TÉCNICO LISBOA

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INSTITUTO SUPERIOR TÉCNICO

Towards an HCI Approach to Communicate and Engage with Climate Change: A Data Humanism Framework

Ana Marta Galvão Ferreira

Supervisor: Doctor Duarte Nuno Jardim Nunes

Co-supervisor: Doctor Valentina Nisi

Thesis approved in public session to obtain the PhD Degree in Digital Media

Jury final classification: Pass with Distinction

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Jury

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To my amazing parents and my awesome brother.
For always being there and making me who I am.
Aos meus espectaculares pais e ao meu fantástico mano.
Por estarem sempre presentes a fazerem de mim quem sou.

Acknowledgements

Contrary to common myth, the PhD journey is not a solitary one. Or at least, I had the privilege of having a very well-populated one. My fellowship had way more than nine companions and way, way more than just Ron and Hermione.

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All the love to my life friends, Angela, Ana, Vanda, Emanuel, Sara, Marisa, Elisabete,

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”

“End? No, the journey doesn’t end here.
Death is just another path, one that we all must take.
The grey rain-curtain of this world rolls back,
and all turns to silver glass, and then you see it.”

— Gandalf, The Return of the King
(*Istar*, Wielder of the Flame of Anor)

Abstract

Climate change is arguably the most urgent issue of our time. However, its communication has been focused on negative framings based on the mere presentation of data, in many cases demotivating or simply not helping in action. Recognising the critical challenge of effectively communicating the complexities of climate change, this research investigates the potential of data humanism to enhance engagement with climate change data through human-computer interaction (HCI).

Responding to gaps found in previous HCI and Design research in interactions for climate change, we propose and test a Data Humanism framework through continuous iterations of a data-story artefact, engaging diverse audiences in daily routine settings. The design of this artefact assisted in answering the defined research questions: RQ1: How have the fields of HCI and Design employed communication strategies, both theoretical and practical, to engage non-academic audiences with climate change subjects?; RQ2: How can data humanism contribute to creating positive and empowering engagements with climate change information?; RQ3: How can data humanism make climate change information more relatable and actionable at a human scale? The continuous iterations in the design were informed by evaluation studies targeting the defined research questions.

Findings indicate that adding layers of information to contextualise and link the data to user's knowledge and experiences helps engagement and relatability with climate change data. Also, solutions-oriented visualisations linked to the narrative create or reinforce a feeling of agency in climate matters and, therefore, the usefulness of the data. Furthermore, novel topics and contexts for the communication exchange enhance user interest in climate change topics. However, even though users appreciate the focus on action, the tested interactions with humanized data were insufficient to alter the person's general perception of the issue considerably. This latter result highlights the challenge of altering the hard-set bias of negative framing associated with climate change and the need for continuous engagement through action-focused and hopeful messages. Finally, AI features can deepen user engagement through empathy with the more-than-human characters. These interaction strategies need to be carefully planned and implemented.

These results have implications not only for future HCI and design research but also

for broader climate change engagement and communication.

Keywords: Human-computer interaction, Data visualization, Data humanism, Communication design, Climate change, Sustainability

Resumo

As alterações climáticas são um dos desafios mais urgente do nosso tempo. No entanto, a sua comunicação tem-se centrado em enquadramentos negativos baseados na mera apresentação de dados, em muitos casos desmotivando ou simplesmente não ajudando na ação. Reconhecendo o desafio crítico de comunicar eficazmente a complexidade das alterações climáticas, esta tese investiga o potencial da humanização de dados[1] para melhorar o envolvimento com dados sobre alterações climáticas através da interação humano-computador (IHC).

Respondendo a lacunas encontradas em trabalho anterior de IHC e Design em interações com temáticas relacionadas com as alterações climáticas, testámos esta nova abordagem através de iterações contínuas de um artefacto de comunicação de dados, envolvendo diversos públicos em contextos de rotina diária. O design deste artefacto ajudou a responder às questões de investigação definidas: 1) Como as áreas de IHC e Design têm aplicado estratégias de comunicação, tanto teóricas quanto práticas, para envolver públicos fora da academia com tópicos sobre alterações climáticas?; 2) Como a humanização de dados pode contribuir para a criação de interações positivas e empoderadoras com informação sobre alterações climáticas?; 3) Como pode a humanização de dados ajudar a tornar os dados sobre as alterações climáticas mais acionáveis e com uma "escala humana"? As iterações contínuas no design foram informadas por estudos de avaliação direcionados às questões de pesquisa definidas.

Os resultados dos estudos indicam que a adição de camadas de informação para contextualizar e ligar os dados ao conhecimento e às experiências dos utilizadores ajuda no envolvimento e na ligação com os dados sobre alterações climáticas. Além disso, as visualizações orientadas para soluções, ligadas à narrativa, criam ou reforçam um sentimento de agência em questões climáticas e, assim, a ideia de utilidade dos dados. Além disso, novos tópicos e contextos para a comunicações aumentam o interesse dos utilizadores em tópicos sobre alterações climáticas. Porém, embora os usuários apreciem o foco na ação, as interações testadas com dados "humanizados"foram insuficientes para alterar consideravelmente a percepção geral da pessoa sobre o assunto. Este último

[1] Proposta de tradução para *data humanism*.

resultado destaca o desafio de alterar o forte preconceito negativo associado às alterações climáticas e a necessidade de um envolvimento contínuo através de mensagens positivas e focadas em acção. Por último, recursos de IA podem aprofundar o envolvimento do usuário por meio da empatia com personagens mais-que-humanas. Estas estratégias de interação precisam ser cuidadosamente planeadas e implementadas.

Estes resultados têm implicações não só para futura investigação em IHC, mas também para o envolvimento e comunicação mais lato de temáticas relacionadas com as alterações climáticas.

Palavras-chave: Interação humano-computador, Visualização de dados, Humanização de dados, Design de comunicação, Alterações climáticas, Sustentabilidade

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Acronyms

ACM Association for Computing Machinery *(pp. 8, 9, 12, 23, 31, 44, 46)*
AI Artificial Intelligence *(pp. ix, xix, 99, 100, 105, 112, 121, 122, 125)*

CHI Conference on Human Factors in Computing Systems *(pp. 8, 9, 14, 110)*
COVID-19 Coronavirus Disease 2019 *(pp. 9, 29, 41, 54)*

DH Data Humanism *(pp. xix, 100–110, 112, 122, 188, 189)*
DIS ACM Conference on Designing Interactive Systems *(pp. 8, 9)*
DRS Design Research Society *(pp. 9, 31, 32, 44)*

HCI Human-Computer Interaction *(pp. ix, 1–3, 5–9, 11–16, 21, 23, 24, 26–31, 35, 37–40, 42, 44, 54, 55, 57, 59, 60, 67, 72, 82, 91, 92, 94, 95, 97, 98, 110, 113, 114, 117–119, 122–126)*

IASDR International Association of Societies of Design Research *(pp. 8, 9)*
IEA International Energy Agency *(p. 30)*
IEEE Institute of Electrical and Electronics Engineers *(pp. 44, 45)*
IFIP International Federation for Information Processing *(p. 31)*
IHC Interacção Humano-Computador *(pp. xi, xii)*
IMF International Monetary Fund *(pp. 62, 63, 67, 72, 82, 83, 85, 89, 120)*
IMI Intrinsic Motivation Inventory *(pp. xviii, 85, 86, 102, 110)*
IPCC Intergovernmental Panel on Climate Change *(pp. 6, 19–21, 41, 43)*
IxD Interaction Design *(pp. 6, 11, 12)*

LLM Large Language Model *(pp. 100, 105, 106, 121, 189, 192, 193, 206)*

RO Research Objective *(p. 4)*
RQ Research Question *(pp. ix, 4–6, 43, 44, 46, 81, 97, 102, 104, 106, 108, 117, 120–122)*
RtD Research through Design *(pp. xvii, 4, 59, 72, 76, 81, 83)*

SHCI Sustainable Human-Computer Interaction *(pp. xvii, 3, 11–13, 28, 38, 72, 93, 111, 112)*
SID Sustainable Interaction Design *(pp. 11, 12)*
SIG Special Interest Group *(pp. 44, 46)*
SIGCHI Special Interest Group on Computer-Human Interaction *(pp. 31, 32, 44)*
SIGCOMM Special Interest Group on Data Communications *(p. 44)*
SIGDOC Special Interest Group on Design of Communication *(p. 44)*
SIGGRAPH Special Interest Group on Computer Graphics and Interactive Techniques *(p. 44)*

T4C Transmedia for Change *(p. 94)*
TUI Tangible User Interface *(p. 27)*

UCD User-Centred Design *(pp. 57, 117)*
UN United Nations *(pp. 6, 57)*
UX User Experience *(p. 14)*

1

Introduction

This chapter delves into the inspiration driving this research endeavour, provides a glimpse into the objectives and inquiries guiding the research journey, and highlights the primary contributions that stem from it.

1.1 Motivation

Climate change represents a critical global challenge, intricately linked to human activities, necessitating immediate and collective action worldwide [157, 309]. The prevailing discourse on this issue is often marked by a sense of urgency and apocalyptic warnings, contributing to widespread public concern and anxiety [100, 187, 174, 64]. This context underscores the importance of effectively framing climate change communication, particularly for audiences outside the academic sphere, to make the information more accessible and relevant to their experiences [71]. In response to this situation, research and communication institutions are increasingly advocating a shift towards more optimistic and action-oriented communication strategies. This approach involves developing a visual vocabulary that extends beyond traditional imagery like melting ice and polar bears, aiming to engage the public more effectively [26, 235, 69, 209, 282].

Emerging research underscores the role of the HCI community in championing climate change discourse, emphasizing hope, meaning, and action [190, 175]. Yet, a gap persists in how environmental narratives are communicated to audiences [110]. The challenge of converting intricate climate data into understandable, actionable, and emotionally resonant concepts remains [107]. With studies offering varied perspectives on the efficacy of negative versus positive emotional framings, the urgency of this communication challenge grows ever-apparent [71]. In particular, the challenge of translating complex climate data into understandable concepts that are relevant to people's lives, highlighting the urgency of taking action without enhancing crisis fatigue or depression [64, 88], is still ongoing. Such a complex communication challenge demands further research and proposals of novel approaches. As a field, HCI has the unique advantage of leveraging technology to engage, educate, adapt, and immerse people in complex phenomena requiring collective action.

1.1.1 Author Positionality

In this section, I would like to point to some challenges that might arise from tackling such a complex topic, such as climate change, and how my own individual perspectives and lived experiences can influence the work. It is crucial to elaborate on my own positionality and its relation to this research.

Starting this research, I was personally interested in studying strategies to improve climate change communication and engagement but was unsure of the focus of this inquiry. In this work, I interpret "creating engagement" as "increasing interest with" the information. Being a communication designer by education and trade, I came across Lupi's ideas for data humanism by chance. Still, this approach deeply resonated with the gaps I had found in previous research and the communication needs for climate change topics. This motivated me to explore data humanism within HCI research.

I hold a degree in communication design and an MA in typography and editorial practices and was introduced to the field of HCI during my PhD. I now collaborate with a multidisciplinary team of engineers, designers, psychologists and neuroscientists. These intellectual affiliations have influenced the direction of the work, the databases and search terms used, the language incorporated in the research, and the themes highlighted during the analysis.

I live in a Southern European country. My personal contact with the consequences of climate change is limited, and I acknowledge the privileged position I live in. My research activities have taken place in Europe, and my social and geographical networks are in the global North. This context plays a significant role in shaping my understanding of climate change, even if I strived to have a global understanding of the issue. I therefore focused my work in the contexts that are familiar to me, both in the audience and in the focus of the research.

On a more personal note, my upbringing was very much connected with a business that is often mentioned in climate change mitigation – the food sector, in particular meat. My family owns a butcher shop business, and I've grown up witnessing the personal lives of hardworking individuals who have built a good life thanks to their very hard work in this business. In my interpretation, this context has led to a balance in the way I approach my research related to climate change: I acknowledge the need for urgent and radical change in the lifestyles of citizens and systems, particularly in the more carbon-emitter countries, but I also know that there are individual stories and motivations behind each person (oftentimes experiences of need and resilience). These must be considered in climate change discussions. Therefore, I hope that my work assists in working towards a more sustainable future, in its own modest contribution, but also does so considering nuance, dialogue and understanding.

1.2 Research Goals and Questions

This PhD thesis investigates how data humanism can be harnessed to enhance climate change communication and engagement through interactive experiences. It addresses the gaps and challenges in (sustainable) Human-Computer Interaction (HCI), climate change communication, and data humanism (Fig. 1.1). The research emphasizes the importance of orienting SHCI on climate change instead of a broader sustainability context to bring existential urgency and a unifying narrative to the many issues within the HCI field. This approach is motivated by the understanding that addressing climate change effectively can amplify and interconnect various political, economic, and environmental concerns, providing a comprehensive and cohesive framework for action and communication. The research scope is further described and discussed in chapter 2.

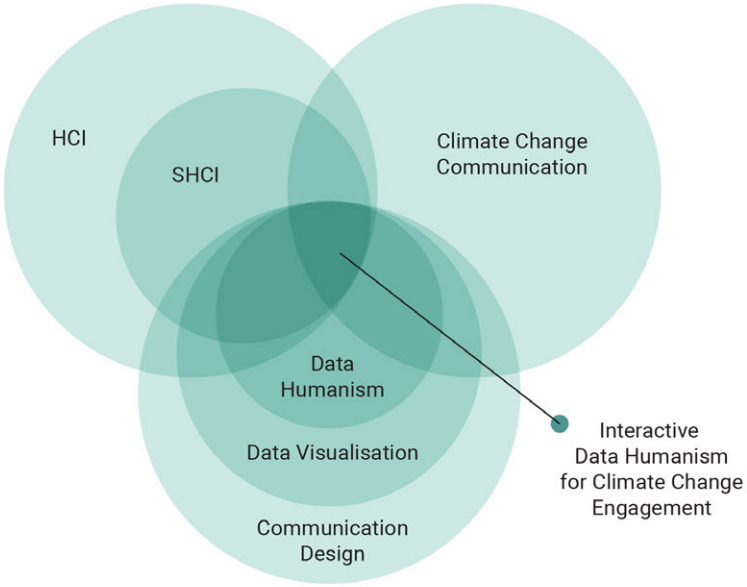

Figure 1.1: Research scope: the scope of the work sits within the knowledge gaps and research challenges of SHCI, climate change communication, and data humanism.

Since climate change is such an urgent global problem [157, 309], and public awareness is crucial in solving it, it is imperative to learn how to communicate these issues effectively. Also, since computing technologies are ubiquitous, they can and should play a crucial role in intermediating this dialogue between scholars and the general public. Based on previous work in SHCI related to climate change (described in 2.1), current climate change communication (described in 2.2), and further mapping of the landscape of interactive projects to audiences outside academia (Chapter 3.1), several gaps in previous work were identified. From these, data humanism [198] emerged as a promising approach to address them, as its aim is to create engaging and personalized data-driven visual narratives that link the numbers (quantitative data) to what they stand for: stories, knowledge, people, and behaviours [198, 197]. To formalise and test this approach within HCI, the following

research questions (RQ1-RQ3) and research objectives (RO1-RO3) were defined:
Research Questions:

- **RQ1:** How have the fields of HCI and Design employed communication strategies, both theoretical and practical, to engage non-academic audiences with climate change subjects? (Chapter 3)
- **RQ2:** How can data humanism contribute to creating positive and empowering engagements with climate change information? (Chapter 6)
- **RQ3:** How can data humanism make climate change information more relatable and actionable at a human scale? (Chapter 7)

Research Objectives:

- **RO1:** Conduct a comprehensive analysis of existing HCI and Design research on climate change interactions and communication strategies to identify gaps and inform future research directions.
- **RO2:** Develop and evaluate an interactive narrative focused on climate change for non-academic audiences to assess its effectiveness in fostering positive, action-oriented engagement and overcoming crisis fatigue.
- **RO3:** Refine and test the interactive narrative, evaluating the role of data humanism in increasing the relatability, interest, and perceived utility of climate change data among users.

Each high-level research question was further divided into more focused research questions to assist in planning each study. These questions are described in their respective chapter.

1.3 Research Overview

The present research intended to have a central applied component with an outlook towards a future "preferred state". Therefore, it was based on the Research through Design (RtD) approach as compiled and proposed by Zimmermann et al. [315, 314]. This approach "employs methods and processes from design practice as a legitimate method of inquiry" that follows the process of "iteratively designing artefacts as a creative way of investigating what a potential future might be" [315]. RtD allows for research on "wicked problems" [247] – complex social and cultural problems that involve conflicting views and multiple stakeholders – through a holistic and iterative framework based on the designer's natural work process. Therefore, the research design followed the following stages of the design process: (1) Grounding; (2) Ideation; (3) Iteration; (4) Reflection [314] – Fig. 1.2.

The first stage of the research, Grounding, consisted of mapping the state of the art on climate change-related HCI and Design projects created by the academic community. The focus lies on interaction projects created for the general public (outside academia), as that would be the focus of future artefacts (Chapter 3.1). A second mapping was performed to understand better current data visualisation strategies for climate change in the media. This was accomplished through the case study of a relevant current event – the Russia-Ukraine war (Chapter 3.2). These surveys were intended to help understand what was being done by the HCI academic community and broader media on communicating climate change and how they have been addressing particular interaction and communication choices – RQ1. The conclusions and implications for design derived from these surveys informed the next research phase.

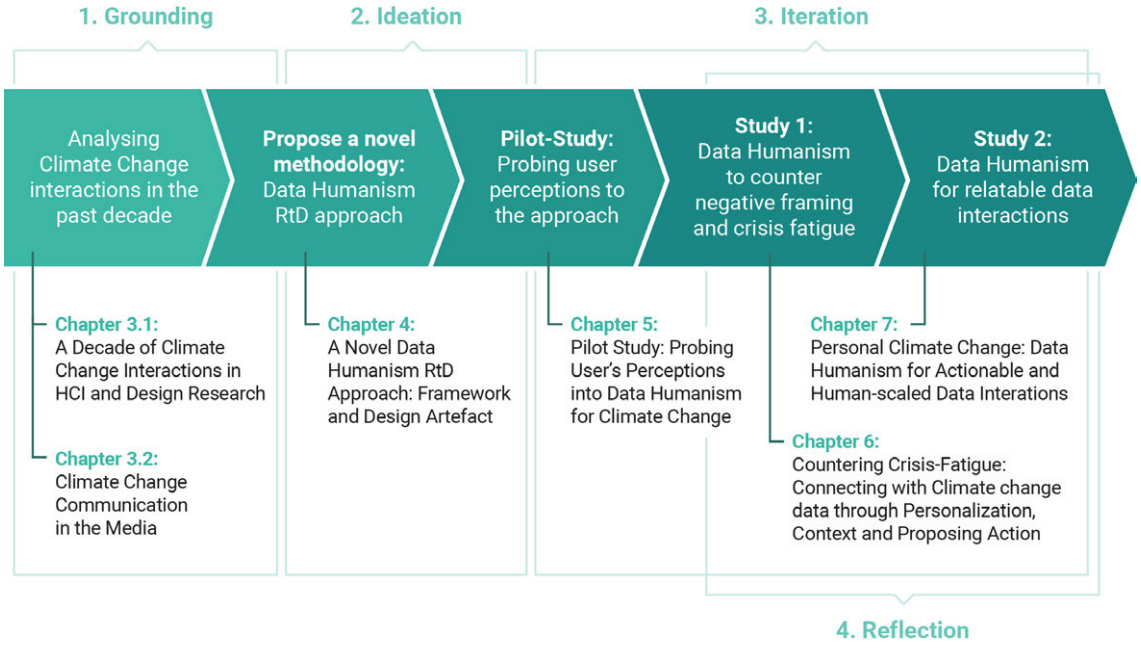

Figure 1.2: Overview of the iterative research process that is documented in this thesis. The coloured section shows the main stages of the work, typically involving an evaluation. The four RtD stages surround this section. Below each research stage is the corresponding chapter.

In the Ideation phase, I started by researching possible communication approaches that could help address the gaps found in previous work. Data humanism emerged as a promising communication strategy. This approach answered the needs that the surveys pointed to and went towards the calls by climate change international institutions regarding this topic's communication challenges (Chapter 2.2). Since data humanism was still a little explored approach within HCI and was based on Lupi's manifesto composed of broad proposals [198], I distilled design steps from her work and proposed a novel Data Humanism framework (Chapter 4). This methodology could then be used in future climate change projects.

To test the proposed framework and answer RQ2 and RQ3, a research artefact was developed following the Data Humanism framework. This interactive artefact consisted of its own research contribution, as in RtD, design relevant knowledge can be gained from the process of designing the artefact, in the artefact itself and in its testing [144]. This led to the Iteration phase – iterative refinements of the concept (Chapters 5-7). The artefact's several iterations were tested and evaluated in real-world contexts, each version learning from and building on the previous one. The various iterations of the artefact were used in empirical evaluation studies focusing on different aspects of data humanism as a communication approach (RQ2-3). The studies involved a mixed-methods approach, using self-reported measures, objective measures, and interviews. During these studies, Zimmerman et al.'s [314] proposed set of criteria for evaluating an interaction design (IxD) research contribution were considered:

- **Process** – *the rigour of the methods and documentation.* For rigorous research, the studies were carefully planned and the process and results were documented and published in relevant venues.
- **Invention** – *propose a novel application of different subject matters as to advance the state of the art.* This research proposes and implements a novel framework responding to gaps found in the field.
- **Relevance** – *frame the research within real-world contexts and justify the proposed preferred state.* This is done though a rigorous analysis of previous work in relevant fields of knowledge, as well as being guided by recent calls and proposals by international institutions (e.g. UN, IPCC).
- **Extensibility** – *the capacity to build on the outcomes of the research.* The proposed framework is intended as a flexible method for future application. Furthermore, the detailed documentation of the design process and user tests intends to allow for a continuous development of the research.

Finally, in the Reflection stage, the results were analysed and theory for design was produced through conclusions, design recommendations and guidelines for future design research. More specifically, the objective was to provide the HCI and Design research communities with information and guidelines on creating interactive communication projects for audiences outside academia and the effectiveness of the tested strategies. Furthermore, the conclusions of this research would have a multidisciplinary outreach as they could also be of interest to other communicators working on climate change topics.

The pronoun "we" is employed throughout this document as the presented work is a collaborative effort, involving contributions from a multidisciplinary team. My personal involvement encompasses all aspects detailed in the chapters, including the creation of artefacts, organizing evaluation studies, and analyzing and discussing the outcomes.

1.4 Contributions and Publications

Aligned with the overarching goal of harnessing data humanism to enhance climate change communication and engagement, the research has made the following contributions:

1. A collection of nine design implications derived from an extensive review of prior research work [110, 105, 108] and media communication [111], which served as foundational guidelines for the subsequent research in HCI and climate change communication.

2. The development of a novel Data Humanism framework [107], which integrates principles of data humanism into the design research process, aiming to make climate change data more engaging and actionable.

3. The creation of a Research Artefact named *Finding Arcadia*, which was developed using the proposed Data Humanism framework and informed by the earlier design implications. This artefact serves as a physical hypothesis [144] and a model for how complex climate data can be communicated in a more engaging and human-centric way.

4. A comprehensive evaluation of the successive iterations of the *Finding Arcadia* research artefact in real-world scenarios. This provided empirical insights into the effectiveness of the Data Humanism framework, demonstrating its potential applicability in practice and its relevance for future replicable research in enhancing public engagement with climate change issues (submissions under review).

The various stages of the work under the scope of this thesis have been published in the following articles:

Journal Publications:

- (Currently under revision) **Marta Ferreira**, Nuno Nunes, Pedro Galvão Ferreira, Henrique Pereira, and Valentina Nisi. Connecting Audiences with Climate Change: Towards Humanised and Action focused Data Interactions. International Journal of Human-Computer Studies.

Full Conference Papers / Pictorials:

- **Marta Ferreira**, Miguel Coelho, Valentina Nisi, and Nuno Jardim Nunes. 2021. *Climate Change Communication in HCI: a Visual Analysis of the Past Decade.* In Proceedings of the 13th Conference on Creativity and Cognition (C&C '21). Association for Computing Machinery, New York, NY, USA, Article 5, 1–16. https://doi.org/10.1145/3450741.3466774

- **Marta Ferreira**, Valentina Nisi, and Nuno Nunes (2022). *Interaction for Crisis: A Review of HCI and Design Projects on Climate Change and How They Engage with the General Public.* In: Bruyns, G., Wei, H. (eds) [ ] With Design: Reinventing Design Modes. IASDR 2021. Springer, Singapore. https://doi.org/10.1007/978-981-19-4472-7_56

- **Marta Ferreira**, Nuno Nunes, and Valentina Nisi. 2021. *Interacting with Climate Change: A Survey of HCI and Design Projects and Their Use of Transmedia Storytelling*. In Interactive Storytelling: 14th International Conference on Interactive Digital Storytelling, ICIDS 2021, Tallinn, Estonia, December 7–10, 2021, Proceedings. Springer-Verlag, Berlin, Heidelberg, 338–348. https://doi.org/10.1007/978-3-030-92300-6_33

- **Marta Ferreira**, Valentina Nisi, and Nuno Nunes. 2023. *Interactions with Climate Change: a Data Humanism Design Approach.* In Proceedings of the 2023 ACM Designing Interactive Systems Conference (DIS '23). Association for Computing Machinery, Pittsburgh PA USA, 1325–1338. https://doi.org/10.1145/3563657.3596003

- **Marta Ferreira**, Nuno Nunes, Chiara Ceccarini, Catia Prandi, and Valentina Nisi. 2023. *The Russia-Ukraine war and climate change: Analysis of one year of data-visualisations.* In De Sainz Molestina, D., Galluzzo, L., Rizzo, F., Spallazzo, D. (eds.), IASDR 2023: Life-Changing Design, 9-13 October, Milan, Italy. https://doi.org/10.21606/iasdr.2023.431

- **Marta Ferreira**, Nuno Nunes, and Valentina Nisi. *Towards Relatable Climate Change Data: Untangling Tensions in Engaging with a Hyperobject*. In Proceedings of the 2024 ACM Designing Interactive Systems Conference (DIS '24). Association for Computing Machinery, Copenhagen, DK. https://doi.org/10.1145/3643834.3661606

Workshop Papers:

- **Marta Ferreira**, Valentina Nisi, and Nuno Nunes (2022). *Designing Positive, Human and Personal HCI Strategies to Engage with Climate Change Data.* In: Viz4Climate: High-Impact Techniques for Visual Climate Science Communication. VIS 2022. Oklahoma City.

- **Marta Ferreira**, Valentina Nisi, and Nuno Nunes (2022). *Finding Arcadia: a data humanism interactive data-story for action-focused climate change engagement.* In: HCI for Climate Change: Imagining Sustainable Futures. CHI 2023. Hamburg.

Doctoral Symposium Publications:

- **Marta Ferreira**, Valentina Nisi, and Nuno Nunes (2022). *Designing HCI Strategies to Communicate and Suggest Action for Climate Change Mitigation.* In: Bruyns, G., Wei, H.

(eds) [ ] With Design: Reinventing Design Modes. IASDR 2021. Springer, Singapore. https://doi.org/10.1007/978-981-19-4472-7_240

- **Marta Ferreira**, Valentina Nisi, and Nuno Nunes (2022). *Designing Positive, Human and Personal HCI Strategies to Engage with Climate Change Data.* DRS 2022. Bilbao.

Finally, several additional contributions were made during the research period unrelated to the primary topic of investigation. As these pertain to different lines of inquiry, they are not included in this document.

- Shuhao Ma and **Marta Ferreira**, Hugo Nicolau, Catia Prandi, Augusto Esteves, Nuno Jardim Nunes, and Valentina Nisi. 2022. *Catering for Students' Well-being during COVID-19 Social Distancing: a Case Study from a University Campus.* In Proceedings of the 2022 ACM Conference on Information Technology for Social Good (GoodIT '22). Association for Computing Machinery, New York, NY, USA, 146–153. https://doi.org/10.1145/3524458.3547261

- Chiara Ceccarini, **Marta Ferreira**, Catia Prandi, Nuno Nunes, and Valentina Nisi. 2023. *Unusual suspects - visualizing unusual relationships of complex social phenomena with climate change.* In Proceedings of the 2023 ACM Conference on Information Technology for Social Good (GoodIT '23). Association for Computing Machinery, New York, NY, USA, 494–503. https://doi.org/10.1145/3582515.3609572

- Sabrina Scuri, **Marta Ferreira**, Nuno Jardim Nunes, Valentina Nisi, and Cathy Mulligan. 2022. Hitting the Triple Bottom Line: Widening the HCI Approach to Sustainability. In Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22). Association for Computing Machinery, New York, NY, USA, Article 332, 1–19. https://doi.org/10.1145/3491102.3517518

- Miguel Ribeiro, Nuno Nunes, **Marta Ferreira**, João Nogueira, Johannes Schöning, and Valentina Nisi (2021). *Addressing the Challenges of COVID-19 Social Distancing Through Passive Wi-Fi and Ubiquitous Analytics: A Real World Deployment*. In: Ardito, C., et al. Human-Computer Interaction – INTERACT 2021. INTERACT 2021. Lecture Notes in Computer Science(), vol 12933. Springer, Cham. https://doi.org/10.1007/978-3-030-85616-8_1

- Cláudia Silva, Catia Prandi, **Marta Ferreira**, Valentina Nisi, and Nuno Jardim Nunes. 2019. *See the World Through the Eyes of a Child: Learning from children's cognitive maps for the design of child-targeted locative systems.* In Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19). Association for Computing Machinery, New York, NY, USA, 763–776. https://doi.org/10.1145/3322276.3323700

- Cláudia Silva, Catia Prandi, **Marta Ferreira**, Valentina Nisi, and Nuno Jardim Nunes. 2019. *Towards Locative Systems for, and by, Children: A Cognitive Map Study of*

Children's Perceptions and Design Suggestions. In Proceedings of the 2019 Conference on Creativity and Cognition (C&C '19). Association for Computing Machinery, New York, NY, USA, 382–395. https://doi.org/10.1145/3325480.3326568

1.5 Document Structure

The remainder of this document is structured as follows. **Chapter 2** describes the theoretical background that supports the proposal of the novel Data Humanism framework. It discusses human-computer interaction and climate change (subsection 2.1), climate change communication (subsection 2.2), and data humanism (subsection 2.3). **Chapter 3** presents two mappings of previous work that ground and inform the following research. First, a survey of interaction projects related to climate change from 2010 to 2020 (subsection 3.1), followed by a survey of climate change communication in the media through the case-study of the Russia-Ukraine war (subsection 3.2). This research led to implications for future work described in each section. **Chapter 4** presents the novel Data Humanism framework responding to the gaps and implications from previous stages and exemplifies its application through the design of the *Finding Arcadia* artefact. **Chapter 5** focuses on the pilot study in the wild, probing users' perceptions of the data humanism strategies used. **Chapter 6** describes the first main study in the wild, using a revised artefact iteration and focusing on data humanism to counter negative communication and crisis fatigue. **Chapter 7** presents the third iteration of the artefact and the second main study in the wild, focusing on using data humanism for relatable climate data interactions.

Finally, **Chapter 8** presents a research summary and findings of the work developed, describing limitations and future directions.

2

Theoretical Background and Related Work

This chapter is divided into the three main areas that informed the research. First, the chapter describes sustainable HCI (SHCI) and the recent shift of orienting it towards climate change. This includes an overview of the field, examples of research relevant to our study, and recent discussions around SHCI and posthumanistic approaches. Secondly, the chapter focuses on climate change communication, its challenges and how the topic has been communicated in general and within the HCI community. Lastly, we analyse data visualisations and data humanism, focusing on how these methods have been used within the HCI field.

2.1 Human-Computer Interaction and Climate Change

2.1.1 Sustainable Human-Computer Interaction (SHCI)

Sustainability should be one of the core focuses of HCI – materialized through, particularly, Sustainable Human-Computer Interaction (SHCI) or Sustainable IxD (SID) – and it has been one of the growing areas of activity in HCI research [32]. The possibilities and responsibilities of the HCI community related to sustainability have been debated for years [205]. SHCI has been committed, particularly, to minimizing the environmental impacts of computing technologies and influencing sustainable behaviours [30, 310]. Blevis described the IxD community [30, 32] as being mainly concerned with two mutually dependent perspectives: design criticism – understanding present practices and informing future ones – and critical design – the actual practice of design with the purpose of promoting sustainable living. Furthermore, discussions looked at the future implications of integrating sustainable principles into current designs [32], as well as the potential of moulding possible futures connected with the broader societal impact and relevance of IxD [102].

Mankoff et al. [205] continue the debate on HCI's role and responsibility regarding sustainability. They categorised SHCI as *sustainability in design* – mitigating effects and

optimizing hardware and software to be more sustainable (energy use; device re-use; reduction of waste; enabling sharing of devices or energy sources) –, and *sustainability through design* – by supporting and influencing behaviour and lifestyles (individual level; group level; societal level). A few years later, DiSalvo and colleagues [86] presented a comprehensive review of the different approaches taken in SHCI. The following genres in SHCI were identified: a) Persuasive technology; b) Ambient awareness; c) Sustainable IxD; d) Formative user studies; and e) Pervasive and Participatory Sensing. They also noticed redundancy in the field, as well as disparities in assumptions and approaches, and little connection to sustainability work outside the field.

In 2014, Silberman et al. identify that little was done in the meantime to "explicitly address the conceptual inconsistencies in the field" [265]. A workshop was created to help address this oversight and, from it, lessons and next steps were derived. They propose that sustainability should be seen as a practical ethical imperative, not as an appealing research topic. As next steps to promote sustainability in HCI, they suggest: i) Specify and operationalize sustainability goals in our work and articulate approaches to evaluating our work in view of those goals; ii) Do research that considers longer time scales; iii) Draw from and support relevant work outside HCI; iv) Build and support systems people use in their everyday practices, and do studies that inform the design and operation of such systems; v) Address the full diversity of sustainability issues; vi) Move beyond simple models to grapple with the full multi-scalar complexity of "wicked" sustainability problems.

Wakkary et al. also point to the importance of SHCI, more specifically, SID, being informed by areas outside HCI and the need to move away from its typical focus on the individual user or artefacts. They propose to position SHCI within a framework of social practices and to focus on practice as the object of study for a more holistic approach [294]. Furthermore, they offer the idea of design fictions – narratives, propotypes, and concepts – as the designer's response to social practices, a response based on making and doing informed by practice theory.

Recently, concerns about sustainable HCI's approaches, and in particular when applied to climate change, resulted in a proposed shift in perspectives and a call to action from the academic community. This proposed change in focus is discussed in the following section.

2.1.2 HCI and the Shift from Sustainability to Climate Change

In-depth debate on climate change and HCI is relatively recent. Mankoff et al.'s 2007 paper mentioned previously [205] presents their goals as raising awareness on climate change consequences and "*start* a conversation about the possibilities and responsibilities we have to address issues of sustainability" [emphasis added]. However, during the past decade, interest and focus on climate change-related research in HCI has risen considerably. For instance, searching the ACM Digital Library for the term "climate change" returned

295 results from January 1991 to December 2009 and 2,282 results from January 2010 to December 2020. The growth and focus in this topic are evident.

The complexity of climate change cannot be solved by changing individual action alone [303]. The considerable focus on persuasion and its limiting factors have been questioned (e.g. [47]), as well as the focus on individual behaviour (e.g. [86]) or on incremental instead of systemic change (e.g. [90]). A growing faction of the SHCI community argues that the onus needs to shift from the individual user to broader concepts and applications [33, 116, 142, 175], focusing on community [82], and challenging current economic systems or pushing for other system changes [90, 119, 36]. The need to empower and support civic and collective action demands the design of interactive systems with a strong social component [184], working towards civic and participatory design practices [63, 83, 84], and political mobilization [176]. Diverse approaches are being proposed. Transition Design [281] emerged as one approach that directly considers the complexity of the many wicked problems we face as a global society. It promotes a design-led transition towards more sustainable futures that is more place-based, participatory and connected to the natural environment [283]. Other approaches, such as design futuring [122], sustainment [120] and speculative design [269], challenge designers to consider the future of their designs and explore complex problems.

Considering the complex challenges posed by climate change, in 2018, Knowles et al. [175] proposed a new vision for SHCI, calling for the HCI community to orient around *climate change* rather than the more expansive and multidimensional concept of *sustainability*. This reasoning originates from Klein's argument that climate change offers a critical unifying narrative that keeps us focused on pressing existential issues [172]. Fifteen years after the emergence of SHCI, Bremer et al. identified a shift from a focus on individual behaviour change towards the design with and for communities (context-oriented) and the increased use of speculation and reflection instead of prescription [42]. This leads to difficulty in measuring impact and questioning if opening design spaces don't pass the responsibility of application and evaluation to future researchers.

Discussions around the role and responsibilities of SHCI, especially when it comes to addressing climate change, are diverse and ongoing. A need for meaning, fulfillment and hope in times of existential crisis asks designers to question *what* and *how* they design so as not to add to a passive and limited digital landscape [190]. Questions surrounding the unsustainability of digital technologies, in particular, data-driven ones [195], have led researchers to call for "more meaningful" digital experiences [301]. Each practice-based SHCI project should clearly define or design specific sustainability objectives and measurements [265], and be transparent about its strategies and materials [294]. The relationship between humans and nature has also been a topic of extensive debate when discussing HCI and climate change. For instance, Liu et al. [193] propose an alternative framing to the dominant SHCI models of "correction" of human behaviour or "control" of resource consumption inspired by permaculture's philosophy of working *with* nature, emphasising human cooperation instead of control. Likewise, Vella et al. [291] explore

a deepening of human-nature relations through care and curiosity. The relationship of humans and nature within HCI is further discussed in section 2.1.4.

