity	Minimalist design	Visibility of system status	**Metacognition (monitoring) → Reasoning:** Prevents premature closure of reasoning by making unresolved reasoning gap categories visible across the interaction.
28	**Reason Scape**	**Acknowledgement when reasoning gap categories are addressed**	Encourage users to complete reasoning checks	Greater follow-through in addressing reasoning gaps	Use lightweight gamification cues to acknowledge completion of reasoning checks	Additional feedback signals may increase interface complexity	Minimalist design	Informative feedback	**Executive Control (self-regulation):** Prevents premature stopping of reasoning checks by using acknowledgement cues to reinforce continued engagement in evaluating reasoning.
29	**Reason Scape**	**Non-scoring feedback framing for reasoning interactions**	Avoid performance pressure during reasoning	Greater openness to exploratory reasoning	Provide supportive feedback rather than evaluation	Less explicit evaluation of reasoning quality	Efficiency of use	Informative feedback	**Executive Control (self-regulation):** Prevents performance pressure from discouraging deeper and more reflective reasoning
30	**Reason Scape**	**Allowing reflective reasoning steps to be skipped**	Preserve user agency during interaction	Greater willingness to engage with reflective reasoning steps	Offer reflection as optional rather than mandatory	Users may bypass useful prompts	None	User control and freedom	**Executive Control (self-regulation)**: Prevents resistance to reflective reasoning support by allowing users to retain control over whether to engage with it.
31	**Reason Scape**	**Framing reasoning guidance as suggestions rather than instructions**	Maintain user ownership of reasoning	Greater openness and willingness to engage with reflective reasoning	Provide suggestive guidance rather than prescriptive instructions	Users may ignore useful guidance	None	User control and freedom	**Executive Control (self-regulation):** Maintains willingness to engage with reasoning guidance by avoiding directive instructions that could trigger resistance.
32	**Reason Scape**	**Integrated reasoning anchors linking chat, reasoning trail, and reasoning gap indicators**	Ensure coherence across the reasoning workflow	Improved continuity of reasoning across long interactions	Provide persistent structural references	Additional interface structure may increase complexity	Minimalist design	Recognition rather than recall	**Metacognition (monitoring) → Reasoning:** Prevents fragmentation of reasoning across extended interactions by maintaining integrated reference points for the reasoning process.

Appendix H

Mapping of Principles and Guidelines to Existing Design Knowledge

The following tables map the six principles and their guidelines against bodies of design knowledge. Blue cells indicate that the principle's guidelines align with or extend the corresponding criterion. Orange cells indicate a direct conflict, where following the existing criterion would undermine cognitive resilience. Gray cells indicate that no guideline in the principle directly addresses the criterion. Colour saturation reflects the strength of the relationship: darkest = strong, mid = partial, lightest = weak.

Table H.1: Principles and Guidelines mapped to Nielsen's Five Usability Characteristics

Characteristic	P1 - Reduce Barriers to Engaging with Support	P2 - Preserve User Agency	P3 - Make Cognitively Relevant Risks Visible	P4 - Protect Attentional Continuity	P5 - Support Memory Continuity	P6 - Scaffold Deliberate Reasoning
Learnability	**Aligned – Strong** G2 helps users understand what the support addresses at first use. G4 lets users begin at the simplest level, reducing the initial learning burden.	**N/A** P2 addresses user control and framing during interaction, which is unrelated to how easily new users accomplish tasks for the first time.	**Aligned - Partial** G7's visibility of active cognitive risks helps users quickly form an accurate mental model of what the system monitors, supporting understanding on first use.	**Aligned - Weak** G9 removes non-essential interface elements during focused use, which may aid initial orientation. However, the learnability benefit is limited and indirect.	**Aligned - Weak** G11 preserves task position and surrounding context at the point of disengagement. This aids orientation when returning to a task but does not significantly help initial learning.	**Aligned - Weak** G13's structured information delivery reduces cognitive overload on first encounter, marginally supporting users' initial understanding of what the system expects from them.
Efficiency	**Aligned - Strong** G1 combines multiple controls into a single trigger, directly reducing interaction steps. G4 matches support intensity to task demand, avoiding unnecessary effort.	**Aligned - Strong** G5 ensures immediate deactivation and skippable steps, preventing features from adding unnecessary effort and allowing users to interact at their own pace.	**Conflict - Partial** G8 reduces the time needed to reorient during extended interactions by keeping the accumulated record visible, but the interface elements add visual complexity that works against efficiency.	**Aligned - Strong** G9 aims focused use, which directly reduces the effort required to maintain task engagement and allowing users to complete tasks more quickly.	**Conflict - Partial** G10 introduces a delay at disengagement and G12 prompts externalisation before exit, adding steps that conflict with efficiency, though G11 reduces resumption effort.	**Conflict - Strong** G13 slows information delivery to prevent passive acceptance. G14 interrupts at moments of likely shallow evaluation. Both directly conflict with efficiency by introducing friction as the mechanism of support.
Memorability	**Aligned - Weak** G3 lightweight reinforcement cues help users re-engage with cognitive resilience features after absence, without requiring relearning.	**N/A** P2 addresses user control and framing during interaction, which is unrelated to how easily users re-establish proficiency after a period of absence.	**Aligned - Strong** G8 keeps the accumulated reasoning trail and prior states accessible without requiring users to reconstruct them from memory.	**Aligned - Partial** Reducing interruptions during focused use limits encoding failures caused by distraction. Sustained attention supports better consolidation of task-relevant information into working memory.	**Aligned – Strong** G10, G11, and G12 directly support memory consolidation at the point of disengagement and reduce the reconstruction effort required when returning to a task.	**Aligned - Weak** G13 segmented delivery may aid recall of individual information units.