2.1.3 Interactions for Climate Change in HCI Research

One of the latest discussions around the future of HCI and climate change took place in April 2023 at the CHI Conference [213] with a focus on data communication and public engagement. This highlights the open-ended nature of HCI's role within climate change-related interventions and the growing responsibility of the field to build awareness and connection with this complex topic. This prolific activity and debate represents HCI's interest in climate change and the continuous search for better approaches and applications. The challenge comes in how to translate these theories into actionable design practice [192, 267]. As examples of public engagement within HCI research related to climate change, we point to several projects with particular connections to the previous discussion, demonstrating strategies focused on action, relation to community, or concern about how to relate to a particular audience. *RisingEMOTIONS* [7] leveraged the impact of emotions and a sense of community to communicate the threats of sea level rise. This work engaged a local community in critical discourse through public interventions and guided the audience to future action by connecting them to local organizations [236]. *Smart Citizen* [236] also focuses on connecting communities with local services, promoting sustainability challenges, and integrating citizen participation through playful, location-based experiences. *Ecorbis* [273], on the other hand, focused on home settings, using a data sculpture to promote environmental awareness relating to user behaviour, and offered actionable facts. The experience helped in raising awareness and facilitated reflection. The design was informed by quantitative data supplemented by insights offered by users. *Saving Aid* [272] exemplifies the importance of framing in presenting data and supporting energy-saving decisions. Their recommender system uses explanations as energy-saving frames with a personalized list of recommendations. Adding a personal touch, *More Weather Tomorrow* [288] uses a personalized data video story shaped like a weather forecast to encourage families to explore weather data collectively. The study establishes a link between data and memories to boost engagement and emphasizes the importance of data presentation familiarity. The importance of relating to personal contexts and experiences in data exploration is also analysed by Wilkerson et al. [302], but testing was not yet reported. To create awareness about drought and wildfires, Han & Khanduja [134] created a data visualization depicting the past, present and future of wildfires. A small informal test points to the multimodal interaction being engaging.

As these examples show, HCI research on connecting users with climate change data is diverse, the concern generally being enhancing engagement and understanding of the information. Furthering these approaches within climate change engagement is crucial. Good practices used in UX, graphic design and psychology can inform the development of more effective visualisations related to climate change data, as these still need to be made

more inclusive to non-expert audiences [280]. Researchers need to carefully consider the choices made about what is included or excluded from environmental data sets and how these are used. They dictate how we abstract the environment and our relationship with it, leading to possibilities of "things to be otherwise" [268]. Because of its complexity and potentially polarising nature, interactions for climate change cannot depend on single, universal engagement strategies. Chapman et al. [59] suggest an audience-focused approach based on *message tailoring*, focusing on the individual's particular needs and avoiding a "one-size-fits-all" approach. HCI already explores strategies to support these more complex forms of communication. Moving forward, researchers must operationalise these methods in adaptable, engaging, and structured approaches for climate change-related interactions.

Innovative forms of visualizing data and storytelling through digital media can influence the public's understanding of climate change topics [134]. One of the proposals by Mankoff et al. for research in Sustainability through Design was "making abstract environmental data concrete for everyday life" [205]. However, at the start of this research and to the best of our knowledge, there were no published surveys or mappings of the landscape of HCI research projects related to climate change.

2.1.4 Posthumanistic approaches in HCI

Non-anthropocentric and posthuman perspectives challenge traditional notions of human exceptionalism and explore alternative ways of understanding the interconnectedness of all entities within ecosystems. Haraway's influential essay "The Cyborg Manifesto" deconstructs rigid boundaries between humans and machines, advocating for a more fluid, hybrid existence that transcends traditional categories [135]. Her concept of the "cyborg" disrupts anthropocentrism by emphasizing the entanglements between humans, animals, and technologies. More recently, Haraway delved into the concept of kin-making in the face of ecological crises, advocating for collaborative, multispecies alliances to navigate and respond to the challenges of the Anthropocene [136]. The Anthropocene, a proposed geological epoch characterized by significant human impact on the Earth's geology and ecosystems, is marked by activities such as industrialization and climate change [73]. The "posthumanism" movement [304] defends non-anthropocentric ideals in which humans and nonhumans are entangled and should be seen as a whole. The purpose is not only to decenter the human experience, but to eliminate the idea of a "centre" (or hegemony) altogether. Anna Tsing delves into the collaborative relationships between humans and non-humans, focusing on the resilience of multispecies communities in the face of environmental challenges [284]. Both scholars contribute to a posthuman discourse that encourages a more inclusive understanding of agency, subjectivity, and ethics, challenging the dominance of human perspectives in environmental and technological narratives.

Concerns about sustainability, inclusion, the environment, and climate change have

also led scholars to question prevalent human-centered and user-centered practices. Design and HCI as disciplines have mainly focused on human functionalism. This focus has led to Design being characterised as "sustaining the unsustainable", going as far as being seen as responsible for "defuturing" [121] by negating a sustainable future for humans and non-humans through its irresponsible practice. The growing concern with the consequences of climate change and Design's humanist research approaches have resulted in a call to shift the field's focus. Arturo Escobar summarised this need for reorientation from a "functionalist, rationalistic, and industrial traditions" towards a set of practices "attuned to the relational dimension of life" [98], for example, through collaborative and place-based approaches.

There has been a growing interest in the idea of nonanthropocentric design [85] and decentering humans in design [114]. Many scholars have turned to Posthumanism as it "expands the circle of moral concern, extending subjectivities beyond the human species" [15]. This transition demands a shift from a merely user-centered design to posthumanistic views. The aim is to consider a more comprehensive, diverse approach that includes the relations between human and nonhuman actors [115], expanding the notion of participation to designing with the more-than-human [2]. This leads to avenues for broader participation and co-production with the more-than-human [20, 63], or decolonising design for more inclusive and plural research environments unshackled from current notions of "modernity" [307]. These recently emerging theories in HCI mirror the current state of society, as demonstrated by Sir David Attenborough's call to action in his documentary "A Life On Our Planet" [163] where he advocates for a reconnection with nature and other species, and how this harmonious cohabitation is essential for their, and our, survival.

Nonanthropocentric approaches allow for the inclusion of multispecies perspectives for example by being inspired by natural processes such as decomposition [192], or through multispecies participatory practices [204] that work towards cohabitation [267]. Examples range from designing for more-than-human entities, such as human-fungi collaborative survival [191], to experimenting with wearable designs for environmental awareness and speculation [27]. These approaches do not intend to remove the human from the equation but consider a multispecies worldview that questions their interaction and cohabitation [190, 189, 204, 267]. In other words, a decentering of the human in design or non anthropocentric HCI [2, 114], opposing human exceptionalism and, instead, positioning us among a network of non-human systems that we can participate in but not control [168]. Natureculture, for example, is a concept that connects natural and cultural elements and asks for humans to reconnect with non-humans in order to move away from our view of superiority and isolation [192, 267].

The Anthropocene presents both obstacles and possibilities, necessitating innovative viewpoints [11, 227]. Design practitioners are now compelled to extend their focus beyond products, incorporating services, networks, and experiences which address intricate socio-technical systems [54]. Such systems prompt a departure from conventional design methodologies that primarily concentrate on "the human" towards inclusive approaches

encompassing a variety of perspectives. Smith et al. [267] even suggest that the union of human-natural systems might be design's greatest and most urgent challenge. Civic and participatory design approaches [63, 83] can link to broader societal issues such as politics [83], resistance, and diverse modes of civic engagement [84].

2.2 Climate Change: A Challenge for SHCI

2.2.1 Climate Change Communication

Climate change and its consequences occupy the top six of the ten most significant societal risks [300]. However, climate change is an extremely difficult issue to engage with – data can be difficult to access and relate to [66] and facts escape everyday experience, only given meaning through communication [217]. The scale of the problem, which demands widespread citizen participation and systemic change [157, 309], means that a multitude of data needs to be conveyed, together with the urgency of the problem and the underlying science. The impact of this data depends on *how* the information is imparted.

Climate change communication aims to bring knowledge via experimentation about the phenomena, making them visible and actionable in everyday life. It examines various factors that affect and are affected by how we conduct this communication exchange, and its research has mostly focused on public understanding of climate change, factors that affect this understanding, framing and media coverage, media affects, and risk perceptions [55]. Climate change is a particularly difficult topic to communicate, even when compared to other environmental issues. Moser [220] compiled some of these challenging aspects: i) Invisible causes; ii) Distant impacts; iii) Insulation of modern humans from their environment; iv) Delayed or absent gratification for taking action; v) Disbelief that humans altered the global climate (cognitive limitation); vi) Climate change's immense complexity and uncertainty; vii) Inadequate and inconsistent signals indicating the need for change; viii) Self-interests from individual and macro stakeholders. In terms of communication, these lead to a need to find clear metaphors, imagery, mental models, and framing; the need for consistent and strong signals; support scientific literacy through relevant communication and supporting mechanisms; understanding of communication strategies by the "holders of knowledge" – scientists and other communicators – as to close the gap between these experts and the lay audience.

In 2011, Anderson concluded that the general public gets most of their information on scientific issues from the media, primarily from television news and documentaries [4]. A more recent report concluded that television is the primary source for climate change information, especially impactful due to its visual content. Online news sites follow, with younger generations preferring alternative sources like social media and blogs. Traditional media like newspapers and radio are less popular across all age groups [5]. Mainstream media plays a crucial role in climate change information dissemination in what Goodman et al. [131] call *spectacular environmentalisms* – "large-scale mediated spectacles about

environmental problems", usually with very negative connotations. Climate change has to compete for attention with more immediate issues, often with little success. As mentioned, because of its nature and complexity, climate change is an 'unobtrusive' topic. Therefore, media communication has a crucial role to play in taking to the public its implications, causes and consequences, especially since it is suggested that mass media has more influence on people's perceptions on the topic than interpersonal communications or workshops/school. However, there is no clear evidence of actual effects on people's behaviour [257]. New approaches on how to evaluate climate change communication are also being debated [188].

Up to the 1980s, coverage of climate change revolved around scientific sources, but as the topic became more widespread and politicized, the sources became more varied, exploring more diverse ways of framing the issue. By 2009, the conversation had mostly moved from questioning if climate change was a reality to focus on its social impacts and mitigation, even though some skepticism still existed in some sectors of society [220, 257, 4]. In 2019, media coverage of climate change increased significantly but the total amount as part of the full news coverage was still quite low [278]. In 2020, climate change accounted for just 0.4% overall coverage on corporate broadcast morning, nightly and Sunday morning news shows in major USA broadcast networks, a 53% decrease when compared to 2001 [203]. Several studies have analysed how the media has covered climate change pointing to the mainstreaming of the topic as well as a strong influence of national culture, politics, economy, policy events, and competing news [4, 16, 39, 38].

Research on climate change communication has also been growing since the 1990s [224], focusing on diverse aspects of the communication process and coming from a need by those directly communicating the topic or those who want to support these efforts through theoretical and empirical insights [220]. Nerlich et al. [224] discuss the difficulties in communicating this complex topic to diverse audiences, as well as the arduous relation between communication and behaviour change. They suggest that communication could be improved by: a) moving from a wish to transmit information or educate the audience to work towards transforming decisions and commitments on both sides – the audience as well as the policymakers, scientists and communicators; b) the importance of knowing public perceptions of a particular local audience beforehand; c) how perceptions are complex and culturally determined which means that there is no thing as an effective communication strategy because the framing of the message and what it should say need to be adapted to the context the exchange will take place. A literature review conducted in 2012 about online communication on climate change and politics focuses on the importance of this communication channel [258] and points to relevant findings: i) climate scientists and scientific institutions seem to have a limited role in online debates; ii) the effort made by NGOs but that still use the internet in conventional ways; iii) the visibility of different stakeholders in Internet debates which doesn't help the conversation; iv) the limited effects of this conversation, thus far, on the wider public. Likewise, the author highlights the increase of publications examining the role of online and social

media in climate change communication, but points to big gaps in the literature. These include the need for research on the use of online media regarding climate change and climate policy, as well as on the effects of online communication on knowledge, emotions, attitudes, values, and behaviours.

2.2.2 Framing in Climate Change Communication

The discourse around climate change has mostly been one of urgency and in many cases "end-of-the-world" rhetoric – the so-called "doom and gloom" [9, 21, 177]. Recent reports show that people are worried about climate change and see it as a serious problem [100, 187], in some cases even leading to anxiety and depression [64, 174]. This highlights the importance of framing in climate change message creation.

"Frames" are typically unconscious structures that offer perspective and salience that then influence judgment [182] and, ultimately, how the information is perceived [226]. Every time we are faced with a message, our brain triggers the systems of frames we associate with it and, therefore, the emotions connected with those systems. By solely focusing on the data of the current situation, what is causing the problem, and how daunting the task ahead is, the frames of "environment" and "climate change" are being associated with "fear", "guilt", even "dejection". An IPCC (Intergovernmental Panel on Climate Change) stakeholder highlights this proposition by stating that if one talks about climate change "in a positive way it creates hope, if you talk about it in a negative way it creates feelings of hopelessness" [72]. In this same report, researchers have found that when indicating that losses might not happen if some preventive action was taken – a positive frame – then the audience would showcase a stronger intention to act more pro-environmentally. Several studies have highlighted the importance of how the information is framed [4, 68, 94, 180, 258]. Already in 2011, there were reports of how the public was becoming desensitised and feeling disempowered [4].

Lakoff [182] stated that framing cannot be avoided and we need to carefully consider what frames are activated during communication and, hence, how the public will react to the message based on their pre-existing frames. Spence and Pidgeon [270] analyse this framing in climate change communication by demonstrating that the ways in which communications about climate change are framed (in terms of gain or loss outcomes and in terms of local or distant impacts) will have a substantial impact on the way that they are received. Generally, results indicate that communications promoting climate change mitigation should focus on what can be gained by mitigation efforts rather than dwelling on the potential negative impacts of not taking action (labelled 'gain frame advantage'). But it also notes the complexity of the framing issue. For example, the gain frame advantage was somewhat suppressed both by fear responses and the amount of information that was remembered. Nabi et al [223], on the other hand, analysed the role of emotion (fear and hope) in climate change framing. The result of the study suggests that hope can be more persuasive (a more positive framing of the message). Another study about message

framing in policy communication on climate change suggests that framing the message in terms of positive outcomes, or avoiding negative ones, is more persuasive [26]. It is now well established that effective climate change communication requires more than just presenting the facts of climate science. Despite its complexity, consistent findings point to how people's values, views about society, and political ideology primarily determine how they interpret climate change-related communication [68]. A person's political and ideological values strongly shape their attitudes towards the issue [24, 104]. Scientific data must be communicated accurately, and the message should be adapted to the audience's values, attitudes, and perceptions [226].

However, the debate around and experiments with differently framed climate change messages are ongoing, and studies on the efficacy of these communications have returned mixed results. Studies point to fear messages causing stronger reactions when compared to hope [149], not having significant differences in climate change risk perception [99], or that simple reframing is unlikely to increase public support [24]. On the other hand, there is also evidence demonstrating that fear is an ineffective tool for motivating personal engagement with climate topics, even though it has the potential to attract people's attention [230]. Bloodhart et al. [34] also found a preference for messages framed without emotion than with negative emotions. Solution-oriented messages seem to assist in the perception of efficacy and engagement [103, 138, 87], pointing to the importance of linking to action [87]. A positive frame reinforces public support [75] and *hope appeals* can be a powerful tool to be harnessed in persuasive communication [56]. On a similar note, guidelines for climate change communication have pointed to the importance of framing the interaction positively to avoid a "feeling of hopelessness" [70]. Barriers to effective climate change communication include the typical "doom and gloom" framing focused on loss and sacrifice [9], paired with a lack of opportunities for action and, therefore, feelings of fear and guilt [274]. Two studies [218] illustrate how higher uncertainty combined with negative framing – focused on possible losses – decreased intentions to behave more sustainably. On the other hand, higher uncertainty combined with positive framing – the possibility of losses not happening – resulted in a stronger intention to take action. The second study suggests that feelings of efficacy influenced these effects on uncertainty. Similarly, recent social movements are fighting against "climate doomism" and focusing on action and hope [1, 49, 140].

The IPCC [69] also highlights the importance of framing by suggesting a focus on real-world ideas that are more relatable to the users in question. Another factor to consider is people's need to feel efficacy to solve complex problems. By framing climate change as something almost unstoppable, communicators might be demotivating action even among those concerned. Reporting the impacts of climate change exclusively portrays an incomplete view of society. Stories about constructive problem-solving, for example, are often neglected. Climate change must be presented as solvable [209, 239], shifting the focus from assumed sacrifices to what becomes possible [282]. Data needs to be presented in a relatable way, using stories besides graphs and statistics to connect it to what matters

to that audience, including solutions in the narrative [60, 69]. Personal stories can be a persuasive communication strategy to engage diverse and even sceptical audiences [132]. A richer selection of narratives to choose from is needed [231].

Climate change is a global and complex problem. Presenting the topic through messages on a global scale, with long-term effects, can lead to "psychological distancing" – seeing climate change as a distant, future problem, disconnected from our daily lives [211, 271]. Framing can counter this perception through, for example, metaphors and analogies that present the unfamiliar through more familiar language [262]. The limitations of the usual communication methods [91] have led to a call for more diverse stories that move beyond apocalyptic narratives. These must address climate mitigation, adaptation, and inequality for interactions focused on climate justice and action [277], exploring more creative and idiosyncratic approaches [52].

2.2.3 Engagement in Climate Change Communication

Max Bruinsma calls us *homini visualis* [46], a species that does not only read and write words, but also images – the visual side of content is of immense importance to our perception of the message. Visual communication is the means of conveying ideas and information through visual elements – graphs, illustrations, photography, typography, color, and so on. Their visual characteristics and arrangement (balance and hierarchy) influence the audience's interpretation of the message. This exchange has been greatly analysed by communication theorists. For example, the approach called Process Theory, derived from information technology, puts the emphasis on the sender and the chosen medium used in a linear process of communication that goes from A to B. On the other hand, Semiotics, from linguistics, focuses on the receiver of the message as the producer of meaning. The message can mean different things to different people, depending on many factors (social, political, economic, etc.) that need to be taken into consideration when crafting the communication [13]. Arguably, communication design should be a mixture of both, concerned equally with the way the message is built (the sender) as well as who the audience is and what are their characteristics and particularities (the receiver). This approach has crucial implications for HCI projects, particularly those attempting to engage users with complex data. Furthermore, Michael Beirut, a prolific graphic designer and design critic, said that "much, if not most, graphic design is about communicating messages, and many of those messages are intended to persuade" [13], another key aspect for interaction projects related to sustainability and climate change for audiences of non-experts.

Visual communication is virtually ubiquitous, which means people usually take it for granted [13]. However, the importance of visual communication in conveying climate change-related information has been discussed as a crucial part of the exchange. The IPCC included this recommendation to communicators in their handbook, advising them to "use the most effective visual communication" [69] as the choice of images and

graphs, and how evidence-based they are, is just as important as verbal and written communication. The visuals are part of how we frame the message – language has a great impact on how the audience conceptualises climate change, and the same can be said for its "visual language". Another report also addresses the limited visual vocabulary currently associated with climate change, mostly consisting of polar bears, melting glaciers, smokestacks and polarising images of environmental protesters. This visual framing can limit the effectiveness of engaging audiences [71]. As an empirical way of addressing these limitations in representing "sustainability", Blevis has utilized photographic observations to empathetically comprehend specific situations and, in a way, make sustainability-related issues visible and accessible [31]. His annotated photographs serve as a method to encode and reflect on his current perceptions and to envision potential futures. The Climate Visuals project [70] suggests seven principles for climate change communication, based on international social research: 1) Show "real people" not staged photo-ops; 2) Tell new stories, as the familiar imagery can cause fatigue and cynicism – less familiar images can tell a new story about climate change; 3) Show climate change causes at scale; 4) Climate impacts are emotionally powerful but can be overwhelming – uniting images of climate impacts with concrete "action" can assist in overcoming this; 5) Understand your audience, for example, images showing “solutions” generated mostly positive emotions, both on the political right and left; 6) Show local (but serious) climate impacts; 7) Be careful with protest imagery.

Information visualization can assist in comprehension, and it plays a crucial role in data communication, including public perception and decision-making [95, 214]. Therefore, data visualization is crucial in climate change matters. It consists of the presentation and representation of data in a graphical or pictorial way to facilitate understanding [171]. This involves making decisions about how the data will be visually portrayed, possibly enhancing the message being told and helping in its understanding. Its main advantages are its ability to visually communicate complex data in a manner that is clear, effective and intuitive, uniting functionality and aesthetics. Communicating complex information presents a big challenge, especially when one needs to do so to a wide and varied audience with diverse media literacies, including data and visual literacy [296]. People are expected to be able to "read" visual information. This visualization literacy has been defined as “the ability to confidently use a given data visualization to translate questions specified in the data domain, as well as interpreting visual patterns in the visual domain as properties in the data domain” [37]. This ability of the audience to interpret visual information relies on the assumption that people have the necessary tools to be capable of such interpretation. Therefore, the people creating the visualizations must also consider these graphical conventions and how they will most likely be interpreted. For visualizations, Bertin [25] has identified three stages of interpretation: a) *external identification stage* – the audience recognizes the frame of visual encoding; b) *internal identification stage* – the audience identifies visual characteristics; c) a final *perception of correspondence stage* – where the audience analyses the content and extracts the messages. These stages highlight the

path the user needs to go through in order to read and understand the information in a visualization. Data visualizations are an effective communication tool, but only when they are designed for these stages to take place by using the appropriate types of visualizations and graphic elements for the information being presented. Furthermore, data visualization is a discipline that brings together multiple areas of knowledge: psychology and semiotics in the way the information is perceived; computer science through new techniques of gathering and analyzing data; graphic and digital design in the way the information is visually presented and interacted with. This multidisciplinarity results in transformative ways of representing the information.

Climate change has been visualized in many forms, from global temperature maps to charts showing rising sea levels. One prominent example is NASA Global Climate Change [261], which uses a variety of interactive visualisations to show changes in temperature, sea level, and other critical indicators over time. Another example is the Climate Central platform [53], which features an interactive sea level rise map that allows users to explore the potential impact of rising seas on coastal communities worldwide. Other visualisations include the "hockey stick" graph [206], which shows the sharp increase in global temperatures in recent decades, the famous Keeling Curve [232], which shows the steady rise in atmospheric carbon dioxide levels since the 1950s, or Climate Stripes [141], showing temperature changes over time in different locations. These visualisations have been fundamental in representing the global and oftentimes invisible effects of climate change. They also help make the complex climate change issue more accessible and understandable to the general public. However, these measures can still feel abstract and impersonal due to their magnitude and long-term effects.

Jordan et al.'s [164] report on climate change data visuals and their effective communication for non-experts proposes the MADE principle that considers: *Message* – do the visuals communicate a clear message; *Audience* – are the visuals appropriate for your audience; *Design* – are evidence-based design principles used; *Evaluation* – have the visuals been tested with the audience. To put the MADE principle into action, the report summarizes these twelve guidelines: 1) Identify your main message; 2) Assess your audience's prior knowledge; 3) Consider how your audience "thinks"; 4) Choose visual formats familiar to your audience; 5) Reduce complexity where possible; 6) Build-up information to provide visual structure; 7) Integrate and structure text; 8) Avoid jargon and explain acronyms; 9) Use cognitive perceptual design principles; 10) Consider cognition for digital animation and interaction; 11) Consider cognition when visually communicating uncertainty; 12) Test visuals to check comprehension. These guidelines once again highlight the importance of a holistic approach to the communication process that should be carefully considered in sustainable HCI projects to the general public. However, the visual communication strategies have not been a deeply analysed aspect when building these interactions. A search was conducted in the ACM Digital Library that combined the term "climate change" (N=2,632) with visual communication terms ("X") – [All: "X"] AND [All: "climate change"]. These were the results: "visual communication" N=23, "graphic

design" N=26, "communication design" N=25, "visuals" N=65. These results point to a gap in the use of communication design in HCI that will be further analysed in the course of this research. This analysis will inform the positioning of the work moving forward.

2.3 Data Humanism and HCI

2.3.1 Data Visualisation and the Growing Focus on Humanisation

In the 18th and 19th centuries, data visualisation pioneers started to explore and leverage the potential of data visualisation to codify and present information. Notably, William Playfair founded graphical methods of statistics [113] and invented several types of diagrams, such as the line, area, bar and pie charts [118]. Florence Nightingale was a pioneer in statistics and her analysis presented in graphical form informed decision-making in the British government during the Crimean War [40]. Charles Joseph Minard is best known for his flow maps, particularly the one about Napoleon's Russian campaign [244] and is considered a pioneer in cartography. More recently, a renaissance of the data visualisation field was made possible by experts such as Tufte, best known for his writings on information design and data literacy [285]; Shneiderman [263] and Heer [143], and their contributions to HCI and information visualization through new systems and techniques; or Cairo [51] through, particularly, his contributions to visual journalism [179].

There is little agreement on the best way to visualize complex data for lay audiences [212]. Leading authors on data visualization from the past three decades have greatly focused on the efficiency of design and clarity of communication in what can be categorized as a "neutrality" principle [312]. Tufte proposed a distraction-free approach focused mainly on presenting the actual data and avoiding *chartjunk*. He argues against excessive decoration in data visualisations through the concept of the "data-ink ratio" [285]. Others point to the importance of accuracy and clarity for effective and efficient communication [112] and warn against the persuasive misuse of data visualizations [51] or suggest following applied human perception [297].

McCandless has proposed a storytelling approach that consists of four key elements: data (information), concept (story), function (goal), and metaphor (visual form) [210]. Storytelling has become increasingly pivotal in data visualization design, transitioning from a neutral showcase of information to more humanistic depictions capable of demonstrating ambiguity and complexity. These approaches recognize that data is neither value-neutral nor independent of the observer [93]. This subjectivity of data was commented by Cairo: "the presence of numbers is believed to be more science-y — but numbers are as subjective as text" [179]. Since 2016, Lupi [198] has advocated a paradigm shift in data visualization that challenges established principles, such as striving for simplicity. This new direction, named data humanism, explores alternative chart types and invites audiences to take their time and appreciate the visualizations [245]. These approaches consider the subjectivity of data and its connection to people's understanding and experiences, moving away from

impersonality.

Still, discussions on data visualization's best practices, purpose, and even on what data actually "is and isn't" are very much ongoing. Efficiency and clarity are factors mentioned, like considering if the visual elements used are "adding enough informative value", but simultaneously, considering specific context, including audience, and concepts of storytelling to "communicate effectively with data" [173]. The complex socio-political environment we live in has, arguably, made "accurate" data more important than ever. However, one needs to acknowledge that data is "a human-made abstraction, socially framed, naturally biased" and the challenge comes from the "potential ways to fill the gap between the nuanced complexity of social, natural, and cultural phenomena and the intrinsic reductionism of data and its science-rooted, conventional, visual representations" [61]. More artistic approaches, such as artist Nathalie Miebach's environmental data translations into sculptures [215], demonstrate the contemporary prolific experimentation with data that embraces paths beyond conventional data visualisation models.

2.3.2 Data Humanism

Data humanism is a recent manifesto for data visualization proposed by information designer Giorgia Lupi [198]. This visualisation approach encourages the audience to slow down, explore, engage with and appreciate the visualization [245]. Data Humanism doesn't conform to the typical "simplicity" principle and instead explores non-traditional chart types that embrace complexity, incorporate context, and recognize data's inherent imperfection and subjectivity. To designers, it opens opportunities to be more creative and look beyond standard data representations, inspiring alternative human-data interactions. Lupi has formalized this call in a manifesto [198] that encourages information designers to:

1. *Embrace complexity*: Embracing the complexity of information at our disposal that can result in rich and dense data stories. Depending on the purpose of the visualisation and content that needs to be conveyed, some visual complexity might be necessary. This can be achieved through the layering of various visual narratives over a main device.

2. *Move beyond standards*: The aforementioned complexity can call for alternative chart types. Furthermore, the uniqueness of each data set can lead to designs that respond to the needs of that specific data or problem. Lupi suggests to take inspiration not only from previous data visualisation work, but also other visual languages that naturally work with patterns, such as music notations or avant-garde geometry.

3. *Sneak context in*: Combining data sets or quantitative to qualitative information can assist in revealing more from the data. It can also lead to better comprehension and connection with the data, particularly with data related to people.

4. *Remember that data is flawed*. Data is primarily human-made and, therefore, subject to nuance. Lupi argues for accepting imperfection and approximation, which can be used to make data more empathic. But this reasoning asks for a paradigm shift in data presentation to include more qualitative aspects of the data.

The purpose of this approach to data collection and presentation is to create engaging and personalized data-driven visual narratives that link the numbers to what they stand for: stories, knowledge, people, and behaviors [198, 197]. This is achieved by integrating layers of qualitative information with the quantitative data, adding context and meaning [199], and therefore creating an intimate connection through relatable concepts [200]. There is an emphasis on user participation, leading to an emotional experience that relates to humanistic qualitative information, not just quantitative [312].

Lupi points to the need to make data contextual and intimate, translating numbers into concepts we can relate to [200], "reconnected to our lives and our behaviours" [197]. These principles align with recent communication guidelines for climate engagement discussed in section 2.2.1: *"Presenting data alone may numb the audience. Make it relatable, local, and personal"* [130]; and with [212]'s opportunities for future work derived from their literature review on data visualisations: an emphasis on contextualisation and context awareness, and allowing users to select more personalised data to display through the use of interactive displays.

This proposal by Lupi follows a growing trend of more "subjective" and "human" experimentation with data, as discussed in the previous section. She delineated her proposal through a manifesto that presents the main principles and intentions summarised above. However, data humanism is not a defined methodology but a visualization language that embraces certain principles. The HCI research field could gain from a more defined methodology for future work applications.

2.3.3 Data Humanism in HCI Research

Data humanism comes into HCI research as one of the most recent contemporary perspectives on data visualization, enabling a shift of data ownership towards people, embedding data in everyday experiences. It was used to empower people to gather and represent personal data for self-reflection and foster engagement and discussion [170]. A similar approach was used in educational settings [50, 181], with marginalised communities focusing on visual disabilities [169] and intimate data traces through an analysis of practices around what we call "confessional data selfies" [248]. Houben et al. [150] looked at humanizing strategies to engage the general public with data by adding qualitative layers of information to quantitative data in a public installation that enticed passers-by to answer questions about their surroundings. Similarly, [256] point to new data visualization approaches targeting non-experts, to tools that connect data with people to inform actionable interactions, and how they can lead to reflexion and empowerment. In a different domain, Angulo et al. [6] presents a simulated interactive infographic game about sustainable

food production and consumption, applying two strategies based on data humanism: i) embedding data diegetically in the image composition and ii) using metaphorical connections between data and elements in the landscape. Two additional studies inspired by *Dear Data* [201] – a year-long personal data-visualisation exploration project by Lupi and Posavec – focus on personalization by creating bespoke visuals to enhance engagement [170, 251]. Custom visuals lead to deeper engagement and enjoyment.

These HCI projects underscore the importance of connecting non-specialist audiences with data through less "neutral" and more engaging methods, opposing the traditional research focus on a limited variety of visualization types [212]. However, to the best of our knowledge, no other HCI research has applied data humanism to climate change-related visualizations. The importance of actionable communication and engagement with climate change topics through positive stories that link to action, communities and personal values is fundamental, as discussed in section 2.2.1. Interactive systems that allow for easy update, personalization, engaging and participatory experiences can assist in the crucial task of creating more diverse narratives associated with climate change [52, 91, 277] and meaningfully engage diverse audiences with this complex data. These experiences can lead to urgently needed dialogues [186, 14].

2.3.4 HCI Explorative Approaches Connecting Users with Data

The concept of "making with data" has taken diverse forms within HCI – from data sonification (using sound parameters) to data edibilization (using edible materials) to data physicalisation (an artefact that encodes data), among others [233]. Engaging users with data in “alternative ways”, i.e. through less-used chart types, is not a novelty in HCI research. Several innovative data representation approaches share goals or concepts with data humanism. Storytelling has long been used in data representation to enhance visual expression and assist in conveying meaning [250], and strategic interactive elements engage in data exploration [259]. The use of strategic interactive elements along the story for user exploration of the data has been mentioned as an effective strategy for engagement [259].

Regarding environmental data, eco-feedback experiences are a popular method of materialising energy and other sustainability-related data, especially in the home [19, 238] or community [28] settings. Also, projects such as the *Indoor Weather Stations* [127] or *Energy Babble* [124] have worked towards the physicalization of environmental data. *Local Barometer* and *Plane Tracker* [126] explored location as a means to engage the user with the data through “situatedness of use” – bringing local outside data inside the home. *Data Catcher* [125] uses location-awareness to relate users with ‘big data’ about the areas they are in. These approaches are examples within HCI that work towards connecting users to somewhat abstract or complex data through some form of relatability, bringing the data to everyday settings.

When exploring *how* the users engage with the data, tangible user interfaces (TUI)

allow users to interact with digital information through physical artefacts [147, 286]. In a similar vein, data physicalizations [160], sometimes called physical visualisations [159], help people to explore and understand data through physical representations [146]. Like data humanism, data physicalisation and TUIs can engage larger audiences with complex data, especially in public spaces [148], as people tend to spend time and effort exploring the experience [160, 10]. Likewise, its approach to data can be highly subjective because of the need to select and translate data into these physical forms [295], but can help elicit affective responses, reflection and memorability.

Within HCI and data science, Strohmayer and Muller [276] recently debated the subjectivity of data sets, and how people *shape* the data through their analysis and how they use it. Effective ways of engaging users with data, and the user's role within this exchange, are ongoing points of debate and experimentation.

2.4 Chapter Summary

In this chapter, we first discussed how the field of sustainable human-computer interaction (SHCI) has evolved over the years. In particular, we note the recent call for a shift in focus formalised by Knowles et al. [175] by proposing a reorientation from the broader concept of sustainability to specifically addressing climate change. Considering the complexity of climate change and the interconnection of human-natural systems, posthumanism is gaining traction, advocating for the expansion of design considerations beyond humans.

We then transitioned to climate change as a challenge to SHCI, focusing on current communication and interaction approaches, particularly how the current prevalent negative framing associated with climate change can be detrimental to engagement and action. This discussion led to data visualization as an important factor for public engagement with climate change topics, looking at how visualisation narratives have been embracing deeper humanization and experimentation. Data humanism emerged as a promising approach to reply to the climate change communication challenges within HCI.

Despite the prolific work in data representations in HCI, to the best of our knowledge, research into data humanism for climate change engagement or communication strategies, such as storytelling or linking to climate action through interactive experiences, have not been explored in HCI research. Building on Knowles et al.'s call [175], this research intends to move SHCI towards climate change by exploring how interaction design, particularly interactive data narratives, can better communicate and engage audiences with climate change.

3

Mapping the Landscape of Interactions for Climate Change

This chapter presents two surveys of past work that informed the direction of the research. First, we present a mapping of the landscape of HCI and Design interactive research projects related to climate change. This analysis pointed to gaps in the field and implications for design that were used to guide the development of the framework proposed in chapter 4 and the applied work presented in chapters 5 to 7. Secondly, we present an analysis of climate change data-visualisations in the media through the case-study of the Russia-Ukraine war. This work pointed to how less-obvious but relevant topics are being visualised, and propose data-visualization strategies that can be explored to enhance engagement with climate data.[a]

[a] Conspicuous parts of the text in this section have appeared in co-authored publications [110, 105, 111]

3.1 Interactions for Climate Change in HCI and Design Research

In recent decades, our society faced many crises: from the financial crash to migration, from climate change to the COVID-19 pandemic. In the prior year to writing (2019-2020), the latter two have been constantly in the media, and both are the consequence of the Anthropocene, in which the impact of humanity on the planet is blowing back on us in catastrophic and unpredictable ways. They equally represent massive challenges for our society and for collective action, but also opportunities for better futures that require study and intervention from Human-Computer Interaction (HCI) and Design research. From philosopher Bruno Latour to science reporter Gaia Vince, many claim the COVID-19 pandemic is an opportunity to rethink how we respond to the larger climate crisis threats. Latour was one of the first to declare the pandemic as a "global catastrophe that has come from within" [298] but that it could "lead us to experience a new Renaissance" [183]. As Gaia Vince puts it: "How we respond to this unique opportunity could set our climate trajectory for thousands of years to come" [292]. These calls to action are echoing regulations in political institutions worldwide. The European Commission announced a

New European Bauhaus "to imagine and build together a sustainable and inclusive future that is beautiful for our eyes, minds, and souls" [67]. The International Energy Agency (IEA) stated the pandemic is a once-in-a- lifetime opportunity to reboot economies and create new employment while simultaneously shifting to more resilient and sustainable solutions [154]. Inspired by this context, we saw an opportunity to examine how the HCI and Design communities approached climate change.

This chapter provides an overview of HCI and Design projects from 2010-2020 that tackle climate change communication and analyses some conceptual and practical choices. By doing so, we intended to understand how these fields have treated the topic in recent years, aligned with the latest recommendations regarding climate change communication presented in chapter 2.2.1, and discuss possible improvements and suggestions for future work. This survey also helped to position recent research in the critical discussion around posthumanistic design (Chapter 2.1.4). An overview of what has been done in HCI and Design research will inform and influence future work in light of these proposed shifts in perspectives.

During the past decade, there has been a significant increase in attention and interest in research related to climate change. We chose to examine their methods of communicating climate change and engaging the general public. Despite ongoing debates about the effectiveness of incremental versus systemic change, the public plays a critical part in both strategies as "individuals play a crucial role in driving wider social change" [235]. With this in mind, our survey centres on academic projects targeting audiences outside academia. We argue that HCI and Design play a crucial part in helping diverse audiences interact with climate change-related issues, be it in transforming complex data into understandable experiences [216, 228, 267], nudging behaviours [18, 152], promoting community engagement/action and amplifying under-represented voices [128, 184], fostering debate [145, 208], support individuals in pushing for systemic change [90, 119], or other forms of intervention.

3.1.1 Grounded Theory Review

We adopted the Grounded Theory Literature Review method [306] to analyse HCI and Design literature on climate-change projects. Grounded theory [129], on which the method was based, has developed in the social sciences to rigorously analyse a particular set of studies to derive new themes, issues, or opportunities.

We do acknowledge the reflexivity and positionality in our thematic analysis [41] and how our biases, backgrounds, and social positions may influence our analysis and interpretation of the findings. We strived to be transparent about our process for rigour and credibility but recognised the impact of our own subjectivities. The results identified in this analysis must be interpreted, taking these aspects into consideration.

3.1.1.1 Work Scope and Data Collection

The first stage of the method focuses on defining the work scope by delineating the criteria for inclusion or exclusion in the corpus. Considering our focus, we restricted the search to academic projects on climate change targeting users outside academia. The area of research centres on HCI and Design, and the interaction and communication approaches used in applied projects.

The data selection criteria were:

1. The project's research topic: climate change – for example, during our search, we came across the project Pixeldust [92], an interactive video that takes portrait images of people and creates animations. While it could portray personalities related to environmental topics, climate change is not the project's focus, so it was discarded from our listing.

2. The project's target audience: a general public outside academia. Lifestyle change and system change both need to be addressed, and the general public is also a propeller for social shifts, government influence and wider climate advocacy [235].

3. Projects with an interaction component, either through an artefact or in-person exchange – we intended to analyse communication approaches, so projects that are tools, systems or frameworks were excluded. Two examples: Simpson et al. [266] describe the prototype of a system that can potentially inform the environmental decision-making of non-experts. However, it was then in a prototype stage with no clear definition of its interaction features, so it was excluded from our set. Timestreams [35] was also not included as it is a tool for artists and serves as an intermediary in the interaction process, not as the final interaction output.

This study focuses on HCI and Design research so we decided to centre our analysis on the ACM SIGCHI proceedings, IFIP-13 Interact proceedings, the Design Research Society (DRS) proceedings, The Design Journal (TDJ), the Journal of Design Research (JDR), Design Studies journal (DS), and She Ji journal. These sources were chosen for the high quality of the work, their comprehensive database covering computing technology and design, and their international representation.

We restricted the search to the last decade, more precisely corresponding to an overall period of 11 years, from January 2010 to December 2020. This parameter was added to make the results relevant and more useful for current and future work. The search was conducted through the search terms "climate change", "climate crisis", and "global warming". These terms were chosen to focus the search specifically on climate change and not sustainability in general.

Our initial search returned the following results: SIGCHI: 395; Interact: 38; DRS: 102; TDJ: 58; JDR: 17; DS: 16; She Ji: 47. Each result was examined through its title and abstract to gather if it mentioned one or more HCI or communication project(s). If so, it

was added to our list. We then refined this data set by analysing the papers to determine if the project(s) fulfilled the selection criteria. This refinement of the data and deletion of duplicates resulted in 74 final entries (Appendix 1): SIGCHI: 43; Interact: 9; DRS: 12; TDJ: 6; JDR: 1; DS: 2; She Ji: 1.

3.1.1.2 Analysis and presentation

This survey aims to understand how particular projects on climate change tackled interaction and communication aspects. First, we analysed what topics they focus on. Then we asked:

1. *Who is the target audience* – a) Children/Teens (up to c. 18 years old), b) Specialised (projects to help adults with a particular profession, for example, science communicators), c) General public (adults over 18 years old);
2. *Where was the project applied (context)* – a) Personal (home context or personal/wearable device), b) Institution (e.g., museum, school, company), c) Place of passage (e.g., street, station, public park), d) Virtual (website, app, not bound to one particular location/institution);
3. *How was it applied (media used)* – a) Physical (tangible object or public installation) , b) Digital (app, web, or public display), c) In person (lab, workshop);
4. *What was the scope of the message* – a) Microscale (personal, local, regional coverage), b) Macroscale (national or global coverage);
5. *What was their framing* – a) Negative (loss outcomes: what will be lost or what will be the negative consequence of not changing; and avoid adverse effects: change to prevent loss or negative effect), b) Neutral (no particular framing, more a neutral exposition of the issue), c) Positive (gain outcomes: what can be achieved with change);
6. *How was this framing conveyed (what data or examples were used as message*) – a) Data (presentation or gathering of data), b) Data visualization (display of information through a visualization), c) Examples (presentation of information through examples, e.g., showing the consequences of an activity), d) Analogy/Metaphor (representing information through comparison, e.g., with a story or personification);
7. *Did they present straightforward solutions or actionable steps* – a) No, b) Yes.

The data was gathered by reviewing the full papers and analysed through 'open coding' to identify the concepts of each article according to our questions. Later, these concepts were organized into categories through 'axial coding' – to identify relations between the information and understand what clusters emerged. Moreover, we collected the keywords of each paper and examined their changes over time. With this step, we focused on understanding the topics' trends and their related theoretical frameworks.

3.1.2 Findings

Based on the aforementioned analysis, we examined the data through varied visualizations (Fig.3.1, 3.2, 3.3). Here, we present the findings from this process.

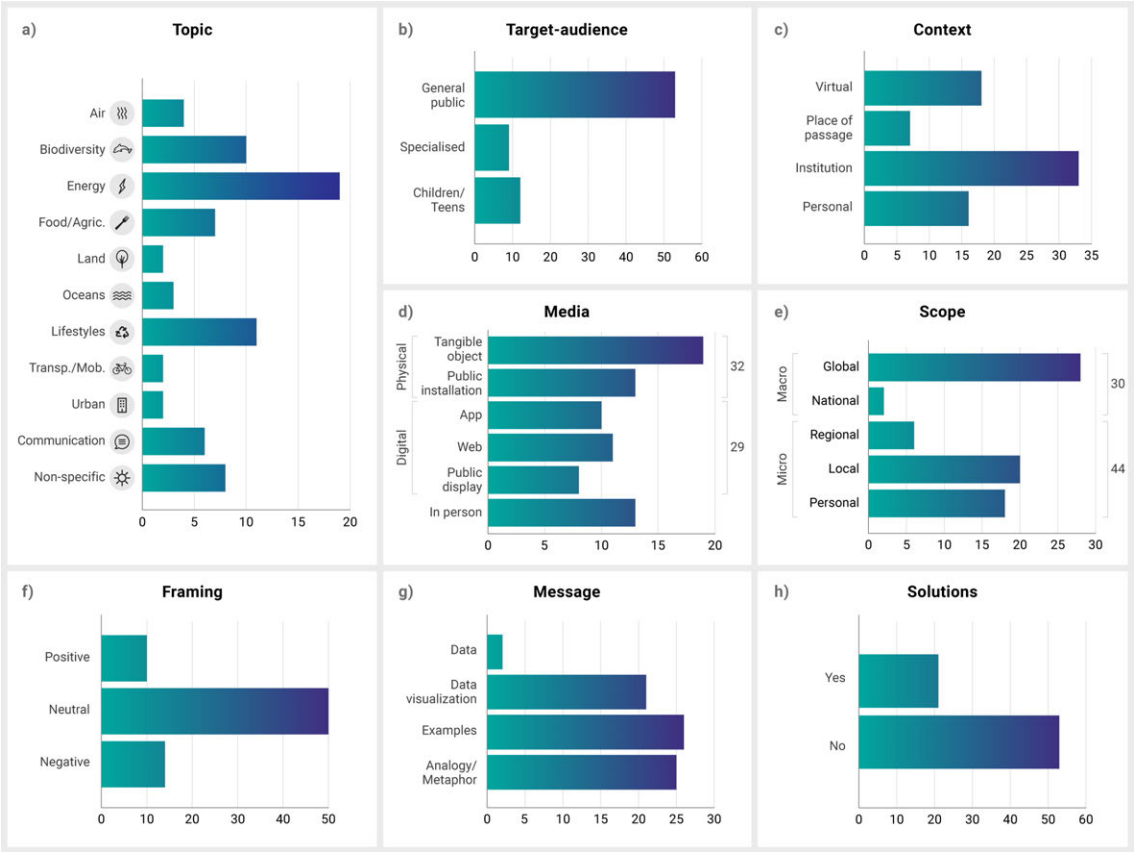

Figure 3.1: Data visualizations for each of the questions asked of the data set.

3.1.2.1 Topic

From our analysis, eleven final topics were identified, distributed as follows (N=74, Fig.3.1a):

- Air (air pollution), n=4;
- Biodiversity (animal and plant conservation), n=10;
- Energy (energy consumption and production), n=19;
- Food and Agriculture (food production and consumption), n=7;
- Land (land conservation and management), n=2;
- Oceans (ocean and marine conservation), n=3;

- Lifestyles (sustainable habits and production), n=11;
- Transportation and Mobility (vehicles and infrastructure, mobility habits), n=2;
- Urban (sustainable cities and buildings), n=2;
- Communication (how the topic is communicated), n=6;
- Non-specific (projects that focus on climate change in general with no specific topic), n=8.

By analysing the most explored topics and their date distribution, it became clear that the topics followed trends based on societal issues. The most explored topics are Energy n=19, Biodiversity n=10, and Lifestyles n=11, with the following date distribution: fifteen of the Energy projects are dated from 2016 and prior, while eight of the Biodiversity projects are dated from 2017 onwards (three from 2020), and seven of the Lifestyles projects are from 2016 and onward (three projects from 2020). Earlier projects focused more on energy consumption and eco-feedback, while in recent years, there has been a shift towards biodiversity and sustainable living. It's essential to keep track of culture, societal issues, and technology developments as these affect the field's evolution. Designers tend to 'look ahead' to bring new themes to the foreground. However, this also raises the discussion about being mindful of the tendency to follow trends. Most addressed topics might not be the most urgent or impactful, as also pointed out by the aforementioned call inside the community to focus on systemic change.

3.1.2.2 Target-audience, Context and Media

Regarding the target audience, the projects were divided into (Fig.3.1b):

- *Children/Teens*, n=12;
- *Specialized*, n=9,
- *General public*, n=53.

As for the context in which the projects operated (Fig.3.1c), the result was:

- *Personal*, n=16;
- *Institution*, n=33;
- *Place of passage*, n=7;
- *Virtual*, n=18.

Figure 3.2: Visualizations of the corpus of data comparing the project's framing of the communication with the types of messages, context and solutions (matrix "a", "b", "c"). Moreover, matrix "d" visualizes target audiences against the scope of the projects.

Following the previous inquiry, we looked at how the interaction was performed in each project (Fig.3.1d). Considering we are analysing HCI and design projects, most of them have a digital component. We decided to make this media categorization by focusing on the most characterizing element. For example, some projects have a physical component (e.g. a statue or object) that is accompanied by a digital one (e.g. screen visualization), but

we labelled them as physical projects. These were the results:

- *Physical – tangible object*, n=19;
- *Physical – public installation*, n=13;
- *Digital – app*, n=10;
- *Digital – web*, n=11;
- *Digital – public display*, n=8;
- *In person*, n=13.

3.1.2.3 Scope

The scope classification resulted in (Fig.1e):

- *Macro – Global*, n=28;
- *Macro – National*, n=2;
- *Micro – Regional*, n=6;
- *Micro – Local*, n=20;
- *Micro – Personal*, n=18.

The projects tend to focus on climate change as a global issue or on personal behaviour and local issues. If we look at the dates, Personal projects are more prevalent up until 2016, with n=15 against n=3 for 2017 onwards. Meanwhile, Local and Global projects were prevalent in the second half of the decade, with n=8 / n=11 until 2016 and n=12 / n=17 for 2017 onwards, respectively. There seems to be a recent decrease in focusing on individual behaviour (Personal) which Energy influenced as a topic (n=11, with n=10 from 2016 and prior).

3.1.2.4 Framing, Message and Solutions

Concerning the framing of the interaction (Fig.3.1f):

- Negative, n=14;
- Neutral, n=50;
- Positive, n=10.

As for how this message was conveyed, we arrived at the following division (Fig.1g):

- Data, n=2;

- Data visualization, n=21;
- Examples, n=26;
- Analogy/Metaphor, n=25.

Following this analysis, we thought it was essential to gather if the projects explicitly presented or discussed actionable steps to help the audience in further action. If the paper did not expressly describe solutions or steps, we considered it as not presenting them. The results were (Fig.3.1h):

- Yes, n=21;
- No, n=53.

By comparing these three axes – Framing, Message, Solutions (Fig.3.2a, Fig.3.2c) –, a primary cluster emerged: projects with a neutral framing that focused on examples or data visualizations, and that did not present actionable solutions. This result supports the idea that most projects present the facts and examples as the message itself and, in a way, expect the user to show interest in the data and search for practical actions themselves, as they are not part of the interaction. This *modus operandi* aligns with the approach discussed previously used by most media outlets – that the 'facts speak for themselves'. For us, the particularly striking aspect is the lack of suggestions for future action. Even if the interaction stimulates the audience, most projects do not explicitly showcase actionable paths to help in action. Furthermore, from the fourteen projects from 2020 (the most prolific year in our set), seven discuss steps for further action. It is too soon to tell if this 'helping in action' is a trend, especially since 2019, for example, had no projects with this characteristic.

Another revealing result is that from the twenty-one projects that did present further steps, seven had a neutral framing, nine a positive framing and five a negative framing, four of which had a focus on avoiding adverse consequences. Of the fifty-three projects that did not showcase further action, forty-three had a neutral framing, and six had a negative, loss outcomes framing (four had either a 'gain outcomes' or 'avoid adverse effects' framing). These results suggest that the clear presentation of actionable steps goes hand-in-hand with how the interaction is framed.

3.1.2.5 Keyword Analysis

Alongside the previous analysis, we gathered the keywords of the papers in our set, analysed their preponderance and compared them through the use of word clouds (Fig.3.3). The most used keywords are:

- "Sustainability" – n=17, the most used keyword.
- "Community", "Design research", "Sustainable HCI" and "Climate change" – n=5 each.

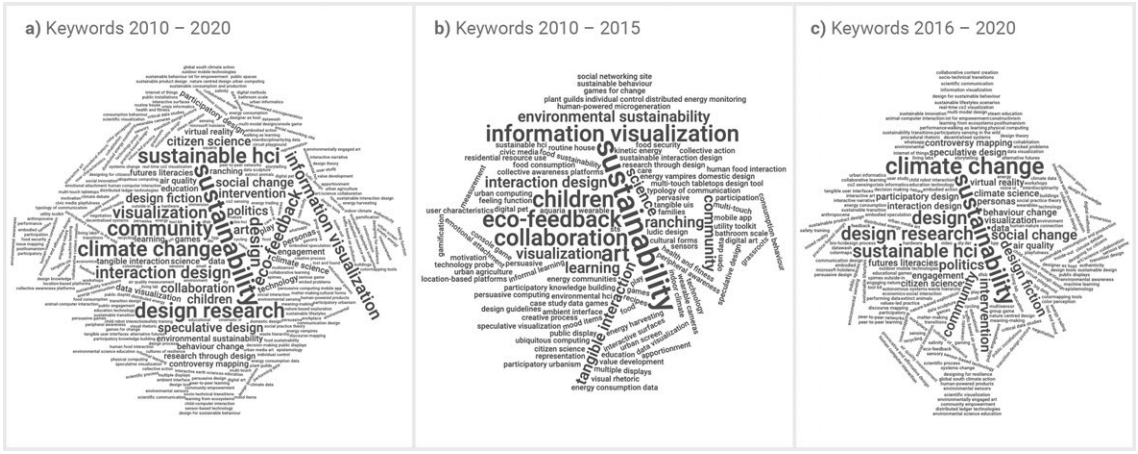

Figure 3.3: Data visualizations (word clouds) of the keywords gathered from the papers in the data set.

- "Design", "Eco-feedback", "Information visualization", "Interaction design", and "Visualization" – n=4 each.

Considering our focus on applied projects with an interaction component, most of these results are unsurprising. Interestingly, comparing the results for "sustainability" and "climate change" highlights Knowles et al.'s [175] call to orient HCI research on climate change rather than sustainability.

Going further, by analysing the first half of the decade against the second, we see some interesting variations. Up until 2015, "sustainability" is still the most used keyword (n=6), followed by "art", "children", "collaboration", "eco-feedback", and "information visualization" with n=3 each (Fig.3.3b). From 2016 onwards, "sustainability" has n=11, followed by "climate change" and "design research" with n=5 each, "design" and "sustainable HCI" with n=4 each, and then "community", "intervention", "politics", and "social change" and "design fiction" with n=3 each (Fig.3.3c). The comparison cannot be linear as there are more projects after 2015 (49 against 25 up until 2015), and the number of keywords varies between papers. Nevertheless, it is revealing that of the four "eco-feedback" keywords, three are from before 2016. This result sustains the previous result about the shift in topics over time and a bigger interest in energy and eco-feedback earlier in the decade.

Also, all five results for "climate change" are from after 2015. The emergence of keywords like "politics" and "social change" and the continuous interest in "community" (n=3 each) after 2015 points to a shift caused by new SHCI research perspectives (discussed in Chapter 2.1.4). At the same time, the only two "behaviour change" results are also from after 2015, indicating that individual behaviour is still an area of interest for researchers. Different perspectives are being debated and explored hand-in-hand.

3.1.3 Implications for Design

Derived from the previous compilation of findings and comparison between dimensions (Fig.3.2), we propose five design implications for future research in HCI and Design on climate change: 1) Choose Topics Based on Impact and Audience; 2) Explore Interactive Engagement in Daily Routine Places; 3) Help the Users Take Action by Proposing Actionable Steps; 4) Positively Frame the Message with a Narrative Adapted to Your Audience; 5) Explore Alternative and More Inclusive Perspectives. These implications strongly influenced the following stages of the research (Chapters 4 to 7).

3.1.3.1 Choose Topics Based on Impact and Audience

Climate change is a very complex phenomenon requiring a diverse range of solutions. The relative clustering of attention around *Energy* especially, followed by *Biodiversity* and *Lifestyles*, can point us towards a gap in the diversification of approaches.

Project Drawdown points out that some of the most impactful solutions receive comparably little attention, and there is a need to "look beyond the obvious, to a broader suite of solutions" [303]. Access to high-quality, voluntary reproductive healthcare and high-quality, inclusive education, for example, are pathways with potentially significant impacts that are not explored at all in the projects we analysed. Furthermore, many of the most impactful solutions are related to the food system and land management (*Food and Agriculture*, *Land*), also areas with potential for further exploration. The HCI and Design communities are already actively debating these issues, for example combining climate-resilient food practices with more-than-human concerns, and proposing the extension of human-food interaction research [78, 89]. The challenge lies in transposing these concerns into design practice, as well as finding impactful areas of application considering the huge challenge that systemic change represents. There is the opportunity for future research in these less developed themes precisely because they can be less obvious to most users and communities and have the potential for significant impact. These alternative paths of exploration can also align with the proposed "positive" framing of the message focused on better user, community and social engagement.

3.1.3.2 Explore Interactive Engagement in Daily Routine Places

Public displays can contribute to the "attractiveness and positive experience of urban environments" [290]. Their usage can be amplified with interactivity, attracting more engaged individuals and groups, stimulating social interaction and positively affecting memorability [3, 290]. Furthermore, these public interventions can be harnessed to design for collaboration and community building [137], interesting possibilities taking into consideration the calls-to-action mentioned in 2.1.4. Despite many of the displays in cities being used for advertising, David and Chalon [77] suggest that information provision, including climate-related, would be more useful.

Taking this into consideration, since only two media *Public installation* projects in *Place of passage* context came up in our corpus, we see an opportunity for future research on interactions for climate change to use public spaces like streets, public transportation, stations, shops, for example, where casual audiences are. In some of these urban settings, people are more idle, with available "mental space", and so there is the possibility of triggering their interest in ways they are not expecting – interactive displays are effective in capturing the attention of passers-by and provide a high converting rate to actual user interaction [237]. Also, waiting areas afford more detailed information to be transmitted [22].

Challenges posed by public interventions need to be considered [22, 77, 151] as it is difficult to hold people's attention or ask the user to accomplish more demanding tasks. Still, there are recommendations to deal with these challenges [43, 221]. Exploring engaging, educational, and action-focused interactions in day-to-day settings can help narrow the gap with particular audiences.

3.1.3.3 Help the Users Take Action by Proposing Actionable Steps

Considering the complexity of the issue and the multitude of pathways possible, it is essential to help the target-audience in their path to more sustainable habits, community engagement, collective action, or other forms of climate action, depending on the intervention's purpose. DiSalvo [86] pointed out that HCI research on sustainability frequently relies on users' moral concerns and that it needs to find different ways to engage with them. We need to explore methods of engaging users, communities, corporations, political agents, through actions.

The great majority of projects analysed explore ways of presenting the facts, a crucial step in climate change interaction, but leave it to the user to then continue their journey if they are interested enough. With the multitude of information associated with this complex issue, we see the need for a more detailed presentation of actionable steps. HCI research in sustainability, including climate change, is a complex field that has sparked deep debate. The previous user-focused, individual behaviour change approach rooted in persuasive design is being contested for perspectives more focused on collective action, community politics, systemic change, more-than-human perspectives, and so on (Chapter 2.1.4). Regardless of the approach taken, arguably, the intention of these types of interactions with the general population is to spark their interest, educate, foster debate and instigate some form of action, be it individual or collective. We suggest making this process more effective by showcasing actionable steps that the user or group can take as part of the interaction.

3.1.3.4 Positively Frame the Message with a Narrative Adapted to Your Audience

Accurate facts are the basis for good science communication, but they are not enough for effective public engagement [71]. The significant cluster of neutrally framed projects is

based on presenting examples or data visualizations. This indicates that most interactions from the set could be more effective if they framed the message in a more positive and actionable way instead of just presenting information, as discussed in Chapter 2.2.2. Considerably fewer projects explored positive framing, propositions that can result in better engagement [26, 209]. As suggestions for future work, we point to IPCC's recommendations [69]: a) focus on the real world, not abstract ideas, to frame the message in a relatable way; b) be compelling by using stories more than statistics or graphs; c) connect with what matters to your audience – consider values and political views; d) include solutions on your narrative so the audience feels empowered instead of overwhelmed [60]. These suggestions can be used towards a more positive framing that works against the typical "doom and gloom" narrative associated with climate change [21]. Especially considering the toll that the COVID-19 pandemic represented to an already crisis-fatigued population, the framing of the interaction is even more relevant. Webster et al. [299] compiled findings and suggestions on how to communicate climate change during the pandemic, from which we highlight six particularly relevant for our discussion and the proposed shifts in the field: 1) Speak to altruistic community values; 2) Embed lifestyle change in the longer term; 3) Emphasise resilience, preparedness and support; 4) Build efficacy; 5) Highlight individual change as a part of wider social change; 6) Use narratives around 'fairness'. Furthermore, audiences "filter" the information according to their values, beliefs, political inclinations, etc., and these factors can become more critical in shaping their views on climate change than actual scientific accuracy. Therefore, if the intention is to engage with a possible uninterested or conservative user, for example, the interaction can be framed in terms of risk-aversion, security-related, or as a way to "conserve natural beauty" as these are essential features of conservative ideologies [70].

3.1.3.5 Explore Alternative and More Inclusive Perspectives

As discussed in Chapter 2.1.4 of Related Work, the prevalent human-centered design regularly focused on individual action is being questioned in favour of more diverse, inclusive and impactful approaches. Our keywords analysis points to some research with a concern with "community", and some limited concern with "participation" and "participatory", "politics", "collective", "social change" and "transition". However, there is only one occurrence of keywords related to systemic change ("systems change"), no keywords containing "species", "inclusion" or "inclusive", "decolonising", "futuring" or "sustainment". We find only one result for "posthumanism" and "cohabitation" from the same project, and another for "animal-computer interaction". For keywords containing "human", only "human-nature connection" points to these recently debated approaches. From these results, we see the opportunity for design research to explore these theoretical perspectives in applied projects related to climate change. There is prolific debate around approaches focusing on system change, nature-culture, nature-based, more-than-human, decolonising design, futuring, sustainment, among others, but the needed step now is to

apply these concepts to design practice [192, 267] and engage the public with them. In this study, we were particularly interested in interaction and communication, and there are many challenging pathways to tackle that Design and HCI could help develop. As mentioned in 2.2, climate change-related interactions with the general public are saturated with negative and often repetitive messages. These alternative perspectives could bring a much-needed shift in the dialogue towards unexpected, more impactful and inclusive interventions geared towards mitigating the Anthropocene.

3.2 Climate Change Communication in the Media

3.2.1 Case Study: Russia-Ukraine War and Climate Change

The mapping of the landscape of HCI and Design interactive research projects focusing on climate change led us to question how the topic was being visualised in the media. To make this survey feasible in the time constraints of the PhD journey, we decided to focus on one case study that could be replicated to other topics. One of the implications for design of the first survey informed our choice of subject, as it pointed to the importance of choosing topics based on impact and audience instead of familiarity. Therefore, we intended to choose a topic for our case-study that was less obvious, that resonated with our audience, was based on current affairs, and had a considerable impact in the environment and climate change mitigation efforts.

On 24 February 2022, Russia invaded and occupied parts of Ukraine, escalating a conflict from 2014 [96] and causing the largest refugee crisis since World War II [287]. Above all, the Ukrainian people have suffered through massive casualties, forced migration, and the widespread destruction of infrastructure. In response, the International Criminal Court (ICC) opened an investigation into possible war crimes, crimes against humanity, the abduction of children, and genocide [153]. The war also has a hugely detrimental impact on the environment and climate change mitigation efforts [45] – damage caused by military operations, including destroying critical infrastructure and releasing hazardous materials into the air, soil, and water. The conflict has also led to increased greenhouse gas emissions due to military efforts, the use of fossil fuels and the disruption of renewable energy projects. The link between wars and climate change has already been the focus of research [23, 249, 255]. President Zelenskyy's address at 2022's COP27 [139] focused on these effects, giving as examples the two million hectares of forest destroyed, the threat of radiation disaster from nuclear plants, the energy crisis that was leading countries to continue or revert to coal, and the food crisis caused by disruptions to grain exports [12] that is worsening the food crises already exacerbated by droughts [158]. The war also has dire consequences on biodiversity [156], and environmental health [293].

Outside Ukraine, the effects of the war have been far-reaching, especially for the global energy landscape [155]. The war spotlighted countries' dependence on Russian oil and gas, the need for energy self-sufficiency, and the push toward renewables. While the

war's impact inside Ukraine has been devastating in terms of carbon pollution, with vast amounts of greenhouse gases released by the destruction of infrastructure and the use of diesel generators, the impact outside Ukraine has been paradoxically more positive, in some regards: the disruption of gas imports from Russia accelerated the global phase-out of fossil fuels as countries turned to renewables for energy security; Europe's non-electricity natural gas consumption has fallen by 17% since the start of the war, leading to a reduction of 117 metric tons of carbon emissions [229]. The 2022 IPCC report underlines this issue by stating the urgency of phasing out fossil fuels and finally starting emissions decrease before 2025 if we hope to keep global heating below 1.5ºC [264]. However, the ultimate impact of the war on the world's long-term ability to tackle climate change remains to be determined [45].

This new crisis has populated our news in the past year (2022-23). In particular, the topics of war and climate change were correlated, presenting the added challenge of conveying this data in ways people find relatable while leading away from hopelessness, as discussed in Chapter 2.2. Visual communication is common in depicting and explaining war, usually portraying battles, military strategy, and the effect on people through photography or video [97, 234]. However, certain information can only be conveyed or understood through data visualisations. Examples of this are the work of Florence Nightingale during the Crimean War, informing decision-making in the British government [40], or Charles Joseph Minard, best known for his flow maps, particularly the one about Napoleon's Russian campaign [244]. Data visualisations about conflicts have been subject to different approaches. Topics explored range from territory changes and troop movements to economic shifts, casualties, and military spending, to name a few [252]. The war in Ukraine is no exception [246]. In recent years, technological advances have enriched and augmented data visualisations, making them more interactive (e.g. [207]), including visualizing war [8, 225]. Web-based interactive infographics or dashboards have become commonplace. The interactive documentary "The Fallen of World War II" [133] is a prime example of the use of data storytelling, narrative and interaction to visualise the staggering data related to the human casualties of war. More subjective data visualisations about war have also been developed, such as "Poppy Field" [74], both a printed visualisation and an installation also representing casualties of conflicts through the position, colour and size of poppies. These are examples of how storytelling with data can help the reader understand complex facts [250] through a more experiential form.

Considering the Russia-Ukraine war's importance in current affairs, its effect on climate change that is not widely discussed, its constant presence in different media, and the direct connection to people's day-to-day lives, it emerged as an appropriate subject for our case-study analysis. The first anniversary of the conflict came as an opportune time to investigate how the topics of the war and climate change were connected and visualized. This study aims to ultimately learn from the approaches employed and propose strategies that can lead to more engaging human interactions for climate change. We set out to answer the following research questions: (RQ1) After one year of the war, how have the

research communities and the broader media linked the war to climate change; (RQ2) How was this connection visualized; (RQ3) What can we learn from the approaches so far and what can we propose for future work. Our previous research led to these questions, as we noted a limitation in the topics explored in climate change communication (3.1.3) and proposed a focus on "less-explored" but relevant topics.

With this study and the suggestions for future work, we contribute to the design community by sharing our findings about how research and media communicate and visualize a less-known but relevant topic and how we can leverage this knowledge to improve future climate change engagement and communication.

3.2.2 Grounded Theory Review

This study examines how communication strategies have been used to visualise the Ukrainian War. To rigorously gather and analyze a corpus of representative work, we again followed the Grounded Theory Literature Review method (GTLR) [306], based on Grounded theory [129]. This method has developed a rigorous approach to analyzing materials to derive new themes, issues, or opportunities. These themes, or key concepts, surface from data gathering and analysis instead of being inferred beforehand. To mitigate problems that could arise from using this method – related to credibility, transferability, dependability, and confirmability [29] – we aimed to be transparent about the choices made during the data gathering and analysis, which we describe in this paper. Furthermore, the analysis and results were iteratively created and discussed throughout the process by the authors. Our analysis followed the five iterative stages of GTLR: 1) Define: the most suitable data set was identified; 2) Search: where the data is gathered; 3) Select: refines the samples to be analyzed; 4) Analyze: qualitative research methods are used to extract value from the collected set; 5) Present: oversees the writing of a coherent overview paper (the article in hand). In the following sections, we describe how we followed these stages to collect and analyze a corpus of 1192 articles from ten research and media venues, from which we gathered 202 data visualisations.

3.2.2.1 Work Scope and Data Collection

In this section, we describe the first three stages of the analysis. In the first phase, we start by defining the scope of the study. Our investigation centred on the Russia-Ukraine war and its relationship to its environmental impact and climate change. Our search spans one year since the date of the invasion of Ukraine by Russian military forces [96] – from 24 Feb. 2022 to 2023. We selected ten venues to consider our research interests in design, HCI, and information communication and visualisation by the broader media. By focusing on research venues and broader media, we intend to accomplish a general overview of the main approaches being explored. Within the research community, we used the ACM SIGs: SIGCHI, SIGCOMM, SIGDOC, or SIGGRAPH; the DRS Digital Library; and IEEE Vis. We eliminated full proceedings and focused on individual articles. To represent the broader

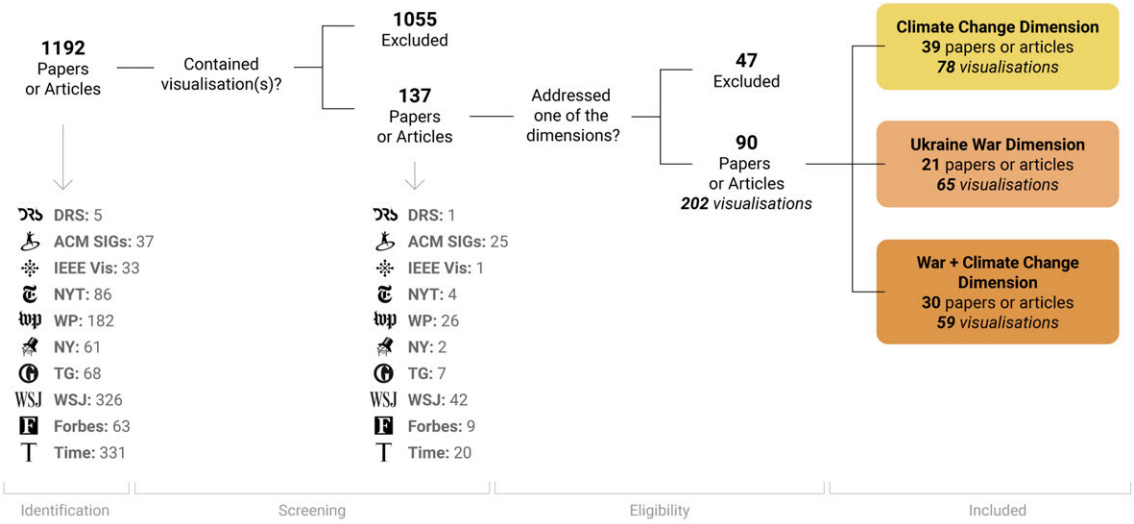

Figure 3.4: Flow diagram of the systematic review methodology.

media, we focused on seven of the most-read newspapers and magazines worldwide that had an English presence online: The New York Times (NYT), The Washington Post (WP), The New Yorker (NY), The Guardian (TG), The Wall Street Journal (WSJ), Forbes, and Time Magazine.

We then proceeded to the Search phase. We focused on the keywords "war" OR "Ukraine" AND "climate change" within the time-frame. We looked into each article for venues with under 500 results to gather if they included a data visualization. If so, we added them to our list. For media with over 500 results – WP (2390), TG (6350), and Forbes (1700) –, we added additional keywords to narrow down the search: “visualisation”, “visualisation”, “infographic”, or “visual”. We chose these keywords after analyzing articles that did contain a visualisation, and how they referred to it (when they did).

Some adaptations were necessary depending on the venue’s search options. For The New York Times, we searched for the keywords “war” or “Ukraine” within their Climate section. For The Guardian, Forbes, and Time, we used Google search within their specific domains to search for the keywords within our time-frame. For IEEE Vis 2022, we analysed articles through their titles, abstracts, and keywords to gather them. The selection criteria applied resulted in a list of 1192 papers or articles. In the Select phase, we focused on the articles that contained one or more data visualization or infographic. From the initial list, 137 met these criteria (Fig. 3.4).

3.2.2.2 Analysis

Our survey aimed at understanding how the war in Ukraine has been associated with climate change, and how this topic has been visualised. Therefore, in the Analyze phase, we examined each of the 137 entries to understand if and how they mentioned climate change or the war in Ukraine. To accomplish this, we used thematic analysis [41] to read

through the gathered articles, how they mentioned the selected terms, and classify them as:

1. Climate Change dimension;
2. Ukraine War dimension;
3. War + Climate Change dimension (connecting both dimensions).

We discarded 47 results that did not fit in either of the dimensions. We further analyzed if the terms were mentioned "in passing" or had some weight in the article's discussion. For example, [279] mentions climate change, or [76] mentions the invasion of Ukraine. Still, these dimensions are not one of the focuses of the discussions, so they were not considered as uniting both issues and were instead classified as focusing on one dimension. This refinement resulted in a data set of 90 articles or papers that contained 202 data visualisations (Fig. 3.4).

3.2.3 Findings

The findings of this study result from three main research questions probing how the connection between the Ukraine war and climate change has been visualised. Firstly, after one year of the war, how have the research communities and the broader media linked the war to climate change (RQ1)? Secondly, how was this connection visualized (RQ2)? And finally, what can we learn from the approaches so far, and what can we propose for future work (RQ3)? We conducted thematic [41] and formal [58] analysis of the data visualizations for the War + Climate Change dimension. Our intention was to see what patterns emerged from the content explored but also to better understand how the visual information was organized and, therefore, how the content was formally communicated. From this analysis, the following patterns emerged: (i) a clustering of the visualisations around the topic of *Energy*; (ii) use of limited visualisation types; (iii) limited design strategies; and (iv) the limited use of narrative. We describe each one in detail below.