Characteristic	P1 - Reduce Barriers to Engaging with Support	P2 - Preserve User Agency	P3 - Make Cognitively Relevant Risks Visible	P4 - Protect Attentional Continuity	P5 - Support Memory Continuity	P6 - Scaffold Deliberate Reasoning
Errors	**Aligned - Weak** G2's visibility of cognitive consequences may indirectly reduce misuse by helping users understand what the support features address and how to engage with them correctly.	**Aligned - Partial** G5 reversibility ensures users are never locked into a constrained state, which functions as a direct error-recovery mechanism. However, immediate deactivation risks accidental exit.	**Aligned - Strong** G7 flags cognitively relevant risks as they arise, enabling users to identify and address issues before they affect the quality of reasoning or judgement.	**Aligned - Strong** G9 removes distractor stimuli from the interface during focused use, preventing attention-driven errors before they occur rather than relying on the user to suppress distractions.	**Aligned - Partial** G11 preserves context so users do not lose their place, preventing resumption failures.	**Aligned - Strong** G14 surfaces reasoning gaps and signs of shallow processing at the point where they occur. This directly prevents users from accepting outputs without sufficient evaluation.
Satisfaction	**Aligned – Partial** G3 and G4 reduce intimidation and performance pressure - users who feel comfortable and unpressured are more likely to find the experience rewarding.	**Aligned - Strong** G5 and G6 prevent the frustration and resistance that coercive design produces, leaving users feeling in control, a direct driver of satisfaction	**Conflict - Partial** G7 and G8 may add interface elements for the visibility of cognitive state and risk. When these are not well integrated, they risk increasing visual noise and reducing perceived clarity, undermining satisfaction.	**Conflict - Partial** G9 suppresses notifications and restricts switching during active use. Users who experience this as a loss of control rather than a useful constraint may find the interaction unpleasant	**Aligned - Partial** G11 reduces frustration caused by losing task context. The satisfaction benefit is real but less salient than the effects of agency or flow on user experience.	**Conflict - Partial** G13 and G14 introduce reflection prompts and structured pauses that, if poorly timed, can feel disruptive rather than helpful reducing the comfort of the interaction and making users less likely to engage with the support again.

Table H.2: Principles and Guidelines mapped to Nielsen's Ten Usability Heuristics and Shneiderman's Eight Golden Rules