3.2.3.1 Visualisations topic clustering

In all three dimensions, the topic distribution is greatly influenced by the high number of visualisations found in The Wall Street Journal (70), which predominantly focuses on *Energy* (35) or *Finance/Commerce* (21) (Fig. 3.5). This suggests that economic factors play a significant role in both issues. However, apart from this influence, there is a noticeable difference in focus. In the Climate Change dimension, the most explored topic is *Weather* (28), focusing mainly on extreme weather events and temperature increases, indicating that these severe manifestations are commonly used to illustrate the consequences of climate change. On the other hand, the Ukraine War dimension, the one with the least variation of topics, focuses on *Digital infrastructure* (33) – all from the five ACM SIG research papers –, and *Fossil Energy* (13). This result indicates that the conflict has implications for the

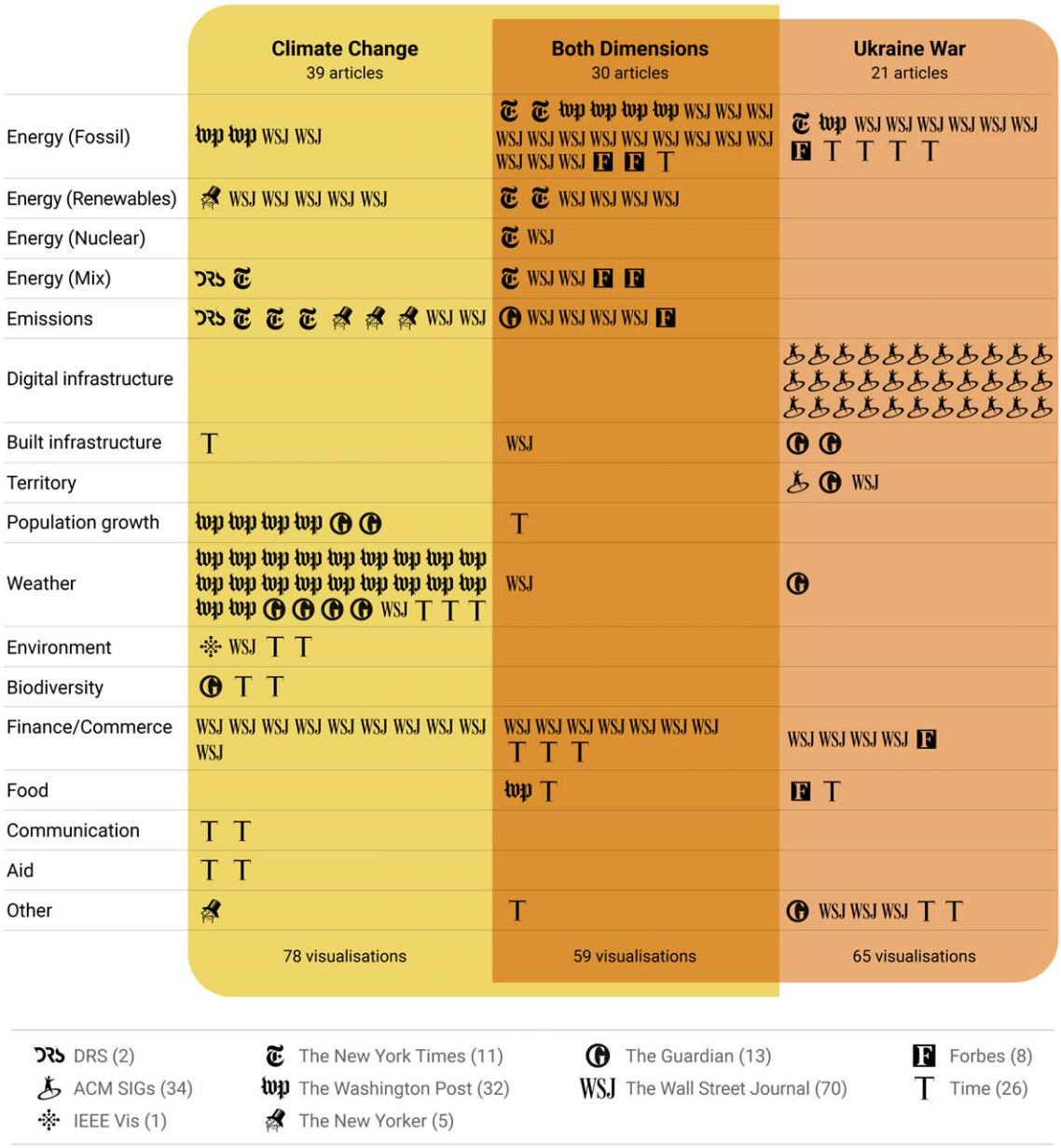

Figure 3.5: The final dataset comprises 90 articles with 202 visualisations. Here we present the visualisations (by publication venue) within each dimension, organised by topic.

use and security of digital technologies, and the research community used this context to better understand its complexity and resilience.

Most articles for the combined War + Climate Change dimension have visualisations related to either *Energy* (37), with a considerable preponderance on *Fossil* (24), or *Finance/Commerce* (10). These are followed by *Emissions* (6), and a small representation of other topics. The WSJ influences this dimension particularly. Of the 59 visualisations, 35 are from this venue, all related to *Energy* (22) or *Finance/Commerce* (7), except *Emissions* (4), *Weather* (1), and *Territory* (1). Therefore, the influence of the war on the energy sector

has been one of the most explored sides of the conflict. Fossil is at the forefront, and of note is that this result was pushed by a financial sector venue (WSJ), as illustrated in Fig. 3.5. The exposure of the dependency on Russian energy imports and the push towards renewable energy has been one of the consequences of the conflict. It has been much linked to climate change and building resilience.

Even though with less representation, the war seems to have also brought to the forefront the debate about *Food* security (two visualisations each for the War dimension and War + Climate Change dimension). The importance of Ukraine in grain exports and the consequences of its disruption, particularly in African countries [65], has highlighted a problem that climate change has aggravated for years.

3.2.3.2 Limited Visualisation Types

Within the articles addressing the War + Climate Change dimension, the great majority of data visualisations fall within two chart types (Fig. 3): bar charts (23) – a chart that uses either horizontal or vertical bars to display numerical comparisons across categories – or line graphs (21) – used to show quantitative values over a continuous interval, normally used to demonstrate trends and data changes over time. This tendency is evident through the two most explored topics – Energy and Finance/Commerce. Of the 48 visualisations, 39 fall within one of these two chart types (Fig. 3.6).

The other chart types found, with much less representation, are distributed as follows: area graphs (5); maps (4); proportional area charts (3); donut chart (1); bubble chart (1), and a simple text chart similar to a Sankey diagram (1).

3.2.3.3 Limited Design Strategies

The data visualisations corpus showcases a consistent but limited use of design strategies. From the 59 visualisations, 26 are static. The remaining 33 use simple interaction strategies focused on hover highlighting / details (31) (e.g. [165]), or animation on scroll (2 from one article [167]). The latter is the only article that connects the text content and the user's progression with the visualisations through animation. Besides being more engaging, it effectively connects the text with the data visualisation.

Furthermore, none of the interactive visualisations uses design elements to highlight their use of interactivity – such as markers for interactivity or tacit tutorials. Visualisations presented in the same article [241], of which one is static and the other is interactive through hover details, bear no apparent difference between the two before hover.

Regarding visual design, the great majority of the visualisations follow very straightforward representations of the data (as exemplified in Fig. 3.6). Six present small text annotations (e.g. [308]), and [44] uses photography within a donut chart. Overall, the design strategies encountered in the examined corpus are consistent in their simplicity and directness.

Figure 3.6: Examples of the chart types found for the visualisations (N=59) from articles of the War + Climate Change dimension.

3.2.3.4 Limited Use of Narrative

The data visualisations analysed only illustrate a particular aspect of the overall content of the articles. For example, one article [17] connects oil companies' massive profits with their lack of investments in climate-related initiatives. The argument in the text is diverse, but there is only one data visualisation about stock buyback authorizations. Another article [65] exposes the complex issue of famine in East Africa and its dramatic humanitarian consequences. Still, the only visualisation is an impersonal choropleth map showing the areas' level of food insecurity.

Many visualisations from our corpus are being used as complements of the text, and most often lack information which is only found in the text of the article. For example, one chart [48] shows data in units of energy called exajoules, with no information about the meaning of this measure. Meanwhile, in the text, there is a comparison of its significance in percentage to global supply. The data visualisation assists in communicating the content of the text but is not a crucial piece of the communication exchange.

Our analysis revealed an absence of detailed and engaging data narratives explaining the crucial dimensions of war and climate change.

3.2.4 Implications for Design

In this section, we discuss the design implications derived from the results of our analysis. We highlight what we learned from the visualisation approaches used so far, and what recommendations we can derive for future work.

3.2.4.1 Contextualising the Quantitative Data

When dealing with complex phenomena, like war or climate change, the data may feel impersonal and hence distant from the reader. As discussed in chapter 2.2, current climate change communication guidelines call for using stories and relation to local situations and communities more than statistics. The data should have meaning to the audience we are engaging with. Furthermore, communicators should avoid enhancing crisis-fatigue and climate-related anguish, that can lead to a lack of action and even psychological distress. Using strategies that contextualize the data can assist in giving a more hopeful and action-focused framing to the message, giving meaning by, for example, linking to personal experiences or community values.

In the following example article [305], climate change-related data is communicated through a personalization strategy (Fig. 3.7-A). The data story starts with the title, "You're one in 8 billion", and the visualisations are fundamental to creating this narrative. The user can input basic demographic information that is used to adapt how the data is showcased – linking you to the data presented. This strategy gives the quantitative data more meaning to the individual user by making the huge global numbers less abstract, being compared

and connected to smaller and more personal measures. There is no manipulation of data – the set is simply treated and presented to maximize connection and interpretation.

Other design strategies such as annotations, visual highlighting, colour coding, or multi-messaging [259] can also be used to add qualitative layers of meaning to the quantitative data. These can visually link sets, and highlight particular points that are important to the data-story being communicated. Such strategies can be used within the conceptual framework of data humanism. As discussed in chapter 2.3.2, this data visualization approach proposes to link the numbers to stories, knowledge, people, and behaviours. Adding layers of qualitative information to the quantitative data assists in translating "numbers into concepts we can relate to" [198].

Moreover, from the results of our analysis, we see potential for future design and communication research to experiment with data visualisations that connect the two crises, adding context and meaning to the effects of climate change. A deeper connection to people's day-to-day can lead to messages that encourage action, not hopelessness (chapter 2.2). The war's impact on the energy sector and the increased debate surrounding the energy transition to renewables can be leveraged to shift the climate debate towards solutions and action.

3.2.4.2 Exploring Alternative Data Visualisation Formats

Looking beyond standard chart models when working with data can be more visually engaging but also assist in communicating complex phenomena [198]. Understanding different audiences' interpretations of and engagement with these alternative data representations can help identify strategies that point to stimulating paths for future work. This research can significantly impact climate change communication.

The work by Lupi about nuclear risk and climate change [196] shows how layered visualisations can represent complex issues without oversimplifying the information (Fig. 3.7-B). These complex graphics don't follow a typical chart format and are enriched with several added layers of information that help emphasize or contextualize the quantitative data (as discussed in the previous section), creating very complex, yet informing and enriching experiences. This alternative format demands more consideration from the designer to ensure that the communication is effective, and more attention from the reader, but can lead to deeper engagement and understanding of the topics.

An article [222] found in the Climate Change dimension, uses photography of the burned areas within the data visualisations (proportional area charts), adding meaning and an emotional component to the numbers by illustrating the consequences of the wildfires (Fig. 3.7-C). The visualisation communicates an added layer of meaning through this visual treatment.

The results of our study highlight a very limited set of visualisation types used to illustrate the war and climate change joint phenomena. This gap points to an opportunity for exploring alternative and more diverse chart types. The complexity of climate change

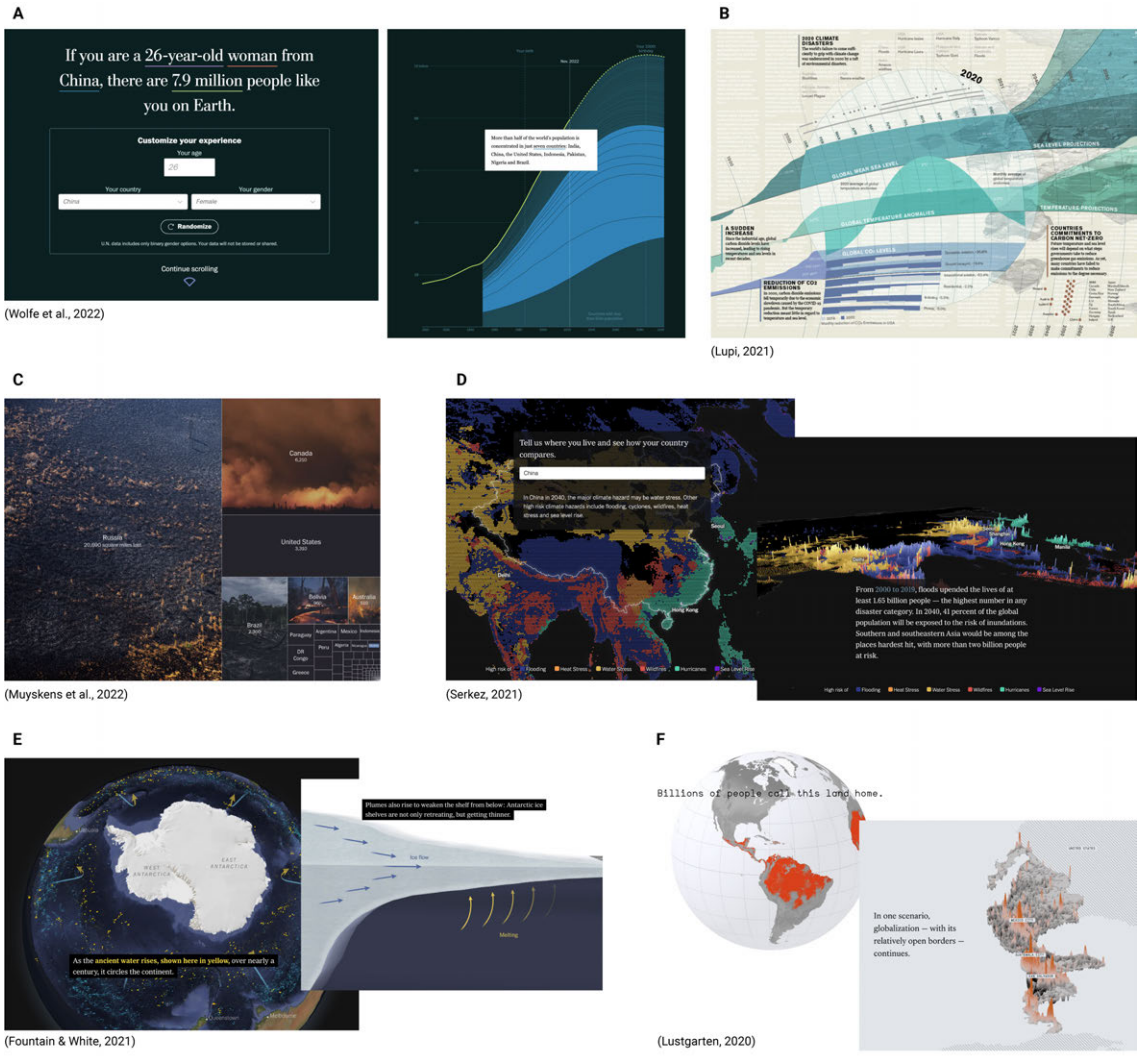

Figure 3.7: Data visualisation examples presented in the Implications for Design section.

opens vast opportunities for more engaging data narratives that can be presented through more creative visual formats.

3.2.4.3 Using Interaction to Assist in Communicating the Data

Our study highlighted how, except for one [167], all articles visualised data as a separate companion to the written content, and not as a self-standing or crucial piece of information. This strategy is limiting, diminishing the impact that digital data visualisations can have when informing and engaging audiences on its own visual grounds. Visual design can convey meaning instantly without the mediation of language. This aspect is fundamental in communicating complex ideas effectively.

The following articles [117, 260], when informing the readers about a certain country's climate risks, animate the country's map through the user's scroll (Fig. 3.7-D and E). The

visualisations are accompanied by small annotations of text that appear as the visualisations change, creating a sequential presentation of the information that is easily absorbed and less overwhelming than asking the reader to connect the separate text and the visuals by themselves. The impactful visualisations immediately catch the reader's attention and are indispensable elements of the article's argument. Unlike static infographics, the animated infographic about ice shelves in [117], controlled by the user's scroll, illustrates the information incrementally and sequentially, making it easier to understand (Fig. 3.7-E) as "information visualisation is not only about visual elements but also about interaction" [208]. Mauri and Ciuccarelli also highlight that these techniques "support the creation of exploratory paths, providing the user a step-by-step introduction into the complexity of the analysis" (ibid). Interaction in data visualisations can be used to showcase extra points of data – as is the case in the data set analyzed – but can also assist in interpreting and guiding the narrative.

Our study highlights the importance of interaction tactics such as markers of interactivity (pointing to interactive elements and guiding the user), filtering, timelines, transitions, etc., to fruitfully engage audiences in understanding and connecting with the data, avoiding information overload, hence disengagement with the topic. This is of paramount importance in climate change communication.

3.2.4.4 Explore Narrative Tactics for More Engaging Visualisations

The data visualisations analysed use a limited set of design strategies. Designers should consider an integrated approach that uses visual language, data content, the story communicated with the data, and the narrative (visual and conceptual). They should "question the impersonality of a merely technical approach to data" [198]. The potential of narrative visualisations can be explored through the use of visual narrative tactics – (i) visual structuring, (ii) highlighting, and (iii) transition guidance – and narrative structure tactics – (i) ordering, (ii) interactivity, and (iii) messaging [259]. These strategies can be used to guide the reader and assist in drawing meaning.

An article in The New York Times about migration caused by climate change [202] uses some of these strategies with great effect. The narrative starts with a simple, greyscale Earth globe that only comes alive as the user scrolls, as a continuous animated slide show (Fig. 3.7-F). The user controls the "speed" of the narrative, but the interaction with the content is limited, in a balance between an author-driven and reader-driven story [259]. This animated data map grabs the reader's attention and sets the stage for the article's argument. The data is further contextualized and humanized through photographs of the affected people. The data visualisations are used throughout the article as integral elements to communicate the information. All the visual and textual elements are designed to tell a coherent and engaging narrative. The interactive visualisations discussed above (Fig. 3.7-A, D, E) are also great examples of the use of data narratives, with the visualisations being a dynamic and indispensable part of the content.

Segel and Heer [259] focused their study on narrative visualisations that "contained clear sequences of narrative events, a diversity of visualisation genres (e.g., flowcharts, slide shows), and a range of interaction strategies (e.g., filtering, timelines)". Visualizing complex phenomena, like climate change, the war, or the COVID-19 pandemic, holds opportunities to employ narrative visualisation strategies to depict complexity without compromising data richness and personal meaning to various audiences.

3.2.5 Limitations of the analysis

Platforms with an English version restricted the venue selection, so these criteria eliminated highly read platforms such as Dainik Bhaskar (India) or Cankao Xiaoxi (China). Furthermore, even though the venues analysed are global in scope and some of the most read worldwide, they originate from the USA or the UK and can lean towards a more highly educated readership. Future work should broaden the analysis to a more diverse range of venues and target audiences.

3.3 Chapter Summary

In this chapter, we worked towards addressing the gap of mapping the landscape of interactions for climate change, with a special focus on data visualisation. In doing so, we intended to get a better understanding of the work that had been done so far, current communication strategies, and derive implications for future work that would guide the following stages of research. From this analysis, we derived nine implications for design.

First, we created an overview of HCI and Design projects on climate change from the past decade, analysing how they dealt with particular interaction and communication aspects. We analysed a corpus of 74 projects focusing on the general public. We found that: a) topics follow trends over time; b) most projects have a neutral messaging (neutral framing, based on examples and data visualisations, with no suggestion of actionable steps for after the interaction). This analysis and findings informed the proposal of the first five implications for design: a) Choose topics based on impact and audience; b) Explore interactive engagement in daily routine places; c) Help the users take action by proposing actionable steps; d) Positively frame the message with a narrative adapted to your audience; e) Explore alternative and more inclusive perspectives.

Even though this survey does not intend to be a definitive list of what has been done in these fields, we strived to further the discussion about the current landscape of HCI and Design research addressing climate change, more particularly concerning communication and interaction approaches. With the analysis and discussion of the work found, we aimed at assisting in the scholarly pursuit of new or less explored pathways that would guide our own research.

Secondly, and informed by the first survey, we focused mostly on mainstream media through the case-study of a "less obvious" topic (as informed by the topics most explored

in the first analysis). We therefore looked at relevant current events that had a strong effect on the environment. These events affecting people and the environment, such as the Russia-Ukraine war, can assist in giving meaning to the frequently abstract climate data. With this study, we set out to understand how the Ukraine war and climate change have been connected and visualized.

The results from the second survey contribute to the design and information visualisation community by suggesting avenues for future research into climate change data visualisations. These were formalised in four additional implications for design. Researchers should consider: a) contextualising the quantitative data; b) exploring alternative data visualisation formats; c) using interaction to assist in communicating the data; d) explore narrative tactics for more engaging visualisations. Additionally, future studies can examine the impact of audience engagement with alternative data representations and how these visualisations can influence climate change communication.

In the following chapters, we present how we applied the implications for design derived from these studies in order to contribute to climate change engagement within HCI.

4

A Novel Data Humanism Framework and Design Artefact

Taking into consideration the gaps and implications found in previous work (Chapter 3), this chapter is focused on the proposal of a novel framework based on the data humanism manifesto. We present the framework through the design and development of our artefact Finding Arcadia.[a]

[a] Conspicuous parts of the text in this section have appeared in a co-authored publication [107].

This research aims to respond to the calls for current climate change communication and engagement (Chapter 2.2), address the gaps found in previous work and implement the implications for design proposed (Chapter 3), while studying the efficacy of the communication choices employed. By testing strategies for making climate data tangible to everyday users, we hope to create purposeful urgency [175, 190].

Information visualization is crucial in assisting comprehension and engaging audiences with climate change data in relatable ways. We argue for the potential of data humanism to provide a general framework for prioritizing the ethical and human values in the design, use and interpretation of data [198, 197]. Following Lupi's approach (Chapter 2.3.2), data should be communicated alongside storytelling and relatable metrics that assist in giving meaning to the numbers. This design framework can be used to make the science of climate change accessible and engaging to a wide audience [199], also aligning with the UN's aforementioned guidelines: "*Presenting data alone may numb the audience. Make it relatable, local, and personal*" [130].

In this chapter, we analyse Lupi's data humanism manifesto [198] and derive methodological steps for future HCI and Design research applications. We intertwine these steps into an adapted version of the user-centred design process (UCD) [80] and propose a Data Humanism framework for designing engaging climate change data visualisations. We present this framework through the design of the interactive artefact *Finding Arcadia*. This project intended to engage users in different contexts of public spaces with ocean climate data in a personalized, contextualized, and action-focused way.

Throughout the chapter, we reflect on the design process, presenting challenges and deriving insights.

With the proposal of this framework and the design of the research artefact, we build theoretical contributions – methodological and through implications for design [144]. With this work, we assist in the future use of data humanism in designing climate change data interactions in public settings and contribute to research into alternative climate change communication.

4.1 The Data Humanism Framework

4.1.1 Integrating Data Humanism

Following the call for humanised data interactions about climate change, we formulated a Data Humanism framework [80] adapted from Evenson and Dubberly [101]. Within the six established phases of the design process, we propose stages that connect the research and design aspects with five steps operationalised from Lupi's proposals for data humanism [198] – (1. to 5. in the diagram – Fig. 4.1).

We followed this framework in the design of and interactive data-story artefact and its iterative testing. In this chapter, we describe each stage of the design process in detail, connecting it to its application in the studies. We also gathered challenges while applying the framework and derived proposals for future work. In Chapters 5 to 7, we detail the studies in the wild, their findings, implications, and iterations from version to version.

The framework was formulated to create interactive systems with a data humanism focus, harnessing both intrinsic characteristics for the urgent task of improving engagement with climate change topics.

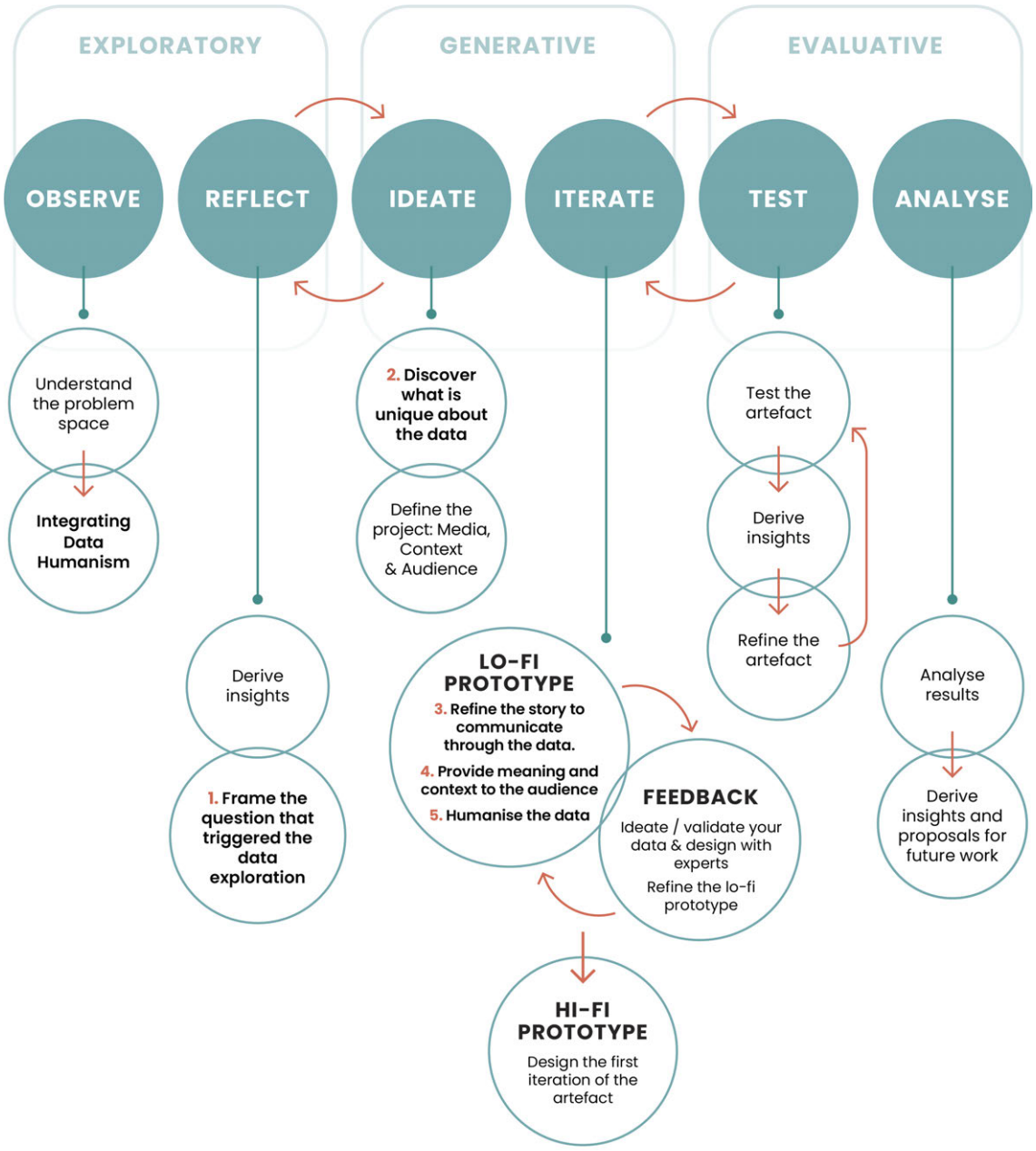

Figure 4.1: Framework of the proposed Data Humanism framework following a Research through Design (RtD) method.

4.1.2 Exploratory Phase: Observe

4.1.2.1 Understand the Problem Space

The framework begins with a deep understanding of the problem. For our study, we conducted literature reviews in several areas of interest, most importantly in climate change communication, sustainable HCI, and interaction and visualization approaches.

Focusing particularly on interaction projects about climate change, we conducted state-of-the-art surveys [110, 105, 106] to compile the communication and interaction strategies being taken by the HCI and design communities when tackling climate change projects. The gaps found in previous research and implications for design informed the work going forward, namely:

ID1. Choose topics based on impact and audience;

ID2. Explore interactive engagement in daily routine places;

ID3. Help the users take action by proposing actionable steps;

ID4. Positively frame the message with a narrative adapted to your audience;

ID5. Explore alternative and more inclusive perspectives.

4.1.2.2 Integrating Data Humanism

Data humanism [200] emerged as a promising response to the challenges of communicating climate change. It focuses on creating a deep connection between data and people by using techniques that help the audience relate and react to the information they are exposed to. Techniques such as storytelling, framing, personalization of the data, comparisons to other information, linking to the environment around the experience or the community it engages. Below, we detail the strategies used and how we implemented them throughout the story. These layers of "soft" data intend to add context and personalization, translating numbers into concepts we can relate to and, therefore, adding meaning to "hard" data [199].

In the *Finding Arcadia* project, after understanding the problem space and the gaps we intended to address, our purpose was to use data humanism to communicate accurate data in a story-led, contextualised, and personalised manner while suggesting specific action points for the audiences to take. The study would focus on testing the chosen strategies to understand if they resulted in more positive and engaging interactions with climate change.

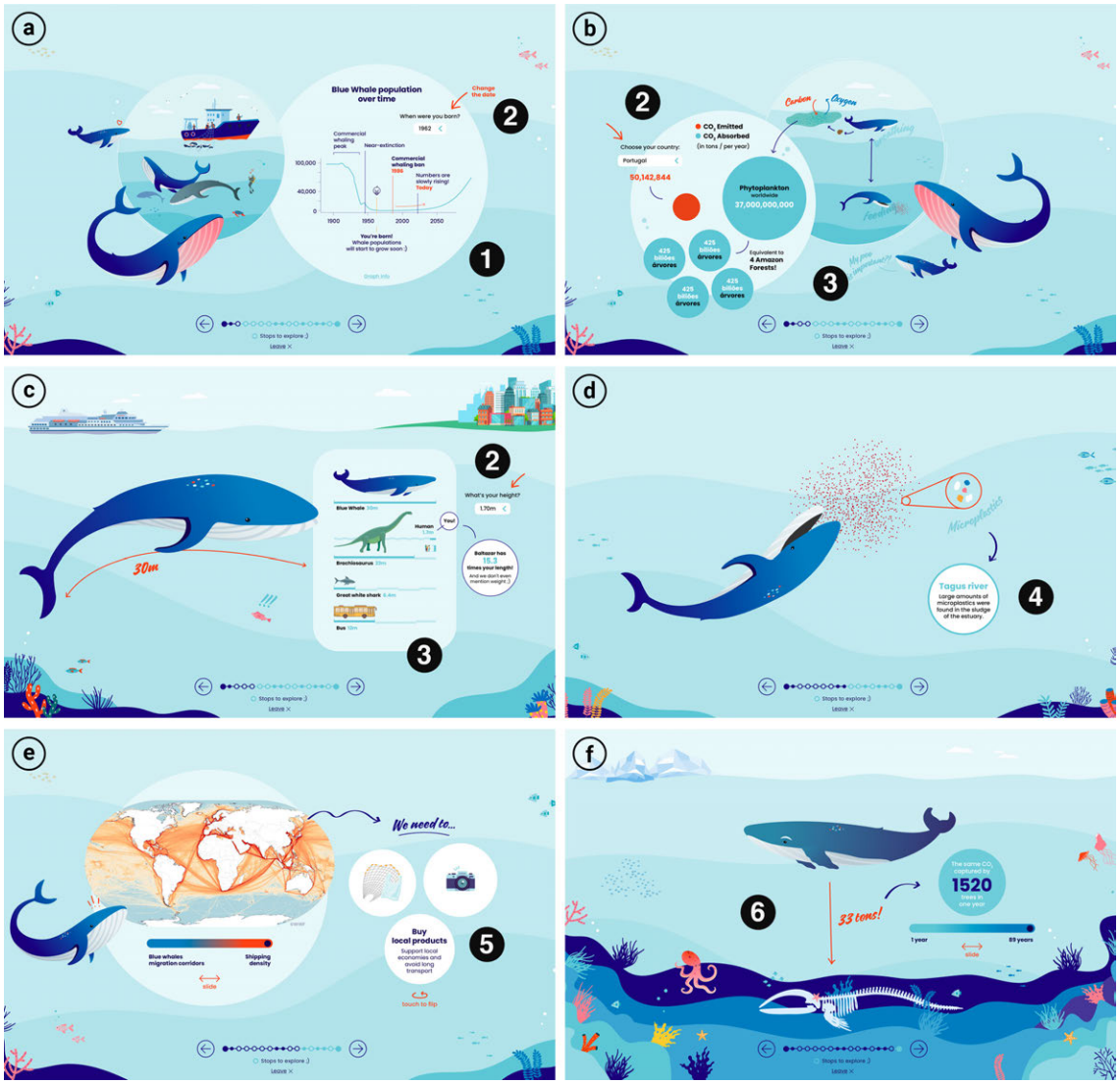

Figure 4.2: Sequence of screenshots from the interactive visualizations that summarise Baltazar's story, complete with the data humanization: 1) Give a positive spin to the narrative; 2) Allow the user to personalize the visualization; 3) Contextualise the data by comparing and adding layers of "soft" (qualitative) data; 4) Make the data relatable to this particular community; 5) Focus on action by proposing solutions; 6) Design the character journey as resilient.

The data about the oceans and whale CO2 cycle is communicated through the story of Baltazar, the Blue Whale (Fig.4.2). Therefore, we contextualize the data by connecting to sections of the story and the life of a whale and create empathy with the main character. Here, we give an overview of the main communication strategies used. The screens of the experience, the script of the story, and the communication strategies used are presented in full in Appendix A.

Striving for Positive Framing

To give a positive spin, we highlighted hopeful elements of the data – e.g. showing

the dramatic numbers caused by decades of commercial whaling while calling attention to the slow but exponential rise after the international whaling ban (Fig.4.2-1).

Personalizing the data

To help the audience relate to the data, we enriched the visualizations with personal layers of information from the user's input, adapting to, for example, their date of birth, height, or country (Fig.4.2-2).

Contextualizing the data

Throughout the story, data was contextualised to assist in interpretation. Examples of this are the carbon cycle and whale carbon/oxygen flux, where we add additional information or compare the data with more approachable information – CO2 absorbed by phytoplankton compared with trees, with CO2 emitted by countries the user can choose, adding elements for size comparison, etc. (Fig.4.2-3).

Linking to the location/community

We also added climate change information related to the Tagus river (Fig.4.2-4), as the communities where we tested the artefact have deep social and historical connections to fishing, navigation, tide milling, and other river activities. Another crucial aspect was closely connecting to action throughout the story, underpinning the idea of "hope" and giving a sense of agency.

Proposing Action

We proposed solutions related to each section's topic (Fig.4.2-5) – e.g., related to plastic pollution: "Look for natural fibres" or "Buy vegies and fruit not wrapped in plastic"; related to ship density: "Buy local products" or "If you do tourism in the sea, make sure it's with a certified company"; or linking to CO2 emission reduction: "Reduce food waste" or "Buy less stuff".

A Story of Resilience

Finally, and related to the previous point, we aimed to communicate a sense of resilience and hope by showcasing a character's journey that ended naturally and was not caused by the dangers he faced (Fig.4.2-6).

4.1.3 Exploratory Phase: Reflect

4.1.3.1 Derive Insights

The following step looks into reflecting on the information found and planning strategies to respond to it.

To address the implications for design, we arrived at the following insights. First, to communicate a recent International Monetary Fund (IMF) report [57] describing whales

as one natural solution for climate change mitigation – each great whale sequesters 33 tons of CO2 on average. This topic was chosen as it is a less-explored theme with great impact (ID1) that considers cohabitation [178, 204, 267] and more-than-human perspectives (ID5) [2, 115, 190]. Furthermore, this study had great coverage in mainstream media (e.g. [275, 311, 242]) and was accompanied by visualisations, presenting a great opportunity for visual analysis. We also proposed actionable solutions along the story (ID3), focusing the narrative on action and framing the message as positive, using strategies to personalise the data (ID4). Finally, we worked towards taking the interaction to "where the audience is" by choosing public locations for the implementation (ID2).

4.1.3.2 Frame the Question that Triggered the Data Exploration

The first step related to data humanism intends to identify the question behind the data exploration, focus the enquiry and lead the data collection process. Our enquiry focused on how to positively engage users with ocean-related data (IMF study) and how to transmit that data in a relevant way to our audience. We intended to highlight:

- That the ocean is crucial for global climate;
- Whales are a fundamental part of the ecosystem [162] and a natural and non-obvious climate change mitigator;
- Engagement with the ocean carbon cycle [57], connecting to users' lives.

4.1.4 Generative Phase: Ideate

4.1.4.1 Discover What is Unique About the Data

Transforming data into "something that can be felt, seen and reconnected to our lives and to our behaviours" [198] requires a deep look into what differentiates your data and how to explore and present it. The IMF study data is not widely known to non-experts. Ocean data, particularly, suffers from a lack of public visibility and needs new communication approaches to reach wider audiences [66]. We, therefore, capitalised on the novelty of this data. Furthermore, we saw the opportunity to create empathy through the whale story, fostering cohabitation and engaging users with less-known natural solutions (Fig. 4.3).

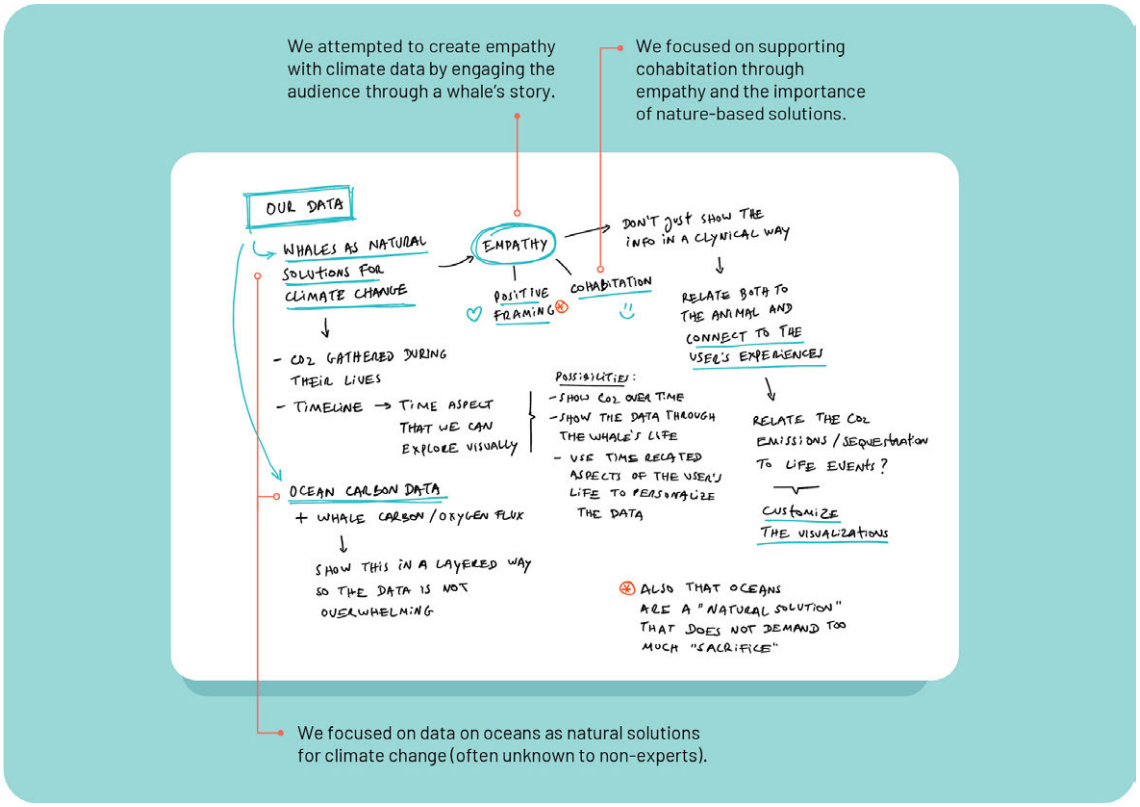

Figure 4.3: One of the sketches produced during the Ideation phase to help understand the differentiating points of the data set we are focusing on.

4.1.4.2 Define the Project: Media, Context and Audience

First, the context of implementation and audience must be chosen as these will greatly define the project's characteristics – informing the appropriate media to engage those particular users in that specific context.

We ideated several solutions to the problem, considering the conclusions from the Exploratory stage – from different outputs like an app, web-based narratives or public display, to different stories and character journeys – and decided to focus on a public interactive installation to bring the data to diverse audiences in daily-routine settings. The first context of implementation was a popular science museum. This meant a diverse audience representing different media literacies, education levels, and social and economic contexts. We considered this crucial aspect when designing the data story and interactive elements, working towards their ease of use and comprehension.

We created user personas and scenarios to help us formalise this information (Fig. 4.4), focus our approach and pinpoint potential challenges.

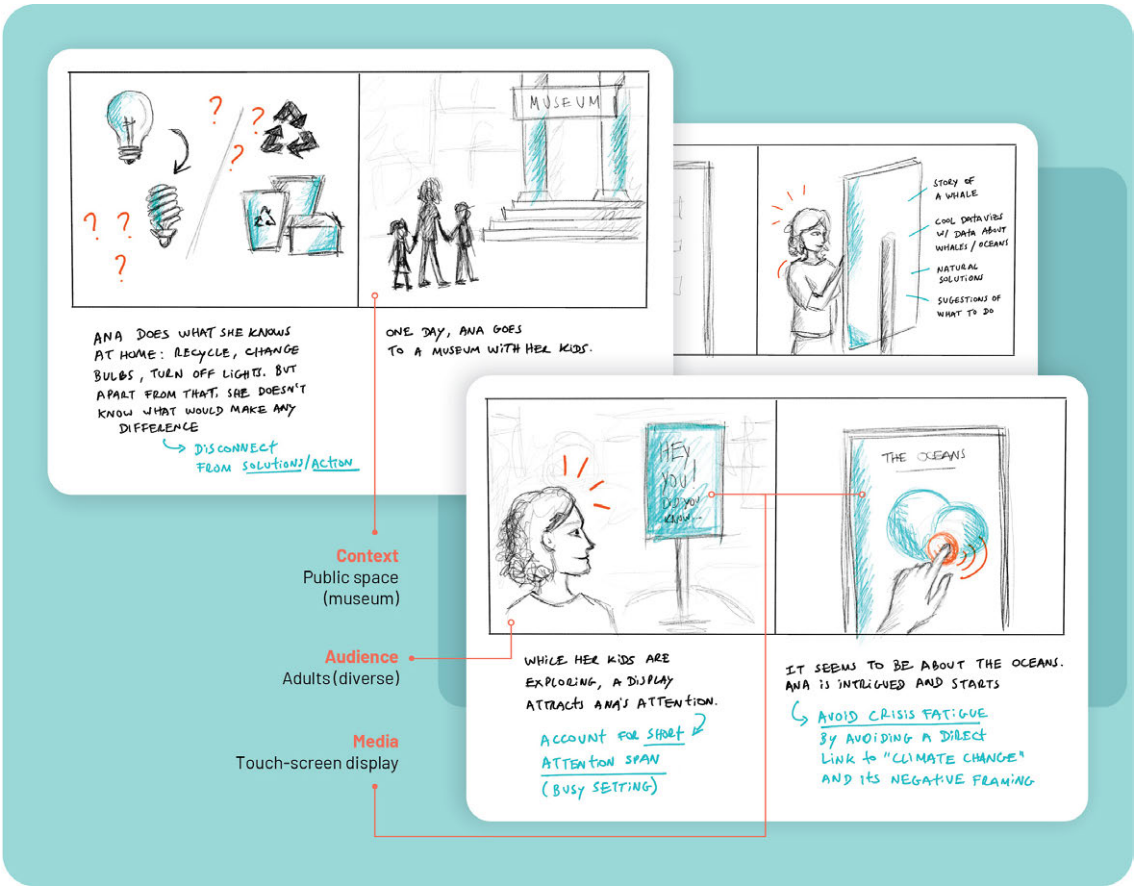

Figure 4.4: Examples of the scenarios created to understand the context, audience and media of the project and understand challenges and opportunities. In the top left, we see the problem the persona faces and the start of the trip to the museum (where the installation is). Next to that sketch, on the top right, there is a depiction of the persona interacting with the screen and a description of what they would see. Finally, on the bottom right part, the sketch depicts the moment the persona sees and starts interacting with the installation. In blue, we see the notes of the problems to solve or elements to consider in each moment of the user journey.

4.1.5 Generative Phase: Iterate – Lo-fi Prototype

We sketched our data story through hand-drawn lo-fi prototyping, considering the following data humanism-related steps:

4.1.5.1 Define the Story to Communicate Through the Data

According to Lupi, "a dataset might lead to many stories" [198] depending on the data collected, what is included or excluded, and how it is presented and contextualised. Therefore, it is essential to consider what story is told through the data – not manipulating information but considering the role subjectivity and context play in complex events and creating meaningful stories.

In our study, we intended to engage users with a positive, resilient and action-focused narrative about climate data. Fig. 4.5 illustrates how the different considerations were integrated in the data story (from a. to j.).

a. A data story that transmits accurate climate change information.

b. Give the narrative a positive spin by highlighting particular points.

c. Focus on action by suggesting solutions in several story stages.

d. Resilience in the character's journey – to give a message of hope and a positive ending to the story, the character embodies a journey of resilience through adversities and dies of old age, instead of succumbing to the dangers he faces caused by the Anthropocene or climate change.

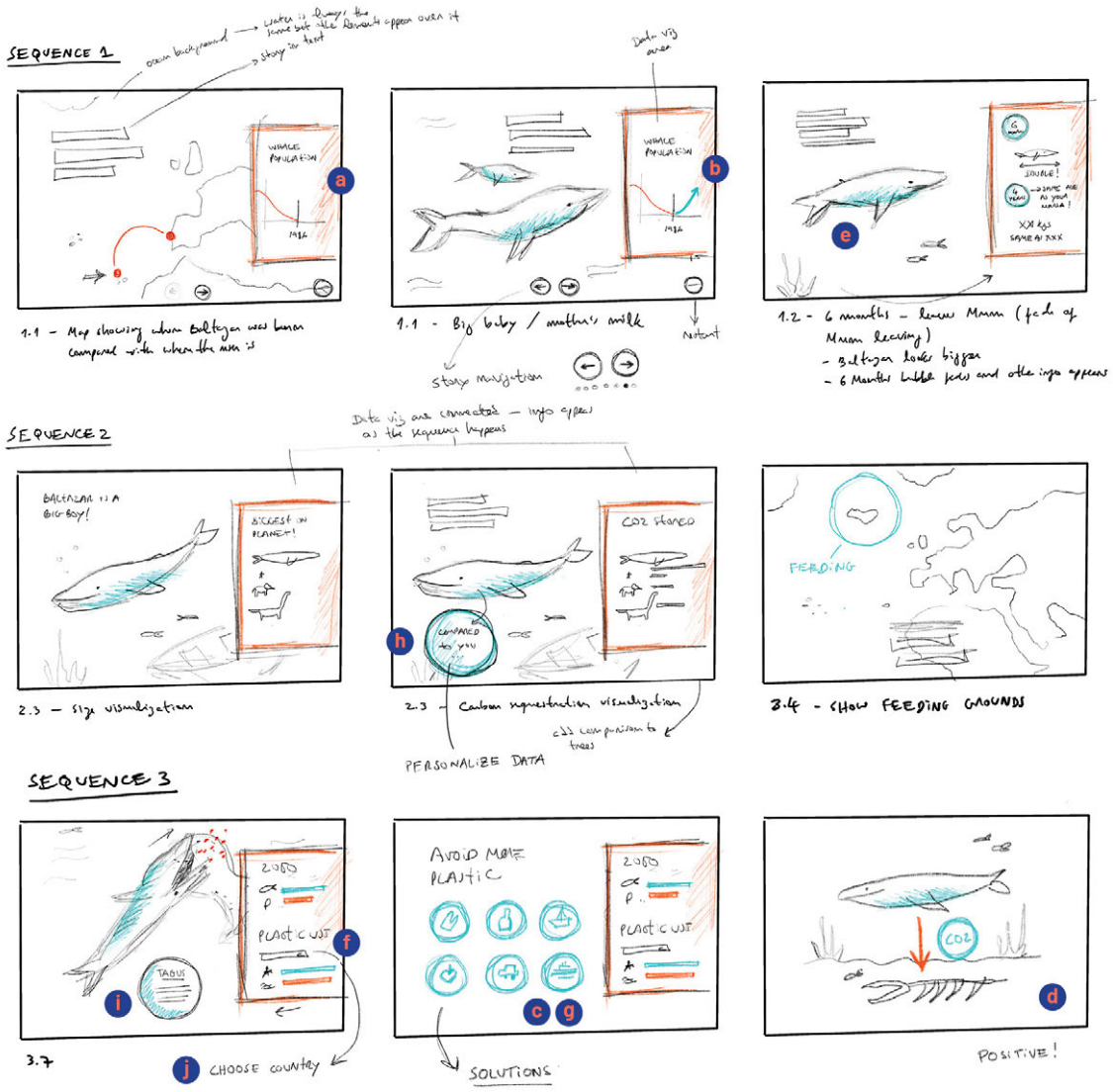

Figure 4.5: Nine boards of the hand-drawn sketches of the storyboard for the data story. With this storyboard, we planned how the data humanism features were integrated throughout the story. These strategies, from (a) to (j), are described in section 4.1.5.

4.1.5.2 Provide Meaning and Context to the Audience

We worked towards countering the generalised assumption that data is an impersonal, technical and clinical design asset by connecting it to relatable concepts. We did so by linking the numbers to what they stand for: stories, knowledge, people and behaviours [198]. These design solutions intend to translate the numbers into relatable and understandable concepts, a particularly important approach in interactions for climate change where the data is very complex and can feel overwhelming and distant. Our main focus points were:

e. To contextualise and humanise the data, it was anchored on the story of one particular (humanised) whale.

f. "Main data" (climate change) accompanied by layers of "soft (qualitative) data" (comparisons to more familiar metrics) to add meaning and assist in interpretation.

g. We linked to people's lives by suggesting actionable solutions and supporting positive communication.

4.1.5.3 Humanise the Data

Climate change data can feel very impersonal. "Humanising" the data can be achieved by combining data sets with layers of softer, more qualitative information to present its more nuanced and human aspects. The goal is to add depth and personality to quantitative information [197].

The following design decisions worked towards making the data personal and relatable, also connecting to a broader social context.

h. Interactive components allowed for personal layers of information to be added to the visualizations.

i. Adding snippets of climate change information particularly relevant to the community.

j. Allow for comparisons between national and global scales for a connection with one's context while also connecting to the global issue.

4.1.6 Generative Phase: Iterate – Feedback

4.1.6.1 Ideate/Validate your Data and Design with Experts

Use expert feedback sessions to ideate and validate the data and design decisions. The study's design process underwent several iterations based on validation and ideation sessions with experts in different fields.

- **Marine biologist:** Refinement/validation of the ocean-related data used to contextualise the IMF data.
- **HCI / storytelling Researchers:** Ideation/validation of the design decisions related to the story, interaction, and data representation.

4.1.6.2 Refine the Lo-fi Prototype

Follow the experts' feedback to improve the artefact. This led to several refinements, which we summarise below. In Fig. 4.6, we illustrate these revisions, from the first to the final version. These refinements eventually led to the development of the hi-fi digital artefact.

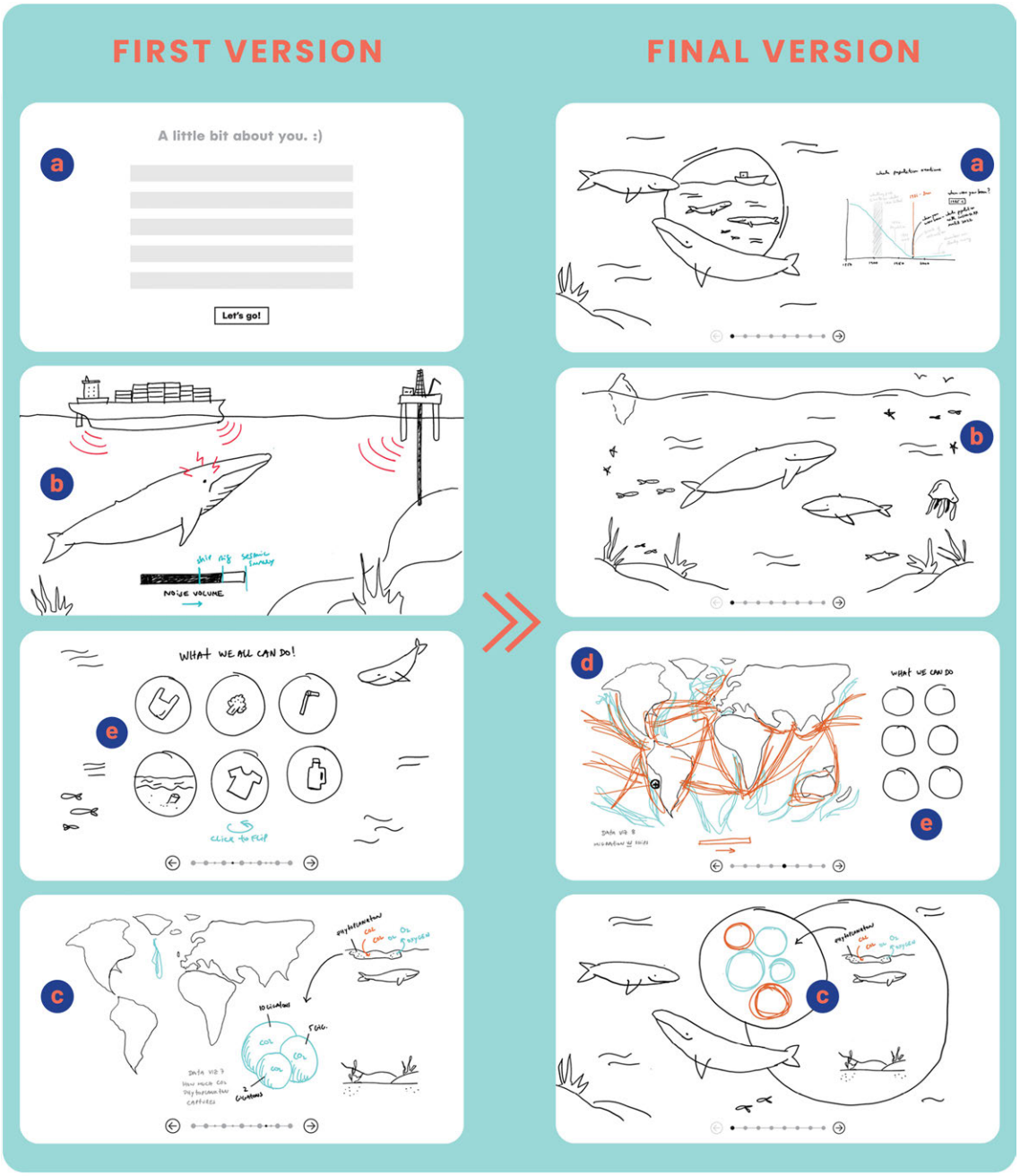

Figure 4.6: On the left, we show four slides of the lo-fi prototype for the first version of the interactive data story. On the right are four slides of the final version of the lo-fi prototype created after the expert feedback sessions. Marked from (a) to (e) are the changes listed in section 4.1.6.2.

(a) User input: The experts suggested that the user info should be incorporated

throughout the story and not at the beginning, for a more natural flow. To this effect, in the final version, the user added the information in each visualization.

(b) Storytelling: The story structure needed work for a better character journey. So, we edited the main character's journey: he's main objective is finding the place of his childhood and facing Anthropocene dangers along the journey. Also, the data needed to be weaved more into the story. One example of solving this issue was to make the character's mum explain part of the problem.

(c) Interactivity: The HCI experts suggested having more elements for users to interact with. Therefore, more interaction was added throughout the story, leading to more opportunities for personalization in the data visualizations.

(d) Whale data: The expert suggested even more dire real-world situations. Also to be less specific about some blue whale data as a lot is still unknown about the species.

(e) Suggestions for action: It was very important to have the biologist's expertise on the suggested actions. We asked his opinion on what solutions to propose relating the oceans to everyday actions. Also, instead of having the proposals for action in just one point at the end of the story, we added them throughout the experience, related to the data in that slide.

4.1.7 Generative Phase: Iterate – Hi-fi Prototype

4.1.7.1 Design the First Iteration of the Artefact

The audience engaging with the experience and their media literacy should be carefully considered, to ensure appropriate navigation and interaction. Besides integrating the data humanism aspects ideated in previous stages of the framework, the data visualizations should be user-friendly and readable.

Since the relevance of our study lies in the application of data humanism, we highlight the design decisions related to the three aspects we focused on regarding the data treatment illustrated in Fig. 4.7. First, focusing on contextualising the data, we used comparisons to personal contexts and better-known metrics. We also added contextualization by demonstrating how the aspects shown affected the whale characters. Secondly, to personalise the data, we adapted the data visualizations to the information the user inputted. Lastly, we worked towards giving the communication a positive framing by relating different points in the story to relevant suggestions for action. Furthermore, we highlighted hopeful aspects in the visualisations by pointing to hopeful aspects of the data sets.

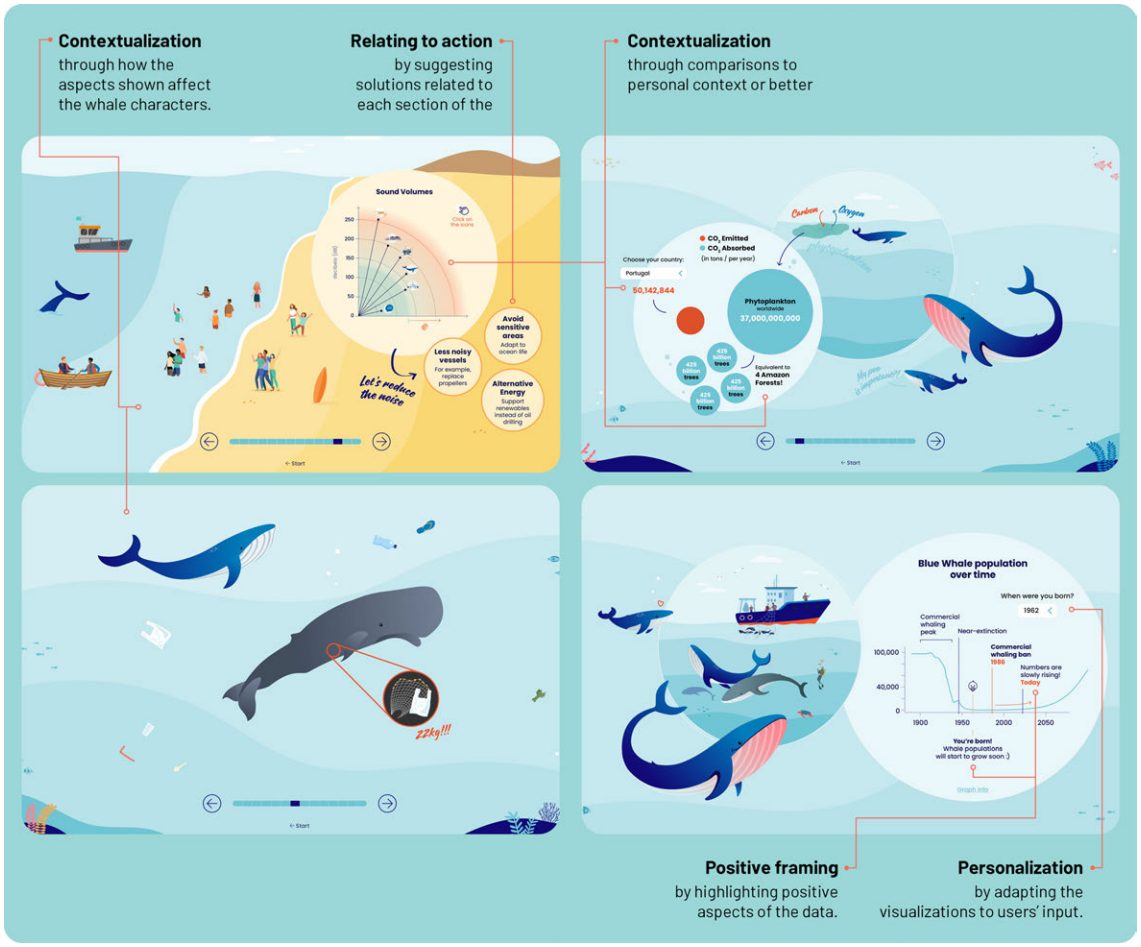

Figure 4.7: Four screens of the hi-fi digital artefact, with mentions of the data humanism strategies employed: Relating to action; Contextualization; Personalization; Positive framing. All the screens of the experience and a detailed description of the strategies used are presented in Appendix A.

4.1.8 Evaluative Phase: Test

4.1.8.1 Test the Artefact

The artefact should be tested in the appropriate context and with the intended audience. For studies in the wild, carefully plan the evaluation protocol considering people's availability and the research outcome.

For the pilot study, we deployed the artefact in a major science museum. We conducted observations and, after the interaction, user interviews (N=12) with six open questions meant to probe users' perceptions of the data presentation, their connection to the data, if it altered their feelings on climate change and if the suggestions for action inspired them. This iteration of the artefact and study are described and discussed in Chapter 5.

4.1.8.2 Derive Insights

After each user test, derive implications for the improvement of the artefact.

4.1.8.3 Refine the Artefact

A new iteration of the artefact should be made considering the conclusions from the user test. In Fig. 4.8, we highlight the most relevant improvements made from version 1 to version 2 of the artefact derived from the conclusions of the pilot study, including: a condensed version of the story to consider the limited attention span in settings of daily passage; improvements to the data visualizations with more interactive components for personalization; more actionable solutions to make them easier for the audience to act upon; link to community by adding information specifically relevant to them.

These refinements are described in detail in Chapter 5, section 4.

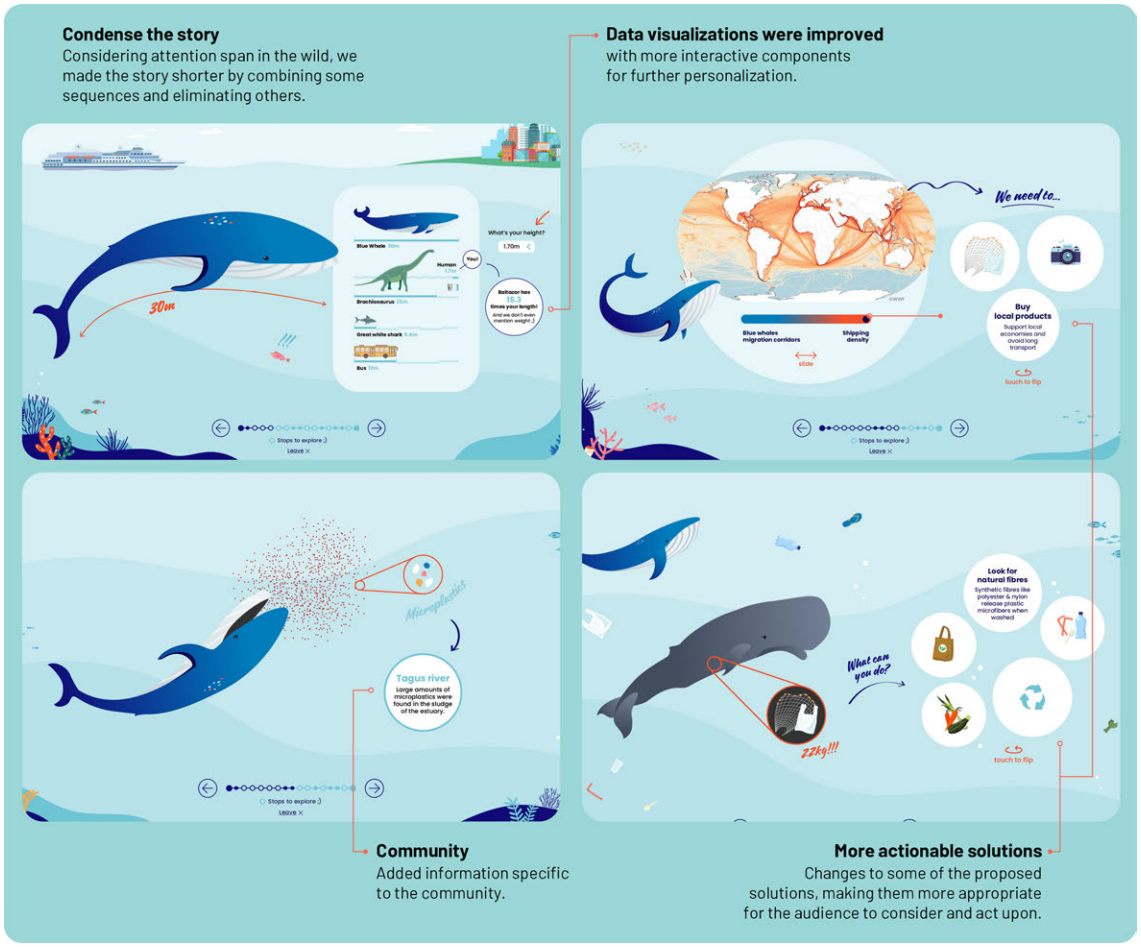

Figure 4.8: Four screens of the hi-fi digital artefact after the refinements derived from the pilot-test. More detailed description in Appendix A.

4.1.8.4 Test the Artefact (V.2 and V.3)

Test the new iteration of the artefact and study protocol. The second experimental study took place in a traditional market in a smaller city. This location was chosen in contrast with the first one: we intended to engage a more diverse range of users in a place of closer community. This new context and the purpose of our study led to changes in the study protocol. Besides noting observations, we conducted user questionnaires (N=64), a further open interview to users that demonstrated more availability to deepen our understanding of their perceptions of the data story (N=12); a follow-up interview a few weeks later (N=11); and a probing study with the original IMF visualisations (N=17). This second iteration of the artefact and first main user study are described and discussed in Chapter 6. We then went through another round of refinements informed by the findings of the study. This process led to a third iteration of the artefact and a second main user study in a Creative Hub (N=42), described and discussed in Chapter 7.

Each study allows for a better understanding of user's perceptions and relation with the data, and, therefore, a deeper understanding of data humanism for climate change engagement. Each iteration learns and build on the previous one. With this iterative process we were able to build theory through the design process in line with the principles of RtD [314].

4.1.9 Evaluative Phase: Analyse

4.1.9.1 Analyse Results

As Zimmerman et al. [314] have cautioned against, design research must consider how the projects should be evaluated and how contributions can be valued to reach high-quality outcomes. Climate change is a polarising topic, and evaluating visualization strategies, users' perceptions of these design choices, and the overall issue presents its challenges. Furthermore, the circumstances of deploying in the wild (museum, market, and creative hub) meant a disruption in people's routines, so the tests had to consider their availability. We considered these circumstances and adapted the questionnaires and interviews to the context and audiences we were engaging.

Our research intends to provide the HCI and Design communities with insights and proposals for the communication of, and interaction with, climate change topics through a data humanism approach. With this intention, we discussed the results and formalised recommendations for future research in each of the studies performed.

4.2 Sustainability Considerations

In line with our commitment to sustainable research and given the ongoing discussions surrounding SHCI's role and obligations, we report on the sustainability measures adopted during this research.

While our research delves into sustainability-related topics, we acknowledge our systems' inherent material and energy consumption. On the energy front, the venues of our main studies use solar energy to a certain extent. Nevertheless, we remain contingent on externalities. Going forward, it's pivotal that lab policies take on a more autonomous and adaptable approach towards fueling our digital outputs.

Focusing on the installation's physical aspect, the public display's principal frame is predominantly crafted from upcycled plastic, excluding components like screws, wheels, and screen-mount. This material was procured from a nearby enterprise specializing in repurposing plastic for outdoor constructs. Notably, the adornments can be removed, allowing the structure's reuse in subsequent projects and as a lab fixture. Pre-existing lab resources like the touchscreen, computer, and accessories were repurposed, eliminating the need for new acquisitions for this project.

4.3 Chapter Summary

This chapter presents the novel framework – the Data Humanism framework for designing engaging climate change data interactions. This framework intends to assist in the future application of data humanism in interactive projects but understands and accounts for the fact that every design problem responds to particular circumstances. The intention was not to arrive at a universal method, but to propose a flexible, speculative and resilient framework that could guide the design of future climate change data humanism interactions.

Through examples of application, we might learn something and create theory [243]. In the words of Bill Gaver, "it is the artifacts we create that are the definite facts of research through design" [123]. We described the various stages of the framework and presented them through the design of the *Finding Arcadia* artefact – an interactive data story to engage users in different contexts of public spaces with ocean climate data in a personalized, contextualized, and action-focused way.

By prototyping and testing different components and stages of the artefact, we were able to refine and improve different aspects of the interactive experience, storytelling, and data presentation. We reflected on the design process and testing in the wild, presenting challenges and deriving insights.

5

Pilot Study: Probing User's Perceptions into Data Humanism for Climate Change

This chapter is focused on the design and testing of the first version of the Finding Arcadia artefact, exploring our Data Humanism framework. We describe the rationale behind the design concept and visual choices, the testing protocol, study results and implications for future work. The knowledge gained in constructing this artefact, and aligned with the theoretical background and related works (Chapter 2), was applied to the following iterations described in chapters 6 and 7. [a]

[a] Conspicuous parts of the text in this section appear in a co-authored publication currently under review.

In the previous chapter, we presented our proposal for a framework that leveraged the principles of data humanism, prioritizing ethical and human values in data interpretation [198, 197]. This framework, emphasizing storytelling and relatable metrics, intends to make climate science more accessible, moving beyond mere data presentation to meaningful engagement. To test the framework, we developed the interactive artefact *Finding Arcadia* following the design principles and steps proposed.

This chapter presents the pilot study performed in *Pavilhão do Conhecimento*, the foremost Portuguese Science Museum. Considering the purpose of this first study as an initial investigation into the framework and the data humanism strategies used, we focused on probing users' relation to the data and gathering high-level feedback on the data visualisation features. We focused on users' connection with the data (or lack thereof) and whether the data story produced feelings of agency and hope towards climate change.

From the results of the study, we derived implications for future work that informed the refinement of the data story and data humanism features, leading to a refined version of the artefact and the first main study in the wild (described in the following chapter).

5.1 Research Artefact: *Finding Arcadia* version 1

Derived from the challenge of engaging users with more accessible and actionable data visualizations, we set out to test interactive data humanism for better engagement with climate change data. During the Exploratory Phase, we conducted a deep analysis of previous work and current visualization strategies (Chapter 3), from which we derived implications for future work. These gaps and suggestions strongly influenced the direction of the research, as demonstrated in several design decisions throughout the Generative Phase. The ideation process led us to data humanism as a promising approach to addressing communication needs.

Data humanism proposes connecting the data to qualitative information and allowing for contextualization and personalization. This approach hopefully makes the data more relevant to users. To operationalise data humanism, we derived five steps from Lupi's manifesto [198, 197] and proposed a novel Data Humanism framework (Chapter 4) [107]. To apply this framework, we designed *Finding Arcadia*, an interactive story-driven visualization of a nature-based solution to mitigate climate change. We started by (1) *framing the question that triggered the data exploration*, our focus is on communicating oceans as crucial for global climate through the ocean carbon cycle data [57], and whales as a fundamental part of the ecosystem [162], as well as connecting the data to people's lives. We gathered (2) *what was unique about the data*, creating empathy through the whale story, fostering cohabitation, and engaging users with less-known natural solutions. Then, we (3) *defined the story to communicate through the data* by crafting a positive but accurate whale story, focusing on resilience and action. To (4) *provide meaning and context to the audience*, the data was communicated through the story of the whale, constantly presenting the "main data" (climate change data) accompanied by layers of "soft (qualitative) data" (comparisons to more familiar metrics and situations), including actionable solutions. Finally, to (5) *humanise (or personalise) the data* to make it approachable and relatable, also connecting to broader social context, we conceptualised strategies that would allow for some personalisation of the visualisations through users' input and added snippets of climate change information particularly relevant to the community while also showcasing the global scale of the topic.

By following the design process, we arrived at an artefact that focused on communicating the whale and ocean data set in a personalized, contextualized and actionable manner, considering more-than-human perspectives and the impact of the topic instead of societal trends. During the ideation stage, we settled on a public interactive installation to bring the data to diverse audiences in daily-routine settings that we could then test in the wild in different contexts.

As RtD proposes, our interactive story-driven visualization is an artefact that works as the "realised design example" [123] from which we derive insights, perceptions and implications to inform theory creation and future research. Through this first iteration, we set out to understand if the data was engaging and relatable to the individual user and

if the experience led to a more positive outlook on climate change propelled by action.

5.2 Pilot Study

This section describes the goals and measures used in the artefact testing and explains the context and protocol used. Finally, we detail the data analysis and results.

The interactive data story was presented through a touchscreen display where the story was narrated. Users could interact directly with the data visualizations (Fig. 5.1). The screen was placed in a triangular module made of recycled plastic – one face with the screen and two other faces with tangible elements that users could engage with and leave their feedback on. The pilot study occurred in *Pavilhão do Conhecimento*, a Portuguese science museum in Lisbon.

We conducted the pilot study for five days in *Pavilhão do Conhecimento*, a major science museum in Lisbon, during the UN Ocean Conference 2022. The pilot was meant to test the data story, understand its appeal to various audiences, and pilot the interview protocol.

5.2.1 Participants

Twelve adults were interviewed (A1 to A12). Even though most of the visualizations and interactions were also suited for younger audiences, our purpose was to understand better how adults deal with the negative communication around climate change and crisis fatigue and how our approach responded to them. Therefore, we focused our study on adults (over 18 years old) – young adults (18-34): n=3; adults (35-64): n=7; senior adults (65-74): n=2. Regarding gender, n=7 identified as female and n=5 as male. All twelve users were educated at the undergraduate level or higher.

5.2.2 Procedure and Methods

The installation was placed inside the museum in an area accessible only to visitors during the conference and then for two days in a passage location to all visitors (Fig. 5.1). Three researchers were involved in the study, taking turns during the opening hours of the museum. All three were responsible for noting observations and engaging with users to conduct the user questionnaire. During the five days of implementation, we gathered observation notes regarding the user's stance, attitude, and comments. The researcher observed at a distance and allowed users to start the activity alone. After the interaction, the researcher approached users, explained the purpose of the study, and asked if they could answer a brief questionnaire based on four demographic questions and six open questions meant to probe: a) what the user thought of the way the data was transmitted and the interactive elements; b) if they considered the information relevant to them personally; c) if the experience made them feel more optimistic, pessimistic, or the same as before; and d) if the experience inspired them to take any form of action. We gathered twelve user interviews (A1 to A12).