Heuristic / Rule	P1	P2	P3	P4	P5	P6
H1 / R3 Visibility of system status	**Aligned – Partial** G2 makes cognitive costs visible at first use.	**N/A** P2 addresses user control and framing, not the visibility of system state.	**Aligned - Strong** G7 and G8 extend system status to cognitive state and accumulated interaction record.	**Conflict - Partial** G9 suppresses notifications during focused use, reducing the system feedback available to the user.	**Aligned - Strong** G11 extends status visibility to task-progress state, keeping users informed of where they are within a task.	**Aligned - Strong** G14 makes the current state of reasoning quality and gaps visible in real time.
H2 Match with real world	**Aligned - Weak** G2 and G3 frame cognitive consequences in everyday terms though alignment is indirect.	**Aligned – Partial** G6 frames support in familiar, real-world collaborative terms, positioning it as a partner rather than an authority.	**Aligned – Strong** G7 and G8 externalise cognitive engagement in relation to interaction, reflecting users' own experience.	**N/A** P4 addresses attentional continuity at the interaction level, not real-world conceptual mapping.	**N/A** P5 addresses cognitive continuity at task breaks and interruptions, not real-world conceptual mapping.	**Aligned – Partial** G13 and G14 mirror the natural cognitive rhythm of evaluating, though not all dimensions of H2 are addressed.
H3 / R6, R7 User control and freedom	**Aligned - Partial** G1 and G4 keep control with the user by minimising activation effort and offering increasing levels of engagement.	**Aligned - Strong** G5 supports H3 through immediate exit and skippable steps; G6 extends it to non-coercive framing.	**N/A** P3 addresses visibility of cognitive state and risk, not user control or freedom.	**Conflict - Strong** G9 restricts switching to other applications during focused use, directly and fully limiting user freedom.	**Aligned - Weak** G10 and G12 guide rather than restrict, preserving user freedom though alignment ois indirect.	**N/A** G13 and G14 affect information pace and delivery, not user control and freedom.
H4 / R1 Consistency and standards	**Aligned - Weak** G1 indirectly supports consistency by ensuring the same engagement pattern is available across contexts and platforms.	**N/A** P2 addresses framing and agency, not consistency and standards across the system.	**N/A** P3 addresses visibility of cognitive state and risk, not consistency and standards across the system.	**N/A** P4 addresses attentional continuity, not consistency and standards across the system.	**N/A** P5 addresses memory continuity at task breaks, not consistency and standards across the system.	**N/A** P6 addresses deliberate reasoning, not consistency and standards across the system.
H5 / R5 Error prevention	**Aligned - Weak** G2 makes cognitive consequences visible, which may indirectly help users avoid misusing support features.	**Aligned - Weak** G5's reversibility may indirectly prevent unintended engagement, but its primary focus is recovery.	**Aligned - Strong** G7 flags interaction risks as they arise, enabling users to address issues before cognitively relevant errors occur.	**Aligned - Strong** G9 suppresses sources of attentional interference during focused use, reducing the likelihood of errors before they occur.	**Aligned - Weak** G10 and G11 may reduce memory reconstruction failures by guiding disengagement and preserving task context.	**Aligned - Partial** G13 reduces cognitive overload, and G14 flags shallow evaluation as it occurs, lowering the risk of errors.

Heuristic / Rule	P1	P2	P3	P4	P5	P6
H6 / R8 Recognition rather than recall	**Aligned - Partial** G1 minimises activation effort by simplifying the engagement pattern, reducing the memory load required to recall how to activate support.	**N/A** P2 addresses user control and framing, not recognition or cognitive load reduction.	**Aligned - Strong** G8 externalises the accumulated interaction record, allowing users to recognise prior states and gaps rather than having to recall.	**N/A** P4 addresses attentional continuity, not recognition or memory load reduction.	**Aligned - Strong** G11 replaces recall of reading position and context with visible cues.	**N/A** P6 paces and interrupts information delivery, which is unrelated to recognition or memory load reduction.
H7 / S2 Flexibility and efficiency of use	**Aligned - Strong** G1 reduces interaction steps for all users and G4 offers increasing levels of support, accommodating both novice and experienced users.	**Aligned - Strong** G5 ensures cognitive resilience features add no unnecessary steps, regardless of users' experience level.	**Conflict - Partial** G7 and G8 add persistent interface elements that increase complexity, working against efficiency.	**Aligned - Strong** G9 suppresses interference during focused use, allowing users to complete the primary task more quickly.	**Conflict - Partial** G10 and G12 add steps at disengagement, conflicting with efficiency, though G11 reduces resumption effort.	**Conflict - Strong** G13 and G14 deliberately slow delivery and interrupt automatic processing, directly conflicting with efficiency.
H8 Aesthetic and minimalist design	**Conflict - Weak** G2 and G3 may add additional information and elements not required for task completion.	**N/A** P2 addresses user control and framing, not interface complexity or minimalist design.	**Conflict - Strong** G7 and G8 add risk indicators and elements that are not task-essential, conflicting with minimalist design.	**Aligned - Strong** G9 removes non-essential interface elements during focused use, implementing minimalist design.	**Conflict - Partial** G11 and G12 add lightweight contextual elements at task breaks that are not strictly task-essential.	**Conflict - Strong** G13 and G14 systematically introduce additional elements throughout the interaction.
H9 Recognise, diagnose, recover from errors	**N/A** P1 focuses on reducing activation effort, not on helping users recognise or recover from errors.	**Aligned - Strong** G5 enables immediate recovery when an unintended state is entered.	**Aligned - Strong** G7 enables users to recognise and address cognitively relevant risks in real time.	**N/A** P4 prevents attentional interference at the interface level, which is unrelated to recovering from errors.	**Aligned - Weak** G10 and G11 support recovery from task context loss, though this is not a conventional interface error.	**N/A** G13 and G14 intervene during processing to prevent reasoning errors, not after they have occurred.
H10 Help and documentation	**Aligned - Partial** G2 makes cognitive consequences visible to users when needed, reducing reliance on external documentation.	**N/A** P2 addresses user control and framing, not help or documentation.	**N/A** P3 addresses visibility of cognitively relevant state and risk, not help or documentation.	**N/A** P4 addresses attentional continuity, not help or documentation.	**Aligned - Partial** G10 highlights cognitive costs of leaving before a natural boundary, reducing reliance on external documentation.	**N/A** G13 and G14 pace and interrupt information delivery, which is unrelated to help or documentation.