5.3 Findings from the Pilot Study

Below, we highlight the insights gathered from the results of the pilot study.

5.3.1 Interactivity helped with engagement

Through the observations, we noted that the parts of the story which included interactive elements had much deeper engagement than the more passive ones. Users commented that the interactive features (e.g. buttons, sliders, and clickable components) promoted engagement and understandability of the data: *"I liked to interact not only with words. Those elements help in understanding the information."* (A8); *"It helped understanding. (...) The interactive elements helped to contextualize. It's not so dense."* (A12). However, most users did not complete the full story. The context of a public setting, particularly one where the project was "competing" with many exhibitions and installations, demands carefully considering the experience's length. This version seemed to be too long for the context and audience.

5.3.2 Information was perceived as generally useful

Some users thought the information was helpful for them personally, and most thought it was beneficial for society in general. However, some commented that the solutions proposed were not actions they could do themselves (e.g., related to public policy). Hence, they pointed to a disconnect with their lives: *"The solutions specific to the oceans are not so actionable. Other things like the ships, you can only ask for government action."* (A7); *"I can't have much impact in these matters." (A10); "I wouldn't say particular to my life but mankind in general."* (A9).

5.3.3 Contextualization of the data through the whale story

The whale story was used to give context to several data sets. For example, one of the visualizations in the artefact shows the whale population over time, becoming almost extinct but slowly recovering since 1986 (Fig. 4.2 a). Despite showing all the "negative" data, we highlighted "positive" aspects to influence the data story. Users commented on this particular point: [how they felt after the story] "*Happy to know that whales are recovering*" (A1); "*The part of already being prohibited left me happy for knowing it's already getting better*" (A6); "*From the numbers of whales growing, I'm more optimistic*" (A11). Communicating climate change through a less-known topic can effectively engage users with the data.

5.3.4 Proposals for action were seen as very positive

The topic of "climate change" tends to trigger the existing negative frames already in place. For example, one user commented that when they realized it was about the impact of the Anthropocene on marine ecosystems, they expected the story to have a dramatic

Figure 5.1: Deployment of the artefact's first iteration: Pilot study in the science museum.

ending: *"I was afraid it would end badly. I was glad he died naturally."* (A9). The proposals for action were one of the strategies used to work towards a more positive framing of the topic, countering current mainstream communication as mentioned by this user: *"Information given is good. The media informs through fear. It has more impact, but then they don't explain what we should do."* (A11). Participants highlighted that the proposals of actionable steps provided a more positive outlook on climate change. However, there was still a conflict between the positive data presented in some visualizations (e.g., the whale population numbers rising) and the perceived negative/overwhelming general information: *"Happy to know whale numbers are recovering."* (A1); *"More the perspective of the future, trying to help. Focus more on action than on the negative."* (A5); *"I felt a bit defeated because I feel there isn't much I can do but felt good because I saw some things are getting better. Like the increase in whale numbers."* (A7); *"It added information. It was nice seeing the whale numbers going up. That's a positive thing. The info about ships, the noise, depresses me because I don't see a quick solution."* (A9). Even with communication strategies in place that are mentioned as positive, these contradictory comments highlight the challenge of engaging users with climate change topics without triggering existing negative biases.

5.4 Implications for Future Iterations

The objective of the pilot study was to get an initial view into users' relationship with the data visualization strategies employed and their perceptions and connection to the data. The results of the pilot helped us pinpoint some important aspects to improve and led to several revisions in the artefact.

First, the fact that most users didn't finish the story, either from an apparent lack of interest or from their attention being demanded by external factors, suggested a need to shorten the experience. Therefore, we redesigned the story of Baltazar to be more

concise and focus more on the data-visualization moments. Linking to this result, we added interactivity to the visualisations to keep the user engaged and enhance the data humanism features.

Inspired by users' comments on the proposed solutions and their feelings of lack of agency towards some of them, we altered some actionable suggestions throughout the story. The purpose was to make them more appropriate for the audience to consider and act upon.

Lastly, we revised the testing methods, adopting a new evaluation survey based on a Likert scale and further open questionnaires for more varied data sets and a more straightforward approach in the wild.

The revised iteration and its study are described in the following chapter.

5.5 Chapter Summary

In this chapter, we presented the pilot study for the *Finding Arcadia* artefact, designed following our proposed Data Humanism framework. We conducted a mixed-method study in the wild in a science museum to probe user's perception of the data through the communication strategies used. The observations and open questionnaire performed with twelve users allowed us to understand that the interactive components greatly helped with engagement with the data visualisations. Furthermore, information was perceived as generally useful, and the proposals for action were seen as positive aspects of the exchange, even though there was some disconnect from the proposals linked with broader system changes. Lastly, communicating the data through a whale's life helped contextualise the numbers. These results from the pilot led to several proposals for the refinement of the artefact. The new version of the project and the first main study are described in the following chapter.

6

Countering Crisis-Fatigue: Connecting with Climate Change Data through Personalization, Context and Proposing Action

In this chapter, we describe the second iteration of the artefact, which builds on the first version pilot-tested in the science museum. In the following, we present the design decisions for this second version, the study methodology, results, and implications for future work.[a].

[a]Conspicuous parts of the text in this section appear in a co-authored publication currently under review.

This chapter presents the first main study testing the second iteration of the *Finding Arcadia* artefact. Considering the communication challenges of engaging users with climate change topics (Chapter 2.2), in this study, we focused on testing interactive data humanism to counter negative communication and crisis fatigue. Following the principles of the Research through Design (RtD) method [314], we built on the findings from the pilot study and improved the design of the artefact. Through this new iteration, we intended to test the data humanism strategies used more in-depth and answer (RQ)2: How can data humanism contribute to creating positive and empowering engagements with climate change information. To guide this enquiry, we focused on three research questions in this study:

a) If and how users engage and feel connected with humanized data;

b) If, through interacting with humanized data, users acquire a positive outlook on climate change;

c) If solutions-oriented visualizations create a feeling of empowerment and agency in climate matters.

We start by presenting the design decisions for this iteration of *Finding Arcadia*. Then, we report on the studies performed: to better understand the user's relation to the data as

communicated by the IMF's original visualizations [57] (N=17), and to test data humanism approaches through the implementation of our artefact in a local food market (N=64). We follow with the study's results, focusing on audiences' prior perceptions of climate change, the overall perceived enjoyment and value of the experience, and the impact of the different strategies used: adding context to the data, personalizing the data visualizations, and relating to actionable solutions. Finally, we reflect on these results, discussing the need to add context to climate change data, how the solutions-oriented data story helped in giving users a sense of agency, but simultaneously the challenge of countering the negative framing associated with climate change. This discussion led to insights for future work in HCI and Design for action-focused interactions with climate change data.

6.1 Research Artefact's Design Decisions: *Finding Arcadia* version 2

For the second iteration of the artefact, we considered the lessons learned from the pilot study and redesigned parts of the interactive experience. The aim was to make the data-story more appropriate for the daily routine settings we focus on and enhance the data humanism features explored. The main edits for this phase were:

- The story was shortened to make it more concise;
- Data visualizations were improved with more interactive components that also enhanced the Data Humanism approach taken;
- Changes to some of the proposed solutions, making them more appropriate for the audience to consider and act upon;
- Testing methods, adopting a new evaluation survey based on a Likert scale and further open questionnaire for more varied data sets and a more straightforward approach in the wild.

The key design principles regarding data humanism, outlined in Chapter 4, are summarized here. We conveyed information about the ocean and whales CO2 cycle through the narrative of Baltazar, a Blue Whale. By weaving the data into Baltazar's story, we provided context and fostered an emotional connection with him. To offer an optimistic perspective, we spotlighted encouraging aspects of the data, such as the significant decline in whaling numbers after decades of commercial exploitation and a gradual yet significant recovery after the international whaling ban. To make the data more relatable, we incorporated personal details based on the audience's input, like their birth date, height, or nationality, into the visual representations. Throughout Baltazar's journey, we made the data more understandable by giving additional information or comparing it to familiar concepts, like comparing CO2 absorption by phytoplankton to

that by trees, or CO2 emissions by different countries. We also included information about climate change impacts on the Tagus River, relevant to the local community's deep-seated connection with river activities. A key element was consistently linking the narrative to actionable steps, reinforcing a message of hope and empowerment.

The audience engaged in the pilot study also informed the placement of the main study, as we wanted to reach a more diverse group of users. In the science museum, all twelve users had higher education. Therefore, we chose a location for the study that would hopefully present a more diverse audience.

The design changes made for the second version of the artefact are presented in full in Appendix A.2.

6.2 User Study

This section describes the goals and measures used in the artefact testing and explains the context and protocol used to examine the research questions. Finally, we detail the data analysis and results.

Our work set out to understand: a) If and how users engage and feel connected with humanized data; b) If, through interacting with humanized data, users acquire a positive outlook on climate change; c) If solutions-oriented visualisations are effective in creating a feeling of empowerment and agency in climate matters. To reply to this enquiry, our RtD process included one study with the original IMF data visualisations and an "in the wild" study with our artefact. For the latter experimental study, the interactive data story was again presented through a touchscreen display where the story was narrated. Users could interact directly with the data visualizations (Fig. 6.1). The screen was placed in a triangular module made of recycled plastic.

We decided to implement the main study in a local food market to cater to a more diverse population of non-experts. As Emily Dawson has shown, low-income and less formally educated groups experience exclusion from spaces of informal science education, such as science museums, often considering that those spaces "are not for them" [79]. A truly socially transversal engagement practice with climate change data must consider these challenges. Furthermore, we would be engrossed in a local community, taking climate change data to a place users attend in their routine while capitalizing on the novelty of such an activity in that context. The physical installation maintained the same structure as in the pilot study, with the new iteration of the story available on the touchscreen display (Fig. 6.1). Two researchers were involved in the study, alternating turns during the opening house of the market. They noted observations and engaged with users to conduct the questionnaires. The study lasted over eight days in two consecutive weeks (Wednesday to Saturday). To further understand users' relation with the data, we also conducted open interviews on-site and a few weeks later. In the following sections, we describe the study in detail.

Figure 6.1: Deployment of the artefact's second iteration: Study in the local food market in Barreiro.

6.2.1 Participants

As in the pilot study, we focused the main study on adult users (over 18 years old). The participants (N=81) were diverse in age: young adults (18-34): n=10; adults (35-64): n=50; senior adults (65-80+): n=21. Concerning gender, n=28 identified as male, n=52 as female, and n=1 their gender identity was not listed. The implementation context also presented an audience diverse in education level: Primary school: n=9; Middle school: n=9; Secondary School: n=20; University education: n=43.

6.2.2 Procedure and Methods

The module was placed near the market's main entrance and worked autonomously, i.e., users could walk up to the screen and initiate the interaction themselves. During the test, we quickly realized that this context and population demanded more proactive participation from the researcher. While being a foreign element in the market and enticing the passers-by's curiosity, most users did not feel at ease initiating interaction. Therefore, the researcher took a more active role in engaging the passers-by and, especially with older users, assisting during the interaction. This resulted in a collaborative exploration of the visualizations, becoming a bridge for dialogue between the researcher and the user.

After the initial contact, the researcher briefly explained the nature of the activity without going into much detail regarding the topic or the data and initiated the story. The intention was for the user to go through at least two visualizations. Afterwards, the users replied to a user questionnaire, and the ones that demonstrated more availability were further interviewed. We also asked users if they agreed to a brief follow-up interview around seven weeks later.

We collected data from five different sources:

1. **User questionnaire.** We conducted three demographics questions (age, gender, and

education level), five questions meant to assess prior understanding of climate change matters, and fourteen questions adapted from the Intrinsic Motivation Inventory's (IMI) Interest/Enjoyment and Value/Usefulness scales [253, 254]. These were randomly ordered and answered on a scale of *1 – Strongly disagree* to *5 – Strongly agree* (Fig. 6.2). This study resulted in 64 valid answers.

2. **User interview.** Afterwards, twelve users answered a semi structured-interview (B1 to B12), going deeper into the content interpretation and the user's perception of how the data was transmitted and interacted with.

3. **Observations.** During and after the user's interaction with the installation, the researcher took notes on user comments, interaction, apparent engagement, and other relevant points.

4. **Follow-up user interview.** To better understand memorability, what aspects users felt most compelled by, and possible changes in perception, we conducted a follow-up user interview of twelve open questions with eleven users (C1 to C11), six to eight weeks after the activity.

5. **Probing Study.** To understand users' perceptions of the original data and its presentation in the IMF study [57], we performed a parallel study where we conducted the user questionnaire and user interview with a group of seventeen users (D1 to D17), recruited from within the same community. We presented the three original visualizations from IMF through a touch-screen device.

6.3 Findings from the Study

The answers from the user questionnaire were organised in a table and the data qualitatively analysed following the IMI scale [253, 254]. The user interviews, observation notes and follow-up user interviews were transcribed and then color coded according to the three aspects of data humanism we focused on: a) contextualization, b) personalization and c) proposed actions. This coding led to the organisation of the qualitative data into clusters that were then linked to the results of the user questionnaire to understand the impact of the tested communication dimensions. The results are presented below, first examining the users' prior knowledge and perceptions of climate change, followed by the overall results, and then focusing on the main analysis regarding data humanism. The answers from the main study and probing study were compared by applying the Mann-Whitney U test using SPSS (Fig. 6.2). This exercise aims to understand if there was a difference in users' perception and engagement with the data between the two approaches. Differences between the two groups were statistically significant for the following questions: i) Interest/Enjoyment: Q7 ($p < 0.05$), Q8 ($p < 0.001$), Q11 ($p < 0.05$), Q12 ($p < 0.05$); ii) Personalization: Q13 ($p < 0.001$), Q14 ($p < 0.001$), Q16 ($p < 0.05$);

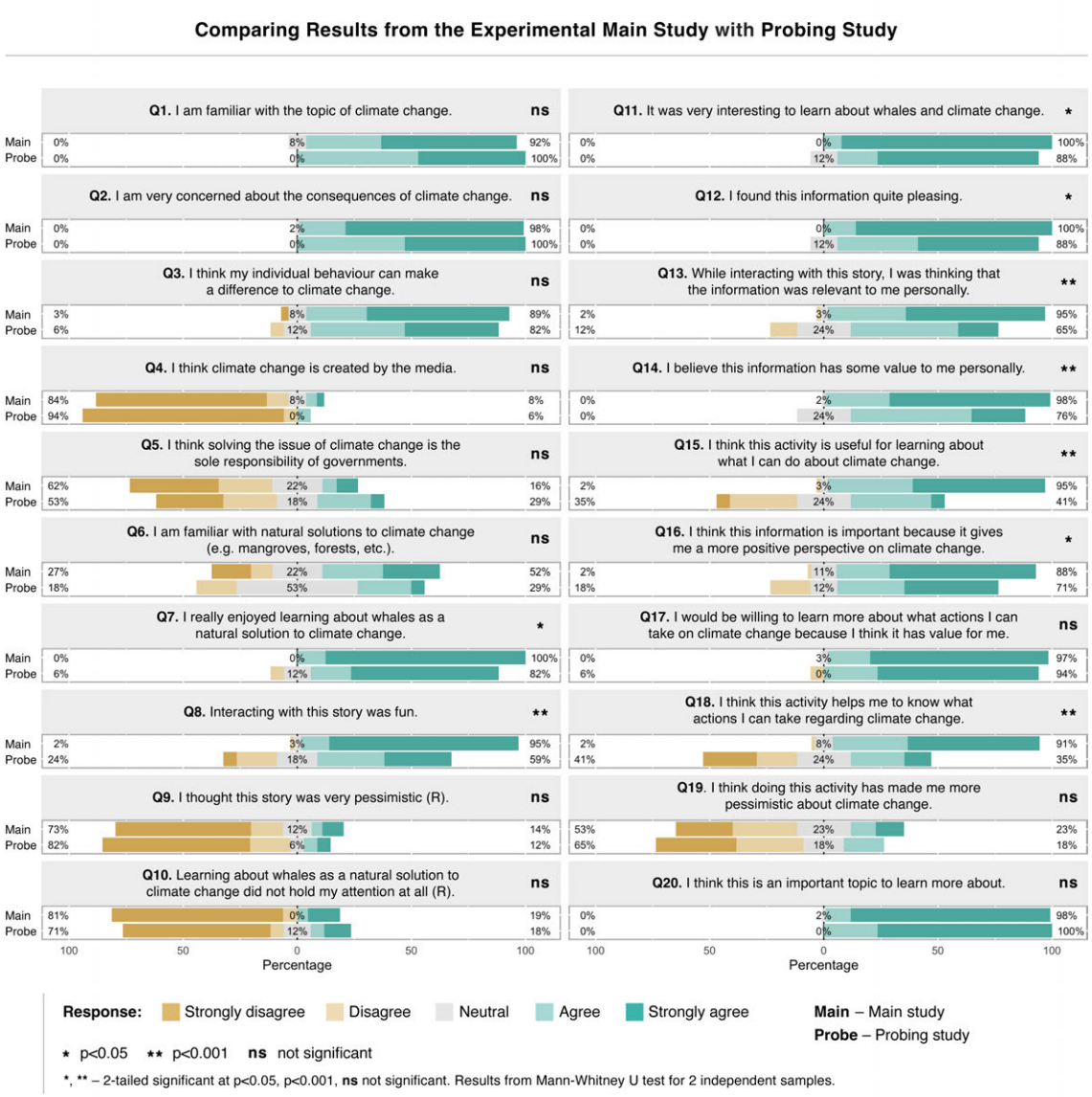

Figure 6.2: Results from the user questionnaire for the experimental group (N=64) and the probing study (N=17) adapted from the Intrinsic Motivation Inventory's (IMI) Interest/Enjoyment and Value/Usefulness scales [253, 254]. Users replied on a scale from 1 – Strongly disagree to 5 – Strongly agree.

iii) Relating to action: Q15 ($p < 0.001$), Q18 ($p < 0.001$). Group differences were not statistically different for the other variables (Q1-6, Q9-10, Q17, Q19-20).

6.3.1 Audiences' prior perceptions of climate change

The first part of the questionnaire focused on the users' prior knowledge and perceptions of climate change. These led to results (expressed in the following as percentage of agreement for the experimental group) that were mainly in line with current trends [185]. Based on a 1 to 5 Likert scale, users were very familiar with climate change – 92% (Q1), very concerned about the issue – 98% (Q2), and did not believe it is created by the media – 8% (Q4). Users thought that their behavior can make a difference – 89% (Q3). Still, when asked if solving climate change is the sole responsibility of governments, the opinions are more nuanced at 16% (Q5). Several people verbalized that governing institutions do have authority to enforce change: "[the solutions] *inspired but I also think that part of this change has to be implemented by governments.*" (B8). Finally, noticeably much less conclusive is the score that answers if they were familiar with natural solutions to climate change – 52% (Q6), comments primarily pointing to forests as what came to mind. Two users expressed their surprise and unfamiliarity with the whale-related data: *"I had no idea that whales absorbed carbon."* (B4); *"I think that there should be more activities like this because I had no idea of the importance of whales."* (B5). The follow-up interviews also point to the efficacy of engaging users with this less known subject within climate change. All users mentioned some aspect of the whale information or marine ecosystems as the topics that first came to mind from the activity. Five users reference human impact – ocean waste, noise pollution, or vessels (C1, C2, C3, C5, C9), two mention the importance of whales in their ecosystem (C6, C8), and four mention specifically whales as natural solutions for climate change (C4, C7, C10, C11).

When comparing the main study with the probe study (Fig. 6.2), the questions related to users' general perception of and concern with climate change returned similar results (Q1 to Q6). Likewise, the answers related to the importance of the information (Q17 and Q20). These results point to both groups having a similar attitude towards climate change.

6.3.2 Overall perceived enjoyment and value

The overall results of the user questionnaire – focused on the use of personalization, adding context to the data, and proposing actionable solutions – were very positive, with participants' subjective experience related to Interest/Enjoyment at 4.61 (Q7-13) – against 3.48 from the probing study – and Value/Usefulness at 4.46 (Q14-20) – against 3.62 from the probe. The result of 95% (Q8) points to interacting with the story being fun. The same question had a result of 59% in the probing study, showcasing one of the biggest variations (Fig. 6.2). This suggests that users found the artefact considerably more engaging. A user comment from the probing study clearly illustrates the issue: *"This is boring. It has a lot of text. I don't even know where to look first."* (D2). The interactive elements helped with

engagement with the visualizations, being an aspect very frequently mentioned in both interviews: "*Interactive elements help to capture my attention. If it were just text it would be less interesting.*" (B1); "*Instead of a simple spectator, I can interact with the information.*" (B6); "*The fact that it's interactive, it makes a difference because it's an action of the person. It makes learning better.*" (C7). The interactive elements also assisted with data interpretation by focusing attention on particular details of the sets: "*I have trouble concentrating and changing information helps me pay attention.*" (B8); "*The interactive things, the person absorbs much more.*" (C6).

6.3.3 The impact of adding context to the data

When looking at aspects related to the way the data was presented and contextualized, the whale story was well received, with scores demonstrating that users immensely enjoyed learning about whales as natural solutions to climate change – 100% (Q7) and 100% (Q11).

6.3.3.1 Contextualising the data through the whale story

In this iteration of the artefact, the contextualization of the data through the story of the whale characters continued to be mentioned as a differentiating point. For example, users (B4, B5) mentioned not knowing of whale's impact on climate change mitigation, even when familiar with climate change. In the follow-up interviews, *"I think that little by little, as in the case of whales, it is changing because the whaling situation has drastically reduced."* (C7); "*I remember it showing some years while the number of whales increased a lot.*" (C6). During these interviews, when discussing why the data related to whales as a natural solution to mitigate climate change came most readily to mind, participants mentioned that it was not an obvious fact, hence more impactful: *"I got a greater awareness of the importance that whales have in the ecosystem, and I had no idea."* (C4); *"I didn't know that when they die, they can feed an ecosystem. (. . .) It was the part that I found most interesting because I didn't know."* (C6); "*I had no idea that whales played such an important role.*" (C7); *"It was the question of the whales being ecologically a solution, which is something I was not expecting at all."* (C10). These results point to the potential of engaging users with climate change through a less-known topic.

Another impacting topic was plastic pollution – not surprising as this is an intensely debated issue and has already been addressed by legislation in several countries. Nevertheless, the story highlighted the seriousness of the problem and added meaning to the data (empathy) through the consequences to the whale characters: "*I had no idea that plastic could harm whales so much. That's what impressed me the most*" (B1); *"The reference to micro-plastics was nothing new, but it was there in a way that was perhaps more explicit and that stuck in my memory."* (C1); *"The noise we make to the whales, from the boats, the oil companies. And the pollution they eat, the plastic. That's what impressed me the most."* (C2).

6.3.3.2 Comparing to more familiar metrics

The 100% (Q12) score also points to the information being considered as presented enjoyably. Comparing the data to more familiar contexts assisted in interpretation: "*The comparisons helped to contextualize.*" (B6); "*Often when they talk about numbers, I don't know the scale, so relating to things I'm more familiar with, it's easier to understand.*" (B8); "*Having a comparison helped me to better understand the dimension of the number*" (B9). The comparisons were also mentioned in the follow-up interviews as a factor that assisted in understanding the data: "*I remember the amount of CO2 that the whales managed to accumulate inside themselves (. . .) compared to the trees.*" (C4); "*These are such huge numbers that we are unable to imagine or have a term of comparison. And I think that the visual comparisons (. . .) help a lot.*" (C11); "*That whale faeces are key to increasing the amount of phytoplankton and it captures CO2 and transforms CO2 into oxygen and much more than forests, or as much as forests.*" (C7).

In the probing study, questions related to interest and enjoyment scored significantly less – 82% (Q7), 88% (Q11) and 88% (Q12). This difference suggests that the strategies used in the artefact assisted in making the data more enjoyable to interact with, increasing engrossment with the visualizations. User comments from the probing study point to disconnection with the data and a clear lack of contextualization: *"Basically, what is the intention of this? It's just so we know: "this is good, it's already happening", or this has potential (...)?"* (D1); *"The message they wanted to convey was not clear."* (D4); *"Show me comparisons. For example, compared to a car. Having a comparison with our day-to-day life."* (D8); *"This should have other information. The Amazon, cars, transport, things that have more influence."* (D17); *"I couldn't tell if it's positive or negative. The information lacks context."* (D6).

6.3.4 The impact of personalizing the data visualizations

When evaluating if the personalization strategies assisted in connection with the data, the 95% score (Q13) indicates that users thought the information was very relevant to them personally and had personal value, 98% (Q14). We found that users connected significantly less with the original IMF visualizations in the probing study – 65% (Q13) and 76% (Q14).

Through our observations, we gathered that users were positively engaged with the interactive elements that personalized the visualizations in the artefact. For example, one of the visualizations allowed users to input their height and compare it to the whale's size ("the whale is X times your size"). This interaction resulted in expressions of surprise and notably assisted in giving meaning to the number. These elements also granted a sense of active participation in the data story: "*Instead of a simple spectator, I can interact with the information.*" (B6); *"The good part is that I felt I was participating too, that this was done for us to participate and better retain the information."* (C2). On the other hand, users from the probing study commented: *"The information is understandable but not in the least appealing."* (D7); *"For me, the first one is very confusing. There is no information guidance. And it's not very interactive."* (D9).

During the follow-up interviews, some users recalled the personalization elements: *"Put our age, and then based on that it would give us a scale. From the time I was born was when work began to improve the numbers."* (C4); *"The part where you had to interact to see the countries where there were more [emissions], (. . .) I think it ends up making you curious, I'm going to see this country, I'm going to see ours. So when you click, you're making comparisons."* (C6); *"Since we are entering "personal" data, like age and height, we are comparing with ourselves. These comparisons helped in the perception of other numbers that are not so familiar to us on a day-to-day basis."* (C11). These comments point to the personalization elements assisting in relating to and interpreting the data.

6.3.5 The impact of relating to actionable solutions

6.3.5.1 Creating positive climate change messages

Testing if the proposals for solutions assisted in countering the typical "doom and gloom" communication returned more nuanced results. These indicate that the story was not considered pessimistic with scores of 14% (Q9) and 23% (Q19), but still, these results are not as expressive as the other answers. On the other hand, when the question was formulated positively – if the information gave a more positive perspective on climate change – the results indicated agreement with an 88% score (Q16).

The user interviews also revealed mixed responses. These highlight the complexity of the issue, for example, with users commenting that the story wasn't necessarily negative but realistic (B7), or demonstrating mixed feelings: "*I was a little more optimistic to know that whaling is not done as it used to be, but it also makes me worried to know that such a drastic change is needed and I don't see people doing what is necessary.*" (B8). Likewise, another user said the interaction made them feel "*More pessimistic because I had no idea how plastic could harm whales so much. Plastic, ships. . .* " (B1), but also mentioned that the information inspired them to take action: "*Yes. Pick up trash on the beach. Don't ignore it.* (...) *Separate the garbage at home.*" (B1).

Likewise, the probing study confirms the difficulty of shifting users' general frames related to climate change. There was no significant difference between both studies for the questions related to possible pessimism of the message (Q9-10, Q19). The follow-up interviews validated this analysis. Nine interviewees responded that the experience did not alter their perception of climate change, with only one emerging with a more optimistic outlook: *"Maybe I even got a little more optimistic. Maybe it was Greta's fault, and I thought the world would end."* (C9). Another user says: *"I'm sadder because maybe I wasn't aware of the situation"*, but then they elaborate: *"But it's a good sad in the sense that I know I can also do something to change."* (C2). Nevertheless, users appreciated the way the data was communicated and considered it useful: *"I still have the same sense of alertness and responsibility, but I was left with a sense of greater awareness of the importance that whales have in the ecosystem."* (C4); *"There's a little light at the end of the tunnel also because the issue of whales,*

I had no idea the effect whales could have in contradicting global warming." (C7); *"It didn't change [my perception]. But the issue of the whales, I didn't know."* (C10).

6.3.5.2 Creating a sense of agency by proposing action

We also wanted to test if users found the proposals for solutions helpful and if they created a sense of agency in climate matters. The results reveal that the activity helped teach what actions the user could take, with scores of 95% (Q15) and 91% (Q18). These two questions presented the most significant differences between the probing study and the main experiment – 41% (Q15) and 35% (Q18). User comments also underline this result. From the main experiment: "[if they found the information relevant] *Yes as it talks about* (...) *actions that people can do daily.*" (B6); "*There were suggestions I didn't know and are things I can do at home in the day-to-day.*" (B8). A couple of users (B2, B3) said they didn't learn much about solutions because they were already quite informed on the subject, but the experience helped to reinforce them. One user linked the experience to the way mainstream media communicates climate change, saying that "*usually they just say the situation is bad, but we don't know what to do.*" (B11). From the probing study, six users explicitly commented on the lack of proposals for action: *"I have no idea what I'm supposed to do."* (D9); *"It might be helpful to specify more if there are things we can do as individuals."* (D1); *"And what can I do? Beats me! The information could link to a set of actions so people know what they can do."* (D7).

In the follow-up interviews, ten users (all except C2) mentioned remembering forms of action that they already implement and, therefore, they already do what they can: *"It helped more in the perception of the problem, because in the day-to-day what I did I continue to do."* (C3); *"I already had this type of behaviour, so I really didn't change anything."* (C10). The actions listed were related to plastic (C1, C4, C7, C8, C9, C11), ocean pollution (C2, C3, C4, C5, C8), recycling (C1, C2, C3, C5, C6, C8, C9, C11), energy use (C2) or meat consumption (C2, C10). Noticeably, several other suggestions were not mentioned. Still, the activity helped in reinforcing sustainable habits: *"I thought there are things I'm doing well and I should continue to do, and even improve."* (C1). One user said they were influenced to adopt more sustainable behaviours: *"If I see garbage, I pick it up. (. . .) I also started to do more recycling. I avoid eating so much meat."* (C2).

6.4 Discussion

The following insights intend to further the debate on the importance of communication choices and *how* climate change data interactions are designed. Instead of a definite generalized strategy, we aim to deepen the conversation within the design and HCI communities, fostering research that considers these aspects to better engage diverse audiences with climate change topics. Therefore, we discuss the study's results related to our research questions and related work to identify factors that can be leveraged in future work.

6.4.1 The need of adding context to climate data

As Lupi mentions [198], the data that is included or excluded defines what story is told through the visualization. By choosing additional layers of information to give a more positive context to the figures, we successfully influenced the narrative the data was supporting. The probing study highlights this aspect, as the questions related to enjoyment/interest (Q7-8, Q11-12), the personalization of the information (Q13-14), and positive framing (Q16) showed that users appreciated the strategies used in the artefact better than the original visualizations.

Working the data story towards empathy points to avenues of including non- anthropocentric voices in a meaningful way, as discussed by [2, 116]. Likewise, comparing climate change data to more familiar and personal aspects, like connecting to people's day-to-day, as called by [130], or creating deeper connections through a form of "participatory" data [312], greatly helped in understanding the real meaning of the numbers. For example, relating the whale size to the user's height, comparing tons of CO2 emissions to the country's, or the Amazon forest.

Climate change as an environmental and societal problem is now a topic that many audiences are somewhat familiar with [185]. However, the scientific data and its specificities are still primarily abstract to many users. Our study demonstrated that carefully crafting the data visualizations by relating to the users' context and personal details (*humanising* the data) helps them engage with and understand the data. Rooting the communication activity in a space not associated with science brings the topic to a wider variety of audiences, including some who might not be mainly engaged with these topics. Equity and access, particularly in designed spaces, represent clear challenges for engagement with scientific data, with "science capital" — a concept used to assess an individual's relationship with science as a consequence of class and other sociostructural issues — representing a clear faultline [81] that HCI interventions, as presented here, can assist in addressing. These HCI personalization strategies are well positioned to contradict the "one-size-fits-all" approach of many data visualizations [59], and results suggest that personalization does help in connecting the user with climate change data. The study presented here was intended as an initial probe into applying these approaches within HCI climate change engagement. The potential of using such strategies to adapt the message for more diverse narratives [231] and engage with diverse audiences within particular communities – and leveraging their own experiences and stories – is a promising avenue for future design applications.

6.4.2 Solutions-oriented visualizations to empower users

The questions directly related to actionable solutions (Q15, Q18) were the ones that presented the most significant differences between the probing study and the main experiment. In the latter, most users felt the artefact's data story helped them learn more about or reinforce what actions they could take to mitigate climate change, with proposals

feeling personally relevant. Users' comments demonstrated the need for linking the data to action, transmitting a sense of hope. The follow-up interviews point to the need to reinforce this solution-oriented communication and ensure that positive engagement during the activity is translated to longer-term perception. People seem to remember best the information linking to what they already knew or did. Possible directions for future research could focus on furthering personalization of the actions proposed by analysing what people are ready to do, or already do. Also, explore ways for users to take information with them (on their mobile phones, for example) and facilitate a further connection with the data.

Focusing on suggestions for action that the user can easily implement made the data feel more personal and relatable. However, despite encouraging more action-focused interactions, this result also highlights the challenge of engaging non-expert audiences with systemic change. When designing the data-visualizations and the link to actionable proposals, we considered recent criticism to SHCI regarding a generalised focus on individual action instead of broader system change [33, 47, 116, 175, 119]. However, we adapted the proposals for action from the pilot to the main study following user feedback, shifting from broader social and political action to personal action. The focus of this study is not on testing possible behaviour-change through persuasion, an approach widely used in SHCI but that has been labelled as narrow and possibly ineffective [47], but rather on the importance of message creation and communication choices in climate change related interactions and how they influence perception-change of such a negatively charged and biased issue. Nonetheless, our study touched on the challenge of connecting users to actions outside their personal sphere of influence, and their perceived role and responsibility within these more complex solutions. Future research needs to continue to address this challenge and further existing efforts [7, 236]. Projects discussed in the related work point to potential avenues, like engaging communities collaboratively and connecting to official institutions or environmental organizations. These interactions give users a sense of agency and collaborative satisfaction while linking to broader solutions. The personalization strategies discussed previously can assist in connecting particular groups to relevant action.

6.4.3 The challenge of countering the negative framing associated with climate change

One of our research questions asked if humanized data helped users to have a more positive outlook on climate change. As expected, this inquiry was the most complex to evaluate. Users did not consider the whale's story as pessimistic, nor that it made them more cynical about climate change. Also, they appreciated the proposals for action, as discussed in the previous section. Still, few found the experience "positive" or as giving them an optimistic outlook on the future.

People have come to expect negative narratives associated with climate change, and

even with different strategies in place to try and counter it, this hard-set bias is challenging to contradict and inevitably takes time and consistent interaction, as discussed by [182]. In response to this tendency, initiatives like Good Energy [166] or Transmedia for Change (T4C) [240] urge storytellers to engage audiences through positive messages that inspire and motivate, in line with the proposals for better climate change engagement mentioned in Chapter 2.2. Furthermore, the limited use of these strategies in previous HCI research [106] points to opportunities for using engaging interaction to communicate climate data in novel (and less neutral) forms.

Our study underlines the incredible complexity of communicating climate change and the difficulty of associating positive frames with this topic. The complexity of framing efficacy and alteration corroborates related work where mixed results were found in negative [149, 99, 34] versus positive messages [230, 103, 138, 75, 56]. However, recent guidelines such as [70, 60, 69] call for a shift towards more positive framing focused on action. The comments made by users point to this need to present more diverse narratives that don't focus only on negative consequences.

We discussed encouraging results related to designing more relatable interactions for climate change through data humanism, especially when focusing on action. We built upon previous research that has started to use this approach within the HCI research community, looking into applying them in the untested realm of climate change data visualisations. However, these strategies must be further tested as shifting negative bias is extremely challenging. Experimenting with novel ways of evaluating these activities and forms of assisting in the retention and application of the information opens exciting prospects for future work.

6.5 Chapter Summary

In this chapter, we detailed the design decisions for the second iteration of the *Finding Arcadia* artefact and the first main study in a local food market. We set out to investigate data humanism applied to climate change communication, focusing on personalization, contextualization, and connection to actionable solutions. Through a research through design study, we probed if and how the strategies used assisted in fostering positive and empowering interactions with climate change data. For this purpose, we used mixed methods to investigate: a) If and how users engage and feel connected with humanized data; b) If through interacting with humanized data, users acquire a positive outlook on climate change; c) If solutions-oriented visualizations are effective in creating a sense of agency in climate matters.

The results suggest that adding layers of information to contextualize the data helps engage and connect with climate change data and that solutions-oriented visualizations effectively engage users and create or reinforce a feeling of agency in climate matters. However, even though users appreciate the focus on action, the tested interactions with humanized data were insufficient to alter the person's perception of the issue considerably.

Despite the varied data and rich insights generated from the study, it represents just an initial attempt at testing and implementing data humanism in HCI interventions.

This research intends to deepen the debate surrounding the complexity of engaging diverse audiences with climate change data and building on the challenges of shifting the climate change dialogue from one focused on "doom and gloom" to action-focused narratives.

7

Personal Climate Change: Data Humanism for Actionable and Human-scaled Data Interactions

This chapter describes the third iteration of the artefact. In this research phase, we focus on making climate data feel more actionable and human-scaled. We describe the design decisions for this iteration, the study methodology, results and implications for climate change interactive engagement.[a]

[a] Conspicuous parts of the text in this section appear in a co-authored publication [109].

To continue addressing the gaps in how we communicate climate change narratives, particularly the challenge of converting climate change data into understandable, relatable and actionable concepts, in this third iteration of the artefact, we focused on RQ3: How can data humanism make climate change information more relatable and actionable at a human scale. To tackle this enquiry, we focused on three research questions:

a) Can data humanism make climate data more interesting and engaging?

b) Do data humanism features enhance connection with climate change data, making it more relatable?

c) Does data humanism help build a sense of usefulness around climate data?

In this chapter, we describe the design rationale behind this iteration of *Finding Arcadia*. We detail the second main user study in a Creative Hub (N=42) and its findings, emphasizing users' perceptions and engagement levels. Conclusively, we discuss implications for future HCI endeavours centred on climate data, advocating for designs that foster meaningful interactions and elevate the discourse within the HCI community.

7.1 Research Artefact's Design Decisions: *Finding Arcadia* version 3

In response to HCI's call for innovative approaches in climate change communication, this study uses an interactive artefact centred on the ocean ecosystem and carbon sequestration. As described in Chapter 4, by drawing inspiration from the International Monetary Fund study on the significance of whales in ocean health [57], we designed a comprehensive story embedded with ocean-related data, paving the way for deeper human-data interaction and advancing the HCI field for climate change communication.

The following presents the main design decisions and concepts behind the artefact:

1. A solution-focused narrative to inspire hope and immediate action without overshadowing the pressing nature of the climate crisis. Exploring storytelling and visual strategies that would lead to a hopeful outlook focused on action and connection to the individual and the community.

2. An innovative representation of more-than-humans that fosters a connection to the global ecosystem. Taking the non-obvious examples of whales, both iconic symbols of nature preservation and hopeful nature-based solutions for climate change.

3. A shift from merely nudging behaviour to deeply understanding users' connections to data, moving *"from 'nudge' to 'think' as a strategy for public engagement"* by *"engaging hearts and minds"* [62]. The artefact and the study methodology focused on the visualization/communication strategies and users' perceptions and feelings toward the information.

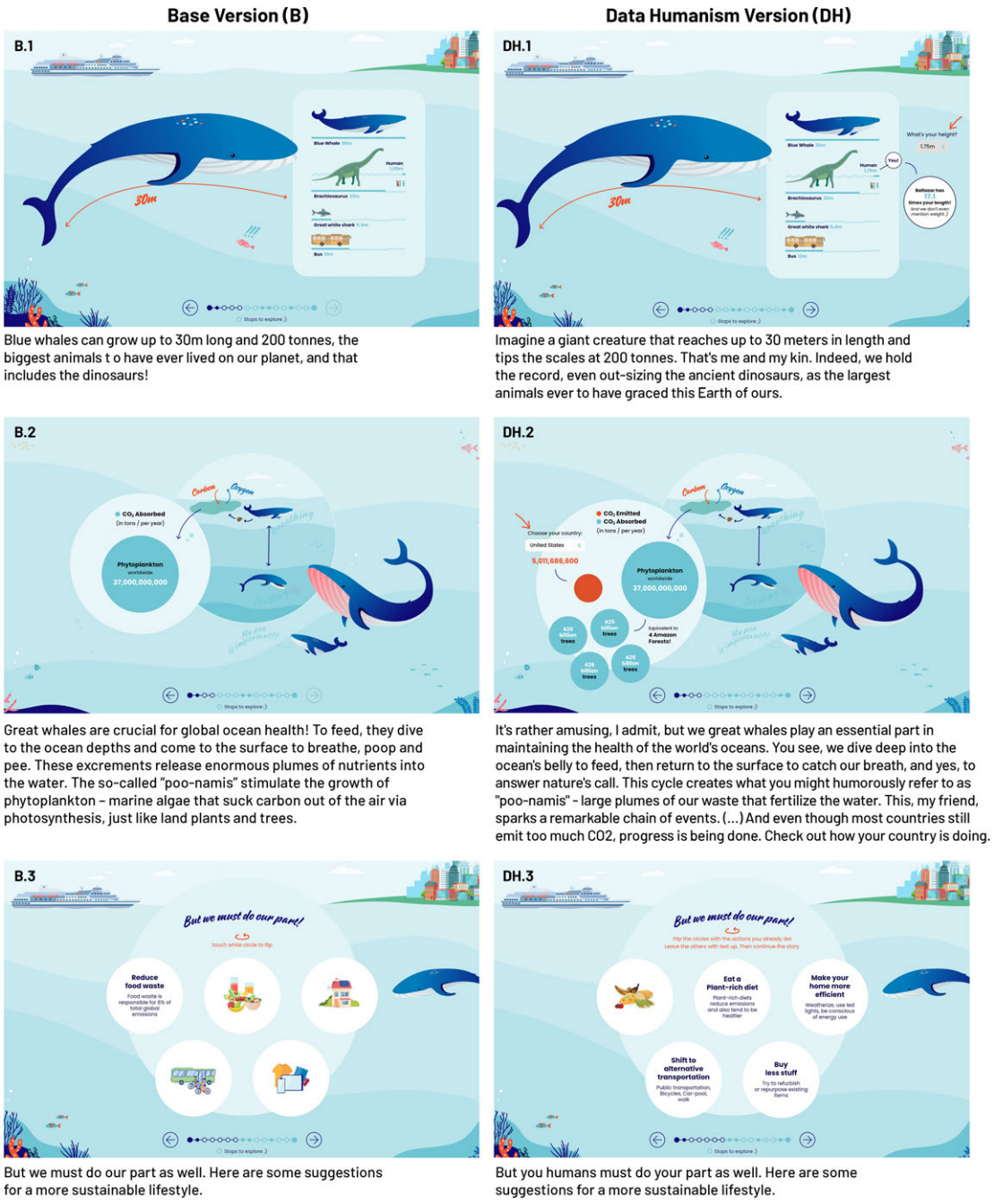

Figure 7.1: Three screens from the data-story comparing the Base version (B) and the Data Humanism version (DH) with narration script below each: base version versus AI enhanced). DH.1: the user can input their height. DH.2: the data is compared to more familiar metrics and the user's country. DH.3: asks the user to flip only the actions they do, so the remaining are showcased in the reminder at the end of the experience.

This study builds on the work developed through the studies in the wild in the science museum and the local market (Chapters 5 and 6). With this study, we focus on understanding if data humanism can assist in making climate change data more actionable and human-scaled. To this purpose, we centred on user perception related to interest,

usefulness, and relatability with the data.

To achieve this, we designed two versions of the artefact: a Base version (B) and a Data Humanism version (DH) enhanced with data humanism strategies (an improved iteration of the previous versions). Both versions implement some of the guidelines mentioned above, namely focusing on a non-obvious topic (whales as nature-based solution for carbon capturing), displaying the information in a public space of passage, and focusing on including proposals for action. However, while both versions retain similar structure and graphical elements, they differ significantly in data presentation:

- Base version (B): is data-focused, stripped of personal elements and storytelling, so the data is reported in an impersonal third-person manner through a human narrator.

- Data Humanism version (DH): makes use of the data humanism features, implementing storytelling, contextualization and personalization of the data – like user-specific adaptability or comparisons to familiar metrics. Besides the data humanism features previously explored, in this version of the artefact, the data is reported in the first-person by Baltazar, a personified whale, who tells the story of his life cycle to the users. At the end of the data-story, the whale initiates dialogue with the use of an AI language model (LLM), to foster deeper connections.

In version B, data is straightforward, lacking in comparative or personalized nuances (Fig.3 – B.1, B.2); interactions are limited to basic flipping. In contrast, version DH is crafted with numerous storytelling and data humanism techniques to foster relatability (Fig.2 and 3). For instance, like in the previous iteration, users can input their birth year, prompting the system to adjust the visualization (Fig.3 – DH.1). Another feature lets users compare their height to a whale's size, and various moments throughout use relatable metrics, like juxtaposing the carbon sequestration of whales with that of trees or equating it to a user's national emissions (Fig.3 – DH.2). Besides these features, this third iteration of the artefact was improved, considering previous study results and the focus of this phases' inquiries. The "humanized" data visualizations were also enhanced by adding extra information related to user's selected date of birth and country: after selection, the visualization adapts and a sustainability-related fact specific to that year or country is narrated. This version also offers personalized solution suggestions based on users' existing practices, with the concluding summary emphasizing potential areas of contribution (Fig.3 – DH.3). To enrich the narrative in version DH, we employed the AI-powered ChatGPT language model to breathe life into "Baltazar", presenting the tale from a more personal, first-person perspective. Our prompt asked the model to personify a blue whale and tell the "facts" of version B through his perspective (Fig.2). Besides the narration, we also used the model to allow users to "chat" with Baltazar at the end of the experience in version DH (Fig.3 – DH.4). These narrative strategies were designed to amplify empathy and deepen user engagement with the content.

The complete script for versions B and DH and the design changes from the second iteration of the artefact to the third are presented in Appendix A.3.

7.2 User Study

This section outlines the objectives and methods employed in the user study, followed by the findings.

Our research aimed to determine: a) If data humanism assists in making climate data more interesting and engaging; b) If data humanism features enhance connection with climate change data, making it more relatable; c) If data humanism helps in building a sense of usefulness around climate data. The study protocol aimed at addressing these questions.

The study was performed in the public areas of a Lisbon creative hub. The setup remained consistent with previous studies, featuring the updated narratives (version B and DH) on the touchscreen (Fig. 7.2). The subsequent sections provide a detailed description of the study.

Figure 7.2: Deployment of the artefact's third iteration: Study in the Creative Hub.

7.2.1 Participants

In order to answer our research questions, we conducted an in-the-wild study comparing the two artefact versions. We set up both versions in a communal setting – a creative hub, specifically its lobby and an adjacent outdoor restaurant area – played sequentially in a touch-screen display (Fig.7.2). Capitalizing on this public location, we casually approached hub residents and passers-by for participation. Furthermore, we promoted the installation to the local community via email and social media channels. We gathered 42 participants, who, given a succinct overview of the study, then signed a participation consent agreement. Their age distribution is as follows: 18-24 (n=10); 25-34 (n=12); 35-44 (N=15); 45-54 (n=5). Twenty-one users identified as female, nineteen as male, and two

users preferred not to say. Their education level is distributed as Middle and Secondary School (n=5); Bachelor and master degree (n=22); and Postgraduate (n=15).

7.2.2 Procedure and Methods

The study was divided into three stages. First, the user answered a questionnaire for demographic information (age, gender, and education level) and to assess prior understanding and relation to climate change topics. The user would then interact with either version B or DH of the data-story (the two versions were alternated throughout the study). After the experience, the user would answer the second part of the questionnaire adapted from the Intrinsic Motivation Inventory's (IMI) *Interest/Enjoyment*, *Value/Usefulness*, and *Relatedness* scales [253, 254]. The questions were selected to assess feelings of interest, usefulness, and relatability towards the data, linking to each of the RQs. These three sets of seven questions each (Fig.7.4) were randomly ordered and answered on a scale of 1 – Strongly disagree to 5 – Strongly agree. Thirdly, we conducted a short (c. 4 minutes) interview further probing the three engagement aspects explored in the questionnaire.

All participants went through the complete data-story and replied to the questionnaire and the open interview, resulting in forty-two valid answers, twenty-one for the base version (B1 to B21) and twenty-one for the data humanism version (DH1 to DH21). One researcher analysed the quantitative output of the scales, while another researcher analysed the qualitative interviews. Results were discussed and agreed upon among all authors, sharing insights and points of view so as to shape the discussion and contribution of the study.

7.3 Findings from the Study

Our study investigated user feedback on interactive data humanism for climate change engagement, specifically related to making the data feel actionable and human-scaled. During our analysis, we concurrently examined user response to the general experience and the specific design choices related to the data humanism strategies under investigation.

Nevertheless, it is to note that version B already addressed several gaps found in previous research [105], described in 7.2. The very positive reaction for both versions confirms the efficacy and need for alternative and interactive climate data narratives.

Responses from the questionnaire were organized in a table and analyzed using the IMI scale [253, 254] (Fig.7.4). The interviews were thematically analyzed [41] – the first author colour-coded the interview data according to: a) interest in the data, b) relatability with the data, and c) usefulness of the data, then proceeded with inductive thematic analysis [41] to derive meaning and group the gathered comments into thematic clusters. All authors discussed and agreed on the clusters. Results were then cross-referenced with the questionnaire findings analysed by the second author, to evaluate the progressive

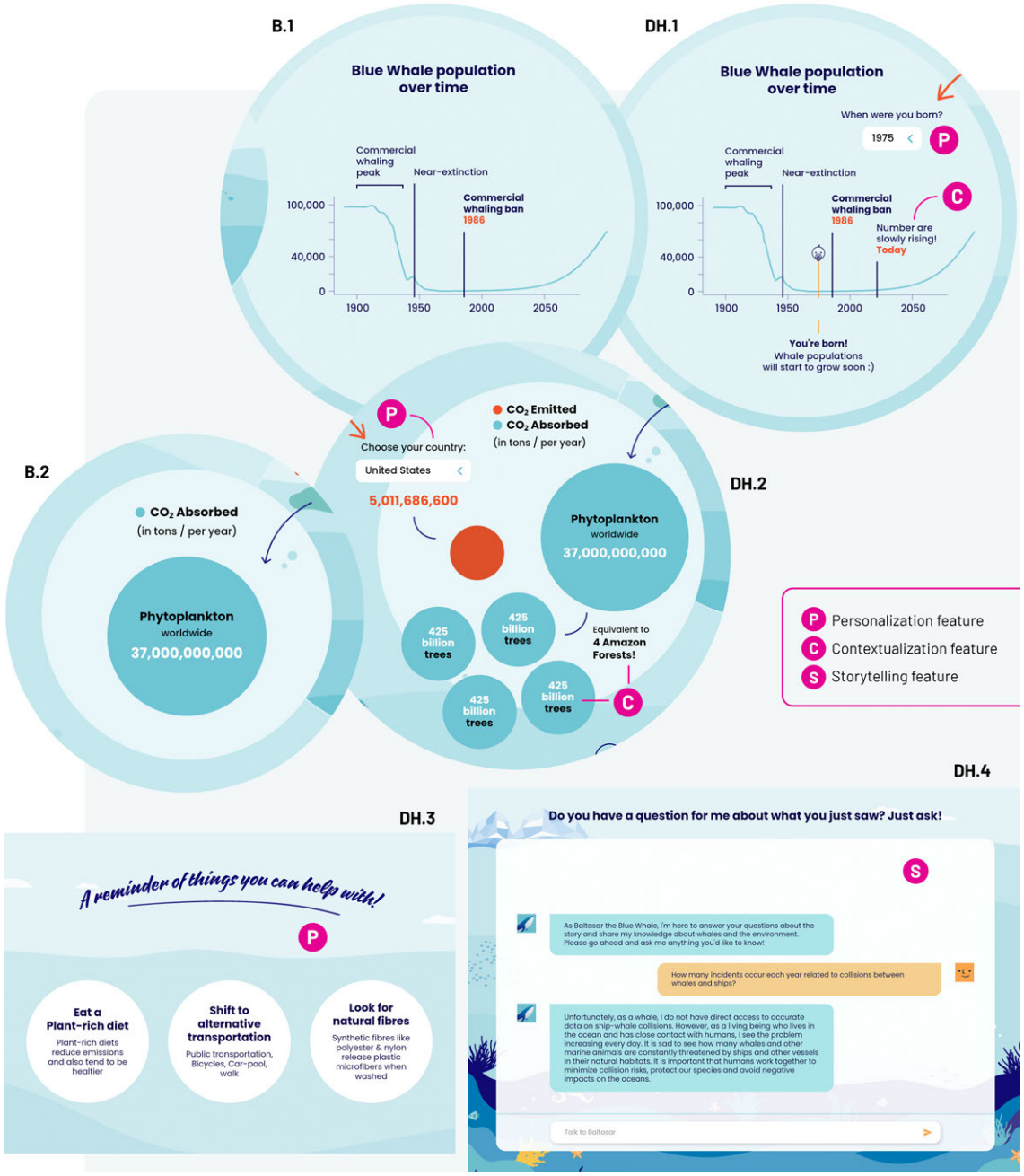

Figure 7.3: Examples of the data visualizations (details) and the data humanism features explored. B.1 and B.2: the Base version (B). DH.1: The data-visualisation is personalised through the user's input of their date of birth, the visualisation adapts to the year, and a fact for that year related to sustainability is narrated. DH.2: Contextualization of the huge global numbers by comparing to more familiar metrics (Amazon forest) and to the user's country (Personalization). DH.3: Reminder for action at the end of DH only shows the ones the user doesn't yet do. DH.4: Enhancing the storytelling by allowing the user to "chat with Baltazar".

Version	Interest/Enjoyment Scale							
	I enjoyed this experience very much.	*This information was fun to learn about.*	*I thought this was boring information.*(R)	*This information did not hold my attention at all.*(R)	*I would describe this information as very interesting.*	*I thought this information was quite enjoyable.*	*While I was interacting with the information, I was thinking about how interesting it was.*	***Total***
B	4.52	4.48	1.38	1.71	4.76	4.71	4.52	**4.56**
DH	4.76	4.81	1.33	1.76	4.71	4.43	4.48	**4.58**

Version	Value/Usefulness Scale							
	I believe this information could be of some value to me.	*I think that this information is useful for learning what I can do about climate change.*	*I think this experience can help me relate climate change to my day-to-day life.*	*I would be willing to do this again because this information has some value to me.*	*I think this experience could help me to understand what I can do related to climate change.*	*I believe this information could be useful to my daily life.*	*I think this is important information for me personally.*	***Total***
B	4.10	4.43	4.00	3.95	4.24	4.05	4.14	**4.13**
DH	4.48	4.48	4.29	4.19	4.38	4.19	4.52	**4.36**

Version	Relatedness Scale							
	I felt distant to this information.(R)	*I doubt that this information is relevant to me personally.*(R)	*I felt like I could really relate to this information.*	*I'd like a chance to interact with this information more often.*	*I don't see the point of interacting with this information in the future.*(R)	*I don't feel like I could really connect with this information.*(R)	*It is likely that this information is relevant to me. I feel connected with this information.*	***Total***
B	1.24	1.57	4.29	4.24	1.48	1.48	4.14	**4.41**
DH	1.48	1.52	4.38	4.14	1.05	1.43	4.19	**4.46**

Figure 7.4: Table with questionnaire results for the Intrinsic Motivation Inventory scales [253, 254], with average scores per question and total per scale, per version of the artefact. Answers were given on a scale of 1 – Strongly disagree to 5 - Strongly agree.

influence of data humanism's in interactions with climate change data as formulated in the RQs. The results are detailed below.

7.3.1 Interest in the data

Our first RQ asked if data humanism assists in making climate data more interesting and engaging. The questionnaire's *Interest/Enjoyment scale* results are positive for both versions of the artefact, with 4.56 (B), and 4.58 (DH) on a 1 to 5 scale. These results indicate that users perceived both experiences as enjoyable and interesting.

The interview results support this outcome, as every user mentioned some positive aspects of the experience, but differences related to perceived interest emerged. Below, we detail these variations.

7.3.1.1 Benefits of the Topic and Output Novelty

Throughout the interviews, most users (n=40) mentioned ocean data or whales as a topic of interest. These comments were frequently linked to the novelty of the data: *"I didn't know that whales absorbed carbon and that this influenced global warming."* (B5); *"The CO2 part, how much the whale takes with it. It was new."* (DH7). The data-story added perspective to more frequently explored topics: *"I thought because with cows, for example, they also output a lot of CO2. So I was surprised that other animals are, like, actually helpful."* (B16).

Likewise, users also positively remarked on the originality of the installation: *"It was quite creative. I had never interacted with anything like this before. . . "* (DH19); *"I think there*

should be more applications like this." (DH8);*"Maybe the walls, the object* [the installation]. *It's, for me, a very different object."* (B7). One user focused specifically on how climate change is being communicated: *"The issue of communicating these issues interactively in a common space. It has to be done and it is not being done."* (B4).

These remarks point to an enhanced engagement through the novelty of the topic and the output in both versions – the interactive physical installation in a public setting. It also highlights the importance of presenting less familiar information and contexts.

7.3.1.2 Engagement through Interaction

Most users commented that they liked the interactive features. However, the two versions were perceived differently. The three users from version B discussed what they enjoyed about the communication by focusing on the interactive features: the ability to control what they read (B12, B17), and the relation of the narration with the interactive elements (B16) – *"I liked those little pieces of paper that were rotating and I think it was really cool. I only see it if I want to."* (B12); *"I think it was that it is narrated. The sound was nice, but also to have some animation to make the customer go with it."* (B16). On the other hand, comments from users of version DH focus on the communication of information, being well presented (DH14, DH15), and immersive (DH4), leading to better understanding (DH8, DH19, DH20). These features led them to want to explore or know more (DH4, DH13). For example: *"I think it's more interesting for me to be able to give free rein to my curiosity and explore some things there."* (DH13); *"I think what is being looked for here is a way to captivate more and interact more and not just show numbers and things like that. I think this effectively achieves this. I think it makes the data more immersive."* (DH4); *"It was quite creative. I had never interacted with anything like this and it was kind of... It made it possible to learn better."* (DH19).

7.3.1.3 Interest through Storytelling and Empathy with AI Live Dialogue Features

The end of version DH included the possibility of initiating dialogue with the main whale character, Baltazar, through an LLM. The feature was meant to satisfy the curiosities of the users while improving engagement with the information and building empathy with the story protagonist. Seven of the twenty-one users who interacted with version DH actively engaged with the "chat with Baltazar" feature. However, none of the users mentioned this particular feature in the interviews. We gathered several insights from the analysis of the questions asked and replies of the AI.

Users asked fifteen questions, eight were related to the information in the story – e.g. *"How much CO2 do you have in your body?"* (DH15); *"How many incidents occur a year because of collision routes between whales and ships?"* (DH8). One regarded whales in general – *"Do whales have predators?"* (DH9) – while four connected to Baltazar – e.g. *"How are you?"* (DH7); *"How old are you?"* (DH19). The remaining two questions were grouped

as "Exploratory" as we saw them as users testing the system's creativity – *"Who is your creator?"* (DH9); *"What is whale heaven like?"* (DH13).

A low number of users engaged with the LLM chat feature. However, most of them used the chat to delve deeper into the topics communicated – a promising result considering the main purpose of developing deeper interest and engagement with the data. The chat feature enhanced the sense of personification with "Baltazar", deepening the relationship and empathy with the storytelling character. Outside of these main insights, the exploratory questions demonstrate the user's curiosity about the tool and point to interesting avenues for future exploration.

7.3.2 Relatability with the Data

Our second RQ asked if data humanism features enhance connection with climate change data, making it more relatable. The questionnaire results for the *Relatedness scale* indicating relatability to the data were also high for both versions: B scored 4.41, while DH scored 4.46.

The interview analysis resulted in 64 comments connected to relatability with the data, with most of the comments being from users of version DH (n=40), compared with version B (n=24). The thematic analysis resulted in nine thematic clusters:

1) *Personalization* (n=15);
2) *Visuals* (n=9);
3) *Contextualization* (n=8);
4) *Nothing in particular* (n=7);
5) *General interactivity* (n=6);
6) *Audio narration* (n=6);
7) *The whole experience* (no specific feature) (n=5);
8) *Suggestions for action* (n=4);
9) *the Information* (n=4).

7.3.2.1 Base Version – Relatability Through the Experience

Users from version B felt the data was made relatable through a variety of features: *the Information* (n=3); *Suggestions for action* (n=3); *Audio narration* (n=2); *Narration and visuals* (n=2); *General interactivity* (n=2) or the *Visuals* (n=2). In general, these comments tend towards generic aspects, such as the relation with the climate topic and its relevance nowadays, the narration as an important factor to connect them to the data, or seeing the proposals for action as a connection thread to their day-to-day. Interactivity and the visuals are also commented upon, but users do not describe what they particularly enjoyed about these aspects. Nevertheless, these features effectively made the data relatable, as shown by the questionnaire results.

To note is the emergence of a cluster of users to whom nothing connected them to the information (n=7), mostly from version B (n=6): [feeling connected to the data] *"Not particularly. I think that's because the interaction is limited in this system, so I don't feel like I was connected because of the visual stuff."* (B1); *"I don't think so, I don't know. No, nothing that specific."* (B8). Three users from version B point to the importance of storytelling in relating to the data and the *Experience or story as a whole* being the reason for a relation with the information, not a particular feature: *"I don't know, there's no special part. I liked the graphics, I liked the colours and I think the set creates empathy with people."* (B14).

Finally, users (B7 and B9) appreciated the metaphor of whales as floating trees. This points to the importance of metaphors and analogies to assist users in interpreting the meaning of the numbers – concepts associated with data humanism.

7.3.2.2 Data Humanism Version – Relatability Through Personalization and Contextualization

When replying to what made the data relatable, comments by users of version DH cluster around three main themes: *Personalization* (n=15); *Contextualization* (n=7); and the *Visuals* (n=7). Two of these three themes are based on data humanism principles. We separated the comments into Personalization and Contextualization to better understand what features users connected to the most, but to note, some of these comments relate simultaneously to both features. For example, DH9 said, *"The aspect of being able to relate to the country we live in also gives us a perspective of how our country is related to others"*. This comment was coded as focusing on contextualization but it also has an element of personalization through the connection to one's own country. These clusters are followed by *General interactivity* (n=4), *Audio narration* (n=2), *Suggestions for action* (n=1), and the *Information* (n=1). Finally, two comments say it wasn't any particular aspect but the *Experience or story as a whole*.

Personalization features were mentioned as the most compelling. Certain expressions highlight the user's positive reactions to these features: *"I thought that was amusing"* / *"I think it's great"* (DH15), *"it's a good idea"* (DH4), *"I think it's important" (DH10), "In think it was well done"* (DH14), *"that's cool, because the information is surprising (...) I wasn't expecting it"* (DH3). Some comments illustrate a deeper and more personal connection with the data, as one user puts it *"by introducing these personal elements, you apprehend the information in an even deeper way."* (DH15). These features assisted in putting the data into perspective by comparing it to themselves: *"and the date of birth part gives you a point of comparison with yourself, doesn't it?"* (DH14); *"The fact that it also asks for our input helps us relate to the information that is on the screen. Because, like, when we have to put our height, for example, our year of birth, it's like it forces us to create a relationship with the information."* (DH15). Likewise, by making the user part of the data-story: *"Putting in your data, I think it helps you relate. (. . .) It's about creating a connection between you and what is being said. (...) Putting you on the plane of what the story is."* (DH10); *"The elements that have to do with me, that is, age, height,*

which in some way bring me more into the information." (DH3). Two comments from version DH (DH8, DH9) specifically mention storytelling as an important factor for relating to the experience.

Contextualization is mentioned by users as helping to give meaning to the numbers: *"I think that visualizing the numbers, for example, visualizing the size of the whale, it's interesting to have an idea of what 30 meters are compared to a bus."* (DH9); *"making the correlation between (...) the number of years that the whale lived in terms of storage or transformation into CO2, I think those were the most interesting aspects"* (DH12). Contextualization also assisted in showing new angles about the topic: *"Yes, puts things into perspective. We don't live isolated and are in an ecosystem."* (DH8); *"Contextualization. That is, given global numbers, for example, CO2 emissions, how could this help?"* (DH15).

7.3.3 Data Usefulness

Our final RQ looked into data humanism to assist in building a sense of usefulness around climate data. The *Value/Usefulness scale* questionnaire results point to users seeing the information as useful. Version B scored 4.13 and version DH had a slight edge with a score of 4.36.

The interview analysis for the perceived usefulness of the data resulted in two main clusters of themes with variations between the versions: perceived usefulness of the data and actionable communication.

7.3.3.1 Degrees of Perceived Usefulness

The coding process resulted in three main clusters for "degrees of usefulness" derived from users seeing the information as: 1) Not particularly useful; 2) Somewhat useful; and 3) Useful.

Most users thought the information was useful to them (n=22) – n=9 from version B and n=13 from version DH. We grouped them into five themes: i) *Suggestions for Action* with users (n=7) finding suggestions useful for their daily lives; ii) users (n=6) associated usefulness with *Information about the ocean and whales* – for example, giving a holistic sense of environmental issues or being surprised by the importance of these marine ecosystems; iii) users (n=4) who *Learned new information or gained a new perspective*; iv) *Reinforcing current knowledge or actions* (n=3); v) users (n=2) who found the information *Good to know in general*. All users but one from version B fall within the first (n=3) or second (n=5) clusters, while users from version DH are more distributed, again showing more heterogeneous responses.

A few of version B users didn't think the information was particularly useful for two main reasons: i) already being familiar with the information (n=3); ii) feeling disconnected from it (n=1): *"This is a lot of things I already knew and things I already do in my daily life. So*

it's not useful, for me personally, not." (B3); *"I don't see the information being very useful, because it's not something I often do."* (B10).

The remaining users (n=16) fell in the middle, finding the information useful to a certain degree. The majority (n=9) replied that they *Already knew the information* (or most of it), but they still think it is useful or they still learned something. The remaining users thought the information linked to *Current behaviour* (n=3) or was *Useful with limitations* (n=4). These limitations were mostly connected to finding the proposals for action insufficient or with a limited range.

These results show that users of the data humanism version tend to perceive the information as more useful than users of the Base version.

7.3.3.2 Actionable Communication

As part of the data usefulness analysis, we also looked at what suggestions for action users mentioned throughout the interviews. Forty-five comments mentioned actionable communication. The themes highlighted the following: *Fibres* (n=12); *Plastic/Recycling* (n=12); *Consumption* (n=9); *Transportation* (n=5); *Ocean tourism* (n=4); *Food* (n=2); and *Energy* (n=2). Interesting to note that the two most mentioned forms of action are, arguably, on opposite sides of the discussion. The suggestion *Look for natural fibres* (because synthetic fibres like polyester and nylon release plastic microfibers when washed) was often mentioned as something people didn't know about and hence became memorable. On the other hand, plastic and recycling is a well-known and much-debated topic in the communication of climate change and sustainability. Even so, nine comments in that cluster pointed to a need to improve behaviour, pay closer attention, or the importance of this issue.

Users from version DH commented on "actions" more often (n=31) than users from version B (n=15), focusing on "useful" suggestions, i.e. actions to improve (n=33) when compared to mentions of actions users already do or feel are hard to implement (n=13). This result aligns with seeing the interactive artefact overall as useful and connected to user's daily lives: *"Yes, of course. Reinforcing. The information you already knew and, above all, try to continue to change habits."* (DH6); *"Yes. So there are some tips that people can, actions that they can take in their lives. These are easy things."* (DH9).

7.3.4 User's Suggestions for Improvement

During the open interviews, users suggested improvements to the experience (N=24). These comments are mostly from users of version B (n=19).

Most comments form users from version B relate to *Interaction* (n=11). They expressed wanting more frequent and more diverse interactivity – e.g. *"I was expecting something a little more interactive."* (B9); *"Maybe I needed more interaction so I could interact more with the experience. Not being so passive."* (B10) – or wanting other forms of interaction – e.g. *"The*

interaction here was just clicking and it rotated. Maybe have other types of interactions. It could have more diversity than quantity." (B3).

Other users feedback remarks were grouped into *Contextualization* related (n=6); *Personalization* related (n=4), and *Others* (n=3). Users of version DH focus mostly on wanting to explore the information further – e.g. *"I understand that it will have a certain impact, but, for example, in global terms, what would that impact be relatively?"* (DH15); *"Maybe (...) you could have a bit more numbers, that is, actually say what the current estimated population is... See how much it was ten years ago..."* (DH3). On the other hand, users from version B pointed to the need for strategies that made them closer to the information, through comparisons to other metrics – e.g. *"When you say 33 tons (...) it's such a big number. That's the same as, like, however many thousand... Compared to some more relatable number."* (B6) – or linking to more personal issues – e.g. *"There was nothing special that made me put myself there."* (B3); *"For now it's like for everyone it's the same. Personally, I prefer to have more input. For example, my current behaviours and then (...) the system can provide some feedback based on my current behaviour."* (B1). These comments highlight the importance of data humanization, creating connections between the person, their experiences, and the data, which the data humanism-informed version DH addresses.

7.4 Discussion

With the present research, the authors extend on the call to rally around the complexity of climate change [175], and the need for diverse solutions and perspectives on it. Echoing Han and Khanduja [134], we also *"believe new ways of visualizing data and storytelling with new media technology will have an impact on the public for their better understanding of climate change"*. The current study examines data humanism for climate change communication and engagement, investigating its potential to enhance interest, relatability and perception of the usefulness of and with the data. While both artefacts scored similarly on the IMI scales, in the interviews, we learned that the enhanced version (DH) led to more diverse conversations and a deeper sense of usefulness. Also, the humanised data version held a stronger data relatability, while the base version (B) relied on engagement through a novelty effect. Users of the DH version connected with the information thanks to the more contextualised data (e.g. personalised and situated metrics). In the following, we discuss research implications for future HCI endeavours, advocating for communication design that bridges complex and oftentimes impersonal data with lay audiences. Building on recent CHI debates [213], we further the HCI discourse with climate change by exploring novel communication design approaches.

7.4.1 Building Interest by Going Beyond Presenting Facts

In the context of our study, we had contradictory opinions on how to preset data about climate change. Some laud the positive framing and the suggestions for action against

the current fatalist engagement. In contrast, a couple of users suggested the inclusion of more drama, in the form of photography of endangered animals, or the use of a more mature visual language as opposed to the vibrant and cartoonish style graphics. Different communication strategies have particular pros and cons. These choices must be carefully considered depending on the targeted audience and context, especially with such a complex topic. The underlying takeaway is that one-size solutions do not fit all audiences. A polarizing topic such as climate change is deeply influenced by one's beliefs and experiences [103, 132], and demands careful design and adaptation of the message. The value of the information is perceived by how it is tailored to its audience. For effective engagement, personalization is essential. What is included or excluded from the data sets we use [198], how is it tailored to specific audiences, and all the media components we choose to adopt, will dictate the story we tell through the data.

When developing and testing *Finding Arcadia*, we carefully considered *what* to communicate and *how*. We went beyond data as numbers by adding context and creating an emotional connection with what was being showcased. The data collection and treatment, i.e., using storytelling and an empathetic character, considering how to present the data and with what complementary information, was crucial for the success of the audience engagement, as demonstrated by the study's positive results. The data humanism and other design strategies helped to translate abstract environmental data into interesting and relatable information [205], leading to deeper connections of the users with the data. Our insights reinforce climate change communication guidelines that ask for a focus on locality, stories, and people as a way of connecting lay audiences with climate change [70, 130, 69].

The SHCI community have called for diverse perspectives and climate change narratives, such as more-than-human cohabitation [267] and collective relations to nonhuman actors [115]. Our climate change communication artefacts worked towards a fair representation of marine ecosystems by using accurate and diverse data, validated by an expert in the field. The experience evoked empathy and a sense of responsibility. We were particularly encouraged by users' comments about gaining a more holistic understanding of our global shared ecosystem. Klein argues that the changes needed to respond to the climate crisis are an opportunity to re-assess our relationships with each other and with nature [172]. This research not only linked climate data with users on an individual level, but it also connected them to a sense of global belonging. The interactive data humanism features assisted in making the data feel more personal, its context relevant to each user but simultaneously linking to its global scale. Inspired by Light et al. [190], we strived to contribute to a more diverse and stimulating digital landscape, that also moves away from the hopeless, negative framing of many climate-related interactions.

One aspect to note in our study is using a large touch-screen display to convey the data-story. This mode of interaction can impact the user's engagement with the data. As discussed in the Sustainability Considerations, this output was used because it was already available in the lab and required no new purchases. Also, it was appropriate

for a public display instead of having users engage with the story with a more common but less practical mouse and keyboard. Nevertheless, the nature of the communication strategies and interactive features allowed for using these "more common" modes of interaction. Future work should test whether user engagement changed with other outputs and contexts.

The current research serves as a starting point for further explorations in the communication of climate change. We look forward to SHCI's further engagements with the climate change communication and engagement challenge.

7.4.2 Climate Change on a Human Scale for Relatability with Complex Data

Climate change can be described as an *hyperobject* [219] – a complex and pervasive phenomenon that exists on a scale beyond our usual human perception and comprehension. This scale and complexity make climate change difficult to connect to our daily experiences. The challenge becomes presenting it on a relatable human scale that transforms it from overwhelming phenomena to solvable problems where we feel we have some agency to affect change.

Throughout this study, we explored the importance of linking climate change data to local contexts and personal experiences, aligning with recent climate change communication guidelines that call for making climate data "relatable, local and personal" [130]. Our study demonstrated how presenting climate information by adding familiarity to the data through personalising the interaction, making it closer to one's experiences, can lead to more relatable interactions. Our data-story harnesses data humanism to communicate a *hyperobject* in a manageable scale that can be understood and even related to. The users of version DH highlighted relatability through the personalization and contextualization of the information, confirming data humanism's fundamental goals of relating to people more effectively – in Lupi's words: *"question the impersonality of a merely technical approach to data and to begin designing ways to connect numbers to what they stand for: knowledge, behaviors, people."* [198]. This approach to data-interactions leads to a meaningful experience for the user [301] and also incentivizes reflection instead of universal prescription [42].