Heuristic / Rule	P1	P2	P3	P4	P5	P6
R4 Design dialogs to yield closure	**Aligned - Weak** G3's acknowledgement cues provide a partial sense of progress and closure, though focus is sustaining engagement rather than signalling task completion.	**N/A** P2 addresses user control and framing, not task closure or completion signals.	**N/A** P3 addresses visibility of cognitively relevant state and risk, not task closure or completion signals.	**N/A** P4 addresses attentional continuity, not task closure or completion signals..	**Aligned - Partial** G10 guides users toward natural task boundaries, supporting a clear sense of closure at the end of a task sequence.	**Aligned - Weak** G13 structures information delivery into units that support a sense of progression, indirectly contributing to closure.

Table H.3: Principles and Guidelines mapped to Norman's Six Principles of Interaction Design

Principle	P1 - Reduce Barriers to Engaging with Support	P2 - Preserve User Agency	P3 - Make Cognitively Relevant Risks Visible	P4 - Protect Attentional Continuity	P5 - Support Memory Continuity	P6 - Scaffold Deliberate Reasoning
Visibility	**Aligned – Strong** See H1/R3 cell in Appendix 7.1.2.	**N/A** See H1/R3 cell in Appendix 7.1.2.	**Aligned - Partial** See H5/R5-P3 cell in Appendix 7.1.2.	**Aligned - Weak** See H5/R5-P4 cell in Appendix 7.1.2.	**Aligned - Weak** See H4/R1-P5 cell in Appendix 7.1.2.	**Aligned - Weak** See H5/R5-P6 cell in Appendix 7.1.2.
Feedback	**Aligned - Partial** See H1/R3-P1 cell in Appendix 7.1.2.	**N/A** See H1/R3-P2 cell in Appendix 7.1.2.	**Aligned – Strong** See H1/R3-P3 cell in Appendix 7.1.2.	**Conflict - Partial** See H1/R3-P4 cell in Appendix 7.1.2.	**Aligned – Strong** See H1/R3-P5 cell in Appendix 7.1.2.	**Aligned – Strong** See H1/R3-P6 cell in Appendix 7.1.2.
Constraints	**Aligned – Weak** See H5/R5-P1 cell in Appendix 7.1.2.	**Aligned – Weak** See H5/R5-P2 cell in Appendix 7.1.2.	**Aligned – Strong** See H5/R5-P3 cell in Appendix 7.1.2.	**Aligned – Strong** See H5/R5-P4 cell in Appendix 7.1.2.	**Aligned - Weak** See H5/R5-P5 cell in Appendix 7.1.2.	**Aligned - Partial** See H5/R5-P6 cell in Appendix 7.1.2.
Mapping	**Aligned - Partial** G2 extends Norman's mapping from control-to-function to behaviour-to-cognitive-effect while making the consequences of interaction visible.	**N/A** P2 addresses user control and framing, not the relationship between controls and their effects.	**Aligned – Strong** G7 and G8 map interaction behaviour to cognitively relevant information, extending Norman's mapping into the cognitive domain.	**N/A** P4 suppresses interface elements during focused use, which is unrelated to the relationship between controls and their effects.	**Aligned - Partial** G10 maps disengagement behaviour to its cognitive cost, making the relationship between task breaks and memory continuity visible.	**Aligned - Weak** P6 implicitly map reasoning behaviour to cognitive consequences (information volume to evaluation effort, interruption to insufficient evaluation) but these must be inferred.
Consistency	**Aligned – Weak** See H4/R1-P1 cell in Appendix 7.1.2.	**N/A** See H4/R1-P2 cell in Appendix 7.1.2.	**N/A** See H4/R1-P3 cell in Appendix 7.1.2.	**N/A** See H4/R1-P4 cell in Appendix 7.1.2.	**N/A** See H4/R1-P5 cell in Appendix 7.1.2.	**N/A** See H4/R1-P6 cell in Appendix 7.1.2.
Affordance	**Aligned – Partial** G1 reduces the execution cost of perceived actions, partially aligning with affordance.	**N/A** P2 addresses user control and framing, not the perceivability or executability of actions.	**N/A** P3 addresses visibility of cognitively relevant state and risk, not the perceivability or executability of actions.	**N/A** P4 suppresses interface elements during focused use, which is unrelated to the perceivability or executability of actions.	**N/A** P5 addresses memory continuity at task breaks, not the perceivability or executability of actions.	**N/A** P6 addresses deliberate reasoning, not the perceivability or executability of actions.