The use of AI-powered models also assisted in bringing the global scale of climate change to the individual sphere of each participant. Besides breathing life into the whale character and allowing a dialogue between this entity and the user, we used the model to detail the information to the user's suggestion of specific times and places worldwide. linking the data visualization to more personal metrics. We see the great potential of AI for personalised climate change data engagement. The strategies used in our design are just early experiments of using these tools to enhance engagement, and we look forward to further delve into how these tools can be harnessed to create closer connections with the data.

These communication and interaction pathways offer new models of how climate change engagement can be explored and the role of digital technologies within these

exchanges.

7.4.3 Empowerment and a sense of Usefulness through Actionable Communication

Acting to mitigate the consequences of climate change is more pressing than ever. However, previous HCI research seldom proposes action or solutions through climate change interaction projects [105, 110]. Our study has demonstrated the importance of an action-focused narrative – we purposefully worked the information to focus on actionable proposals and positive aspects without altering the data represented by the numbers. The sense of usefulness of the data and its connection to people's daily lives largely came from the call for action proposed throughout the data-story. Users commented on these proposals, mostly positively, but also debated their usefulness and limits. We argue that this open debate is important for productive climate dialogues and to lead to much-needed recurring conversations in our every day [14].

The success of action-focused strategies and their limited range led us to envision future work that explores a broader set of proposed solutions and uses deeper personalisation strategies to connect users with actions that are appropriate and stimulating to each person. Users tend to focus on what they already know and do, even when they mention that they learned something and will start to pay attention to it (e.g. B2, B10, B12). Interactive strategies focused on more personal data connections can assist in linking to less obvious and more impactful suggestions, for example, by allowing users to "zoom in" on what interests them and what they can help with, including within their particular communities. Data humanism interactions can assist people to "find joy in climate action" [161]. Furthermore, these interaction features can help address the largely debated challenge of engaging lay audiences with broader social change (besides individual behaviour) [205, 32, 47] by promoting civic engagement [84] through adapted suggestions that still feel relevant to an individual actor. Previous work [107] has pointed to the difficulty of connecting users with actions outside their personal frame of influence as they feel they have no agency in such matters. The HCI and Design communities can further develop interactive systems with a strong social component [184] that connect to community and global challenges. This is no small feat, but only through experimentation and testing can we hope to contribute to this global challenge.

7.4.4 Reflections on LLMs for More-than-human Representation

The use of AI-powered models assisted in bringing the global scale of climate change to the individual sphere of each participant through personalised date and location information. Furthermore, we used the LLM to breathe life into the whale character by adapting the narration to "his" perspective and allowing a dialogue between this entity and the user. The AI Live Dialogue feature was meant to satisfy the curiosities of the users while

improving engagement with the information and building empathy with the non-human story protagonist.

A few users engaged with the LLM chat feature, pointing to a need for better integration with the story. However, most of them used the chat to delve deeper into the topics communicated – a promising result considering the main purpose of developing deeper interest and engagement with the data. Furthermore, the exploratory questions demonstrate the user's curiosity about the tool and point to interesting avenues for exploration. Future experiments should integrate such a feature more carefully into the story. Crafting engaging narrative hooks is essential to ensure user participation, especially towards the end of the experience. Designing AI prompts that maintain the character's story and personality is crucial. These conversations with the character, in crucial points throughout the story, could link more clearly to each data set and enhance engagement with the tool.

AI-powered conversations between humans and more-than-human characters can be explored to inspire empathy and posthumanistic perspectives. We acknowledge that using AI systems to give voice to more-than-human entities could be problematic as "AI technology itself imports a traditional, humanist form of logic" [289]. Building on the challenges posed by [168], we tried to work through the discomforts of designing in the intersections of human and non-human relations. The use of these systems demands a careful critical lens. Besides the dangers of possibly spreading misinformation [313], one needs to consider which perspectives are represented or what stereotypes might be inadvertently reinforced, depending on the information the LLM uses or is fed with. Also, one should question how these systems can help represent more-than-human entities since this information is human-made and inevitably carries a human perspective.

This work is an initial experiment at using, in particular, storytelling and an attempt at decentering the human in the narrative to work through these tensions. We look forward to further delve into how these tools can be harnessed in this urgent context to enhance the sense of personification and empathy with a non-human character.

7.5 Chapter Summary

This chapter described in detail the design decisions and features of the third iteration of the *Finding Arcadia* artefact. Moreover, the chapter describes the user study in the wild in a Creative Hub. Using a mixed-methods approach, we gleaned insights from qualitative interviews and quantitative feedback. By contrasting two versions of the interactive narrative (a base version and a data humanism version), we shed light on the tangible benefits of introducing data humanism principles into HCI design — chiefly regarding its potential to enhance interest, relatability with, and usefulness of the data.

Key findings and design implications point to the potential of data humanism to enhance user interest, relatability with the data, data usefulness, and how storytelling and empathy through AI can be explored. The implications for the HCI community include filling a pivotal gap in the literature and emphasizing the importance of data humanism in

creating engaging and relatable user experiences for communicating complex phenomena like climate change, particularly pointing to paths of making climate data more actionable and human-scaled.

8

Conclusion

This final chapter summarises the research and results of the studies of the Data Humanism framework through the Finding Arcadia artefact in light of each research question. The remaining chapter reflects on the research limitations, future research directions, and concludes with some final remarks.

8.1 Research Summary and Findings

Converting intricate climate data into understandable, actionable, and emotionally resonant concepts and balancing the urgency of action with avoiding crisis fatigue or depression, remains a complex challenge. HCI's potential to leverage technology for engaging and educating about this collective issue calls for further research and novel approaches.

The goal of this research and thesis dissertation has been to study, design, develop, and evaluate a framework that leveraged data humanism to promote engagement with climate change data. The approach was threefold:

1. To propose a theoretical framework inspired by climate change communication research, data humanism principles and the user-centred design process (UCD).

2. To draw from previous research on interactions for climate change and current climate change communication practices to create a series of design insights to inform the design of the data experience.

3. To create, iterate and evaluate a research artefact, following the Data Humanism framework.

Therefore, the research focused on three main research questions. The following reflects on the research results considering each RQ.

8.1.1 RQ1. *How have the fields of HCI and Design employed communication strategies, both theoretical and practical, to engage non-academic audiences with climate change subjects?*

This thesis presents a comprehensive analysis of existing HCI and Design research on interactions for climate change and communication strategies to identify gaps and inform future research directions. Performing these surveys of previous work compiled an exhaustive mapping of what has been done in climate change engagement and their communication choices from two different perspectives and resulted in the proposal of nine implications for design.

First, HCI and Design projects on climate change from the last decade were reviewed, analyzing 74 projects targeting the general public. Our findings point to topic selection following trends and that most projects have neutral messaging with no suggestions of actionable steps.

The results informed the proposal of five implications for design, namely that topic selection should be based on impact and audience, interactive engagement in daily-routine settings, proposal of actionable steps as part of the experience, positive framing, and inclusive perspectives. These implications were presented in section 3.1.3 and then highlighted when applied in different stages of the development of the artefact.

Secondly, we focused on climate change communication in the media through the case study of the Russia-Ukraine war. The study helped to understand how the Ukraine war and climate change have been connected and visualized. The findings suggest four implications for design that highlight new research avenues in climate data visualizations, emphasizing contextualization, alternative formats, interactive communication, and narrative tactics. These implications can be found in section 3.2.4.

These surveys do not intend to be a definitive list of what has been done in these fields. The aim was to further the discussion about the current landscape of HCI and design applied research addressing climate change, more particularly concerning communication and interaction approaches, and assist in the scholarly pursuit of new or less explored pathways. These analyses can inform and inspire future designers in making decisions about approaches and features that they can employ or adapt by looking at the *Finding Arcadia* case study.

8.1.2 Framework and Research Artefact

Designing data-driven narratives for wicked problems is a complex process that presents myriad challenges [247]. Wicked problems, such as climate change, comprise many interdependent factors. Design research has been proposed as one possible method to help address these complex challenges through solutions for the current situation [315]. Even though wicked problems are difficult to define and characterized by uncertainty and tradeoffs, addressing them should focus on specific, situated challenges – the design theory *of something* [243]. The complexity of wicked problems makes them seem impossible

to solve and very hard to communicate. The audience's attention span, willingness to engage and finding personal relationships with data relevant to each user, contribute to variability in responses.

To address the implications suggested in the first research stage and the challenge of engaging users with a "wicked problem", the work presented in this thesis relies on constructing an artefact – *Finding Arcadia* – and its several iterations based on a novel framework, supporting the exploration of the research questions. Based on previous work, challenges in HCI for climate change (section 2.1) and climate change communication and engagement (section 2.2), and the implications mentioned previously, data humanism emerged as a promising methodology to explore (section 2.3). Therefore, we propose a novel Data Humanism framework (Chapter 4) to operationalise the principles of data humanism for designing engaging interactions for climate change communication.

The Data Humanism framework strives to go against a sector of data visualization that focuses on neutrality and simplicity for effective data communication [312, 285, 51] leaning towards an observer-dependent, more complex and nuanced approach [93] in an attempt of connecting audiences with climate change data.

Using the proposed framework and informed by the design implications, *Finding Arcadia*, the research artefact, was developed. This artefact serves as a model for how complex climate data can be communicated in a more engaging and human-centric way. Its several iterations (Chapters 5-7) embody the approach and techniques developed and the design process provides knowledge through its construction and testing. Various evaluation studies were conducted through the artefact and considering the research questions posited. While they cover different enquiries within data humanism's potential for climate change communication, the studies share methodological considerations. The Data Humanism framework intends to make the data relevant, hopeful, and actionable. This flexible and resilient approach is not a universal method but a guide for future interactive projects.

8.1.3 RQ2. *How can data humanism contribute to creating positive and empowering engagements with climate change information?*

The first iteration of the artefact served as a test bed for the Data Humanism framework and the communication strategies employed. This study focused mainly on exploring ways of making the data feel more personal, contextualised and action-focused. The findings from the pilot study (Chapter 5) conducted in a major science museum (*Pavilhão do Conhecimento*) pointed to interactivity helping with engagement with the data, information being perceived as useful, especially the proposals for action, and the efficacy of contextualising the data through the whale story. These results and observations during the test in the wild led to improvements in the design of the artefact, culminating in its second version.

When deploying in the wild, the diversity and unpredictability of users interacting

with the artefact called for particular attention to the amount of information conveyed – it should consider people's different media literacies, attention spans and time availability, particularly in daily-routine settings. This called for adapting the questionnaire's format, and a calibration of the narrative length, from one iteration to the next. Also, refinements in the interactive features were also done to keep users engaged and focused on the climate change data, or to enhance connection with the data.

The second iteration of the artefact was tested in a local food market: the first main study (Chapter 6). Addressing RQ2, this study focused on testing data humanism's potential to assist in countering negative communication and crisis fatigue. To help in the study focus, the high-level research question was divided into three more circumscribed enquiries:

- **RQ2.1** If and how users engage and feel connected with humanized data.
- **RQ2.2** If, through interacting with humanized data, users acquire a positive outlook on climate change.
- **RQ2.3** If solutions-oriented visualizations create a feeling of empowerment and agency in climate matters.

The mixed methods study engaged with eighty-one users through different enquiries: to better understand the user's relation to the data as communicated by the IMF's original visualizations (N=17), and to test data humanism approaches through the implementation of our artefact in a local food market (N=64), looking at user feedback and data perceptions after the interaction and a few weeks later (N=12).

In response to RQ2.1, results suggest that adding layers of information to contextualize the data helps engage and connect with climate change data. Regarding RQ2.3, our study points to solutions-oriented visualizations being effective in engaging users and creating or reinforcing a feeling of agency in climate matters. However, replying to RQ2.2, even though users appreciate the focus on action, the tested interactions with humanized data were insufficient to alter the person's perception of the issue considerably. These results pointed to the promise of humanising data to make it feel more action-focused and empowering. However, shifting the hard-set negative framing associated with climate change is extremely challenging. Continuous positive and engaging interactions are needed.

Results from the study led to the discussion of implications for future interactions for climate change. First, the importance and need of adding context to climate change data. These complex and oftentimes global-scale data sets can feel overwhelming, hard to connect with our daily experiences, and difficult to understand, thanks to their scale and scientific nature. This study pointed to the added layers of context in the data visualizations, their personalization, and the connection to a character and their life events, assisting in data engagement and connection and countering the premises that

"one size fits all" in climate change communication exchanges. Secondly, how solutions-oriented visualisations helped give users a sense of empowerment. The proposals for action throughout the experience were very well received. However, further work is needed to diversify the proposals, especially testing ways of linking to system change, and assist in memorability after the interaction. Lastly, discussing the challenge of countering negative connotations with climate change led to proposed avenues for more diverse narratives. Some aspects discussed point to the need of continuous engagement, a deeper connection to community values, and testing strategies for further information retention.

Regarding the contexts of deployment, we noted a correlation between the novelty effect of the experience and the location. The market was an unexpected location for such exhibits, attracting more people and instilling more curiosity, observed through people's posture towards the module, their comments, and interactions. In the science museum, alongside other interactive exhibits, the artefact was less surprising. Taking this data to "where people are" is reported as a gap in previous research [106], and study results prove its positive effects.

To continue investigating data humanism as a communication approach to improve climate change data engagement, a third research question was formulated, looking into a different angle of the approach.

8.1.4 RQ3. *How can data humanism make climate change information more relatable and actionable at a human scale?*

To this purpose, the study centred on user perception of interest, usefulness, and relatability with the data. Therefore, the following sub-questions were formulated:

- **RQ3.1.** Can data humanism make climate data more interesting and engaging?
- **RQ3.2.** Do data humanism features enhance connection with climate change data, making it more relatable?
- **RQ3.3.** Does data humanism help build a sense of usefulness around climate data?

To investigate these enquiries, two versions of the data-narrative were created – a Base version (B) and a Data Humanism version (DH) enhanced with data humanism strategies. The insights from the first main user study led to a new round of improvements in the design of the artefact (version DH), which included the addition of extra adaptable information to the data humanism features, a more personalised form of showcasing the suggestions for action, and enriching the personification of the whale character through the use of the AI-powered ChatGPT LLM. The two versions were tested in the wild in a Lisbon creative hub with forty-two users (Chapter 7).

The findings indicate that interactive climate data narratives are positively received. Addressing RQ3.1, users expressed positive feedback on the interactive features in the two versions, although their perceptions differed. The unfamiliar territory of ocean

data and its relationship with climate change was identified as a unique contributor to engagement. Users lauded the novelty and creative approach of the installation, emphasizing the importance of unique narratives in public settings. Engagement was also enhanced through interaction. Quantitative feedback affirmed the success of both versions in piquing interest. However, qualitative interviews revealed that the DH version generated deeper, more diverse user interactions, emphasizing the importance of nuanced interactive features in HCI.

Despite introducing an AI-driven dialogue feature with the main whale character in version DH, only a few users actively engaged with it, with none mentioning it in interviews. These features demand careful implementation to maintain character consistency and enhance the user experience. The analysis of user questions revealed a mix of information-seeking inquiries related to the story, general queries about whales, and exploratory questions testing the system's creativity. Despite low engagement, the users who utilized the chat feature demonstrated interest in the communicated topics, aligning with the intended goal of fostering engagement with the information.

In response to RQ3.2, the results pointed to personalization, contextualization, and storytelling, particularly using metaphors and analogies, assisting in making data more relatable, i.e., a more personal, and therefore understandable, scale. Version B stimulated relatability through the experience and the information. In version DH, personalization and contextualization stood out as pivotal elements to enhance connection and bring the complex data to a "human-scale". The lack of these features in version B indicates a missed opportunity to connect users more deeply with the data when storytelling metaphors and analogies are not present to help users interpret and make sense of the data. These results point to data humanism assisting in making climate data feel more human-scaled by linking to personal metrics and contexts.

Furthermore, and replying to RQ3.3, users find suggestions for actionable communication highly beneficial. These suggestions, shown throughout the experience, largely assisted in the sense of usefulness, and both versions were generally deemed useful. Participants found the information useful when it reinforced their current knowledge or provided insights into their daily lives. Version DH, however, edged out with a more varied range of responses and with no users finding it unuseful, highlighting the importance of diverse data presentation strategies in enhancing perceived utility. Nevertheless, users asked for more diverse interactivity and proposed actions.

These results led to discussions around building interest in climate change topics by going beyond presenting the facts, using data humanism to link global data to local and personal experiences, and the crucial importance of actionable communication to give audiences a sense of empowerment and make the data feel useful.

While an AI-driven chat feature can deepen user engagement and connection to the storytelling character, it's critical to position it correctly in the interactive experience. Crafting engaging narrative hooks is essential to ensure user participation, especially towards the end of the experience. Designing AI prompts that maintain the character's

story and personality is crucial. The chat feature enhanced the sense of personification of our main character, deepening the relationship and empathy with the whale character. Outside of these main insights, the exploratory questions demonstrate the user's curiosity about the tool and point to interesting avenues for future exploration.

This research unveils the crucial intersection of data humanism techniques, climate communication and HCI, demonstrating how intricate design elements influence users' engagement and perception of data-centric content for climate change. By contrasting two versions of an interactive narrative, we shed light on the tangible benefits of introducing data humanism principles into HCI design — chiefly regarding its potential to enhance interest, relatability with, and usefulness of the data.

8.1.5 Summary of Research Contributions

This research yielded the following research contributions:

1. The identification of a set of nine Design Implications derived from a review of prior research work and media communication used to inform the design of the experience.
2. The novel Data Humanism framework.
3. The design of the *Finding Arcadia* research artefact following the proposed Data Humanism framework and design insights.
4. The results of the evaluations of the successive iterations of the *Finding Arcadia* artefact within real-world contexts, providing empirical insights into the effectiveness of the Data Humanism framework.

This research highlights the critical role of data humanism in developing engaging and meaningful user experiences, especially for conveying intricate issues like climate change. The research outputs from this thesis can inspire and lead the design of future interactions for climate change to promote understanding and engagement with this data. They point towards ways to make climate data more relevant and accessible on a human level. The real-world significance of this research lies in its demonstration of the societal benefits of effective HCI design, showing how innovative interactions can educate and motivate the public. HCI and design practitioners are in a privileged position to assist in the evolution of socially responsible messages in an informative but also engaging and action-focused manner.

8.2 Limitations

The artefacts and evaluation studies have certain inherent limitations due to their applied nature, interdisciplinary approach and study implementations in the wild. These limitations are examined below.

Firstly, the scope of theoretical research relevant to this thesis is extensive and intricate. This complexity makes it challenging to comprehensively cover all existing contributions. Furthermore, many research projects, especially in HCI, lack descriptions regarding their design process and choices. Working in the intersection of different fields, in this case, uniting HCI and communication design, can lead to such difficulties. The lack of specific information can be challenging for accurate analysis and discussion.

Another limitation of this research is that the proposed framework has not yet been tested in other experiences. The framework is an initial effort to offer new perspectives and establish a unified methodology for using data humanism in interactions for climate change. It is hoped that this initial step will spark further developments in creating experiences that further explore paths to making climate change closer to audiences outside academia. Further explorations with different topics and data sets, tested in different cultural and social contexts, are necessary to generalize the findings. Particularly since this research advocates that "one size does not fit all" in climate change communication, this greater variation in contexts would be extremely beneficial for the development of the research.

Thirdly, engaging users in the evaluation process in daily routine places posed challenges, as they were going about their affairs and didn't always have much availability. Therefore, the testing protocols had to adapt to this limitation, not taking too much time and being flexible to adapt to diverse and unknown audiences. This signified that some of the results were less varied than desired, even though there was the concern of trying to balance quantitative and qualitative forms of enquiry. Furthermore, the needs of the subjective nature of human perception and communication could have benefited from other evaluation forms. Findings are limited to the degree of analysis used.

Additionally, findings are necessarily limited by the choices made during the construction of the artefacts and the elaboration of research questions. The framework proposed in this research presents guided steps for the design of projects following a data humanism lens. However, the open nature of the design process signifies a multitude of options within each creative step. The artefact presented in this thesis and its iterations are but one example of application, even if applying different strategies for more accurate results. Nevertheless, research artefacts are useful even if the result of a subjective process [144].

Lastly, the studies' durations were not extensive enough to determine if the experience could influence long-term perception or habit changes. This aspect was tentatively addressed in the follow-up interviews some weeks after the experience. Still, a longer-term study would give meaningful insights into the effectiveness of the communication strategies tested.

8.3 Future Directions

Directions for future work have already been discussed in their individual chapters and the previous section. Here, these suggestions are compiled.

This document provides valuable insights for experience and communication designers, HCI researchers and other communicators focusing on creating climate change data experiences that enhance connection and interest. The work described points to various avenues for future exploration.

Regarding the studies methodologies employed, future work could look into alternative evaluation methods that allow for more nuanced results. Balancing accurate research enquiry and the nuances of human experiences is challenging. Using creative probing methods through precise analysis presents opportunities for exploration.

Considering one of the current limitations identified in this work, conducting long-term studies to assess further the effects of the experience on user perception and habit changes would be beneficial. Furthermore, engaging audiences in different cultural and social contexts is a stimulating avenue for data humanism interactions moving forward, as these would explore the framework's potential to link datasets to diverse audiences. These explorations could also consider closer links to communities and personal values – again, exploring the intrinsic potential of data humanism in connecting groups and individuals with data through their particular experiences and concerns. Additionally, alternative features within the data humanism framework and diverse datasets must be explored. As research and academic knowledge in this field evolve, it's important to update and refine the list of design insights continuously.

When looking at the results from the studies and the challenges related to climate change, it is crucial to keep exploring engaging ways of connecting lay audiences with system change. Throughout the research, this aspect was refined, but the work is still in its infancy. The HCI community has pointed to this gap in recent years. Engaging interventions to connect complex systemic change to individual citizens and communities, making it relevant and achievable, is crucial. In addition, continuing to explore alternative ways to "give voice" and represent the more-than-human opens stimulating possibilities for HCI and design research. For example, using AI to assist in personifying more-than-human entities was explored. This path alone has great creative potential. I hope that this research inspires paths to continue exploring.

8.4 Final Remarks

Digital technologies are practically ubiquitous and have evolved exponentially in recent years. However, designers and communicators may find it challenging to effectively use these advancements to meet the needs of such a complex issue as climate change. In particular, the saturated media landscape we currently live in, with ramping misformation and crisis after crisis populating every media channel, makes it extremely challenging to engage users with climate change in a productive manner. The objective of this research is to introduce a framework that integrates data humanism for climate change engagement. This framework is intended to assist in creating interactions that make climate change data feel more personal, meaningful and useful.

I propose that designers integrate data humanism principles in interactions for climate change, particularly personalization and contextualization, to increase user engagement, perceived value, and connection with complex datasets. I look forward to seeing the directions that the HCI and Design fields will take regarding climate change communication and engagement.

Throughout the various phases of research, the *Finding Arcadia* experience emerged as effective in engaging users with climate change data. Even so, it is only the beginning of harnessing data humanism to help communicate and engage with climate change topics. I hope that this work inspires other designers to explore novel techniques to connect people with sustainability and climate change in a positive way so that we fight against defeatism and work towards action and a more sustainable future.

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A

Finding Arcadia – complete data story and strategies used

This Appendix presents the full data story of the artefact *Finding Arcadia* through all the screens of the experience. Each section of the story is accompanied by the script that was narrated and the data visualisation or storytelling strategies used.

We present the first iteration of the artefact, tested in the pilot study (Chapter 5), followed by an illustration of the changes made for the second iteration (Chapter 6), concluding with the edits made for the third iteration (Chapter 7).

A.1 Artefact Version 1

Initial screen.

Figure A.1: *Finding Arcadia* artefact – Initial screen before entering the story.

Screen 1

Narration – This is the story of Baltazar, the blue whale, and his life in today's oceans. Baltazar was born in January not too far from the Azores islands.

Strategies – Story told through the life of a whale character, creating empathy and contextualising the data by linking to his context and life events. Also, linking to the context of implementation by mentioning the location where the user is and by mentioning the Azores islands (part of Portugal).

Figure A.2: *Finding Arcadia* artefact – Story screen 1.

Screen 2

Narration – He's a big baby, 6.2 metres long! And he keeps growing fast at about 100kg a day.

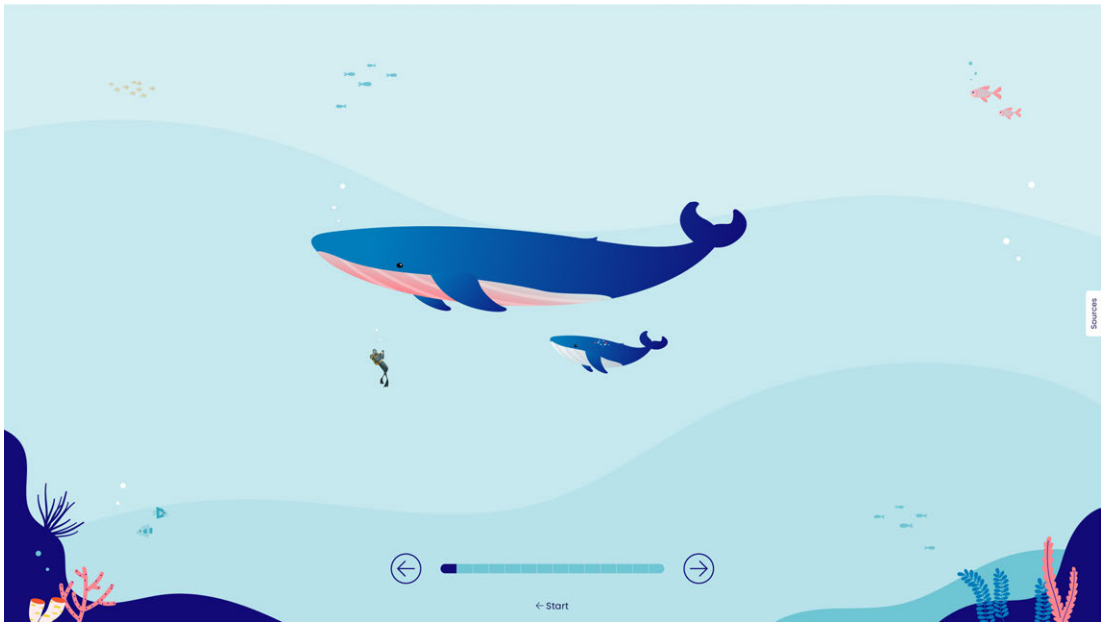

Figure A.3: *Finding Arcadia* artefact – Story screen 2.

Screen 3

Narration – One day, his mother tells him the tale of a time when whales were hunted almost to extinction by tiny two-legged creatures.

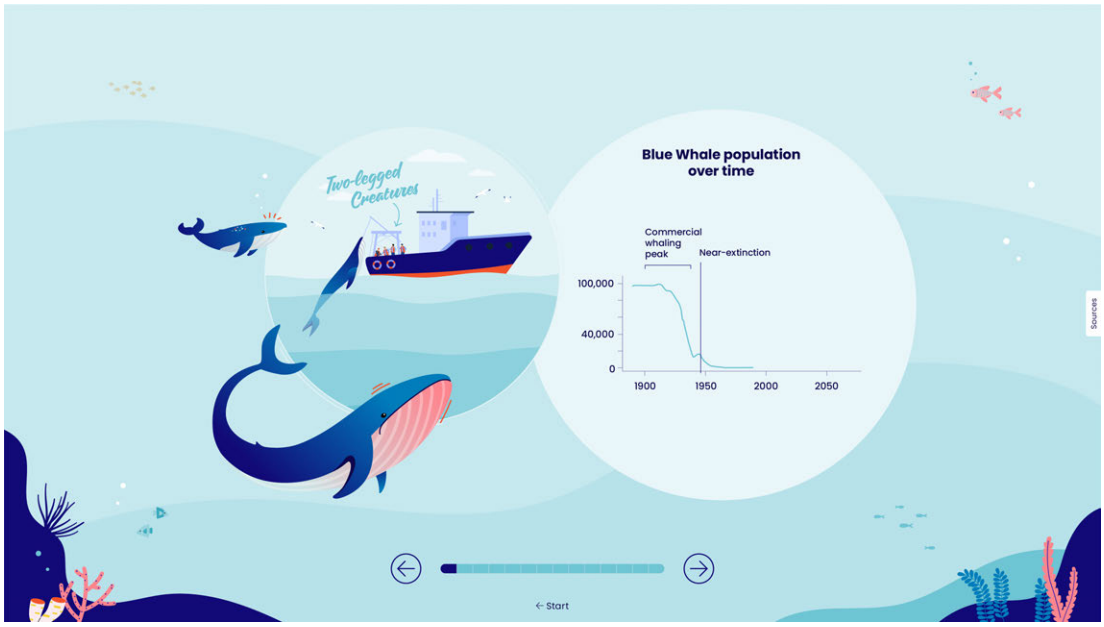

Figure A.4: *Finding Arcadia* artefact – Story screen 3.

Screen 4

Narration – But these beings seem to have changed somehow. They mostly stopped hunting whales a few decades ago, and now their numbers are slowly but steadily growing. She dreams of the day when the oceans are once again populated with whales, just like they used to be.

Strategies – Positive framing through the story narrative and by highlighting positive aspects of the data set in the visualisation – the fact that whale populations have been rising since the commercial whaling ban. Also, personalisation of the information through the input of user data: the visualisation adapts to the date of birth.

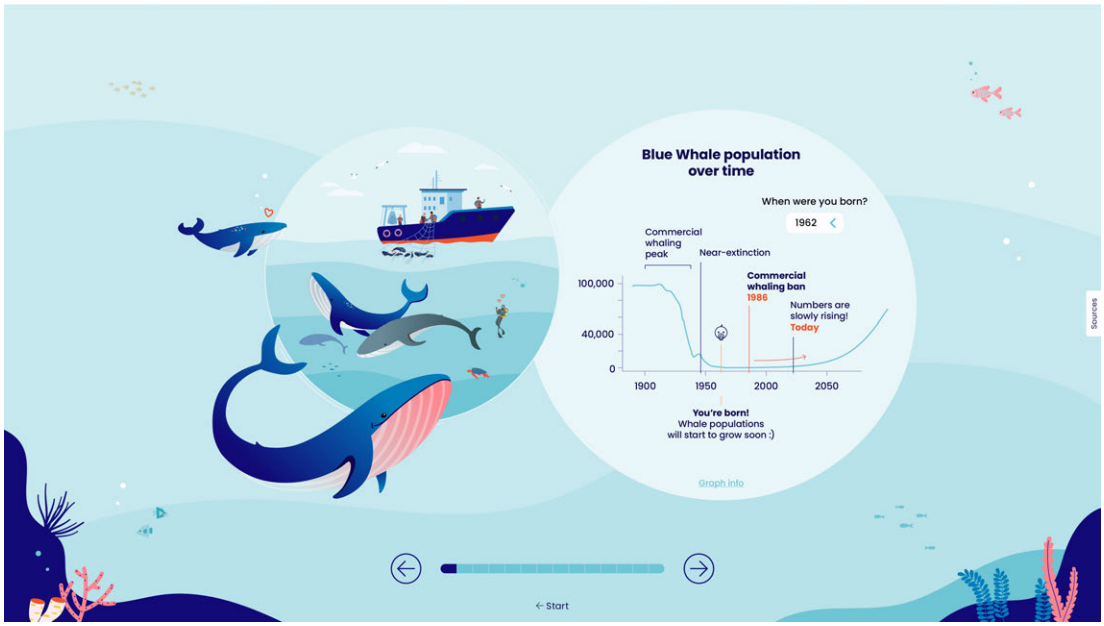

Figure A.5: *Finding Arcadia* artefact – Story screen 4.

Screen 5

Narration – You know... Because great whales are crucial for global ocean health! To feed, they dive to the ocean depths and come to the surface to breathe, poop and pee. These excrements release enormous plumes of nutrients into the water.

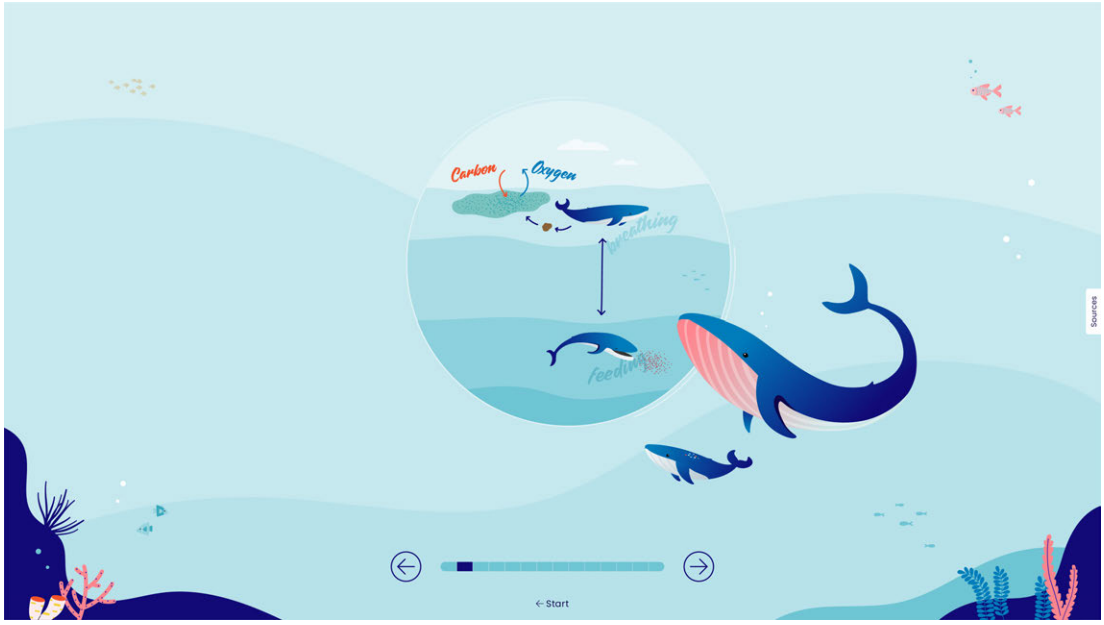

Figure A.6: *Finding Arcadia* artefact – Story screen 5.

Screen 6

Narration – The so-called "poo-namis" stimulate the growth of phytoplankton – marine algae that suck carbon out of the air via photosynthesis, just like land plants and trees. Baltazar had no idea that his poop was so important.

Strategies – Presenting the whale ocean pump through Baltazar's story and contextualising it by showing the impact that phytoplankton has in global CO2 capture. This impact is further contextualised through comparisons to more familiar metrics – the Amazon forest – and personalised by comparing to the CO2 emissions of the user's own country.

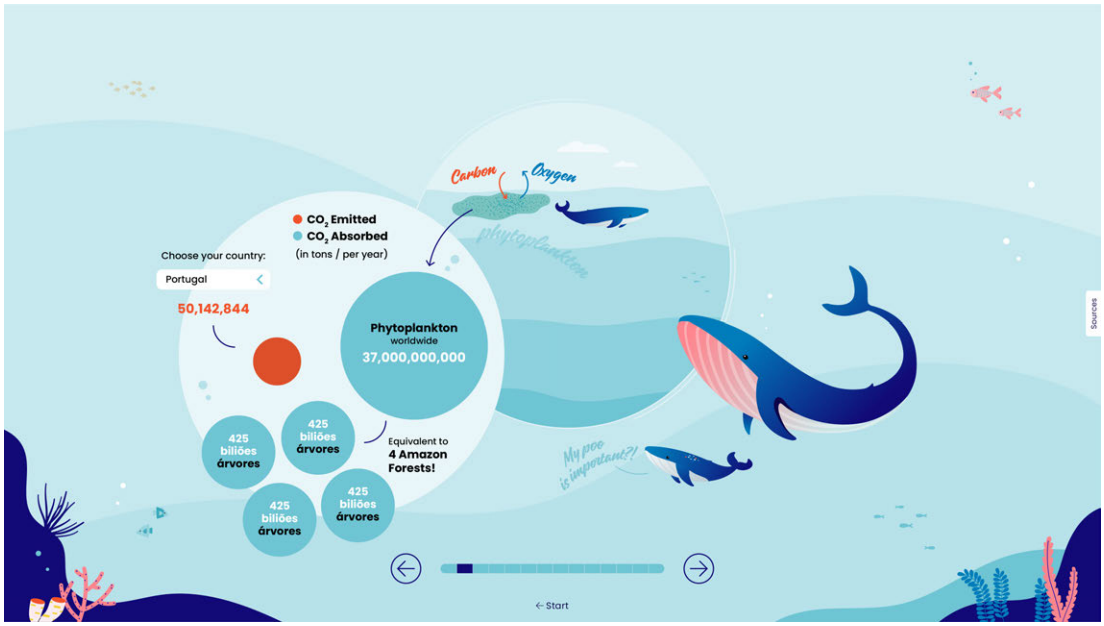

Figure A.7: *Finding Arcadia* artefact – Story screen 6.

Screen 7

Narration – That summer, when it's feeding season for great whales, his mum takes him to a gorgeous, peaceful spot in the northern seas. There's plenty of food, it's peaceful, beautiful – It's perfect! She has called it their little Arcadia. Baltazar hopes to never leave.

Strategies – Storytelling: coming back to this perfect place of his childhood becomes the main character's objective throughout the story. It's the catalyst for his journey and the dangers he faces caused by the Anthropocene.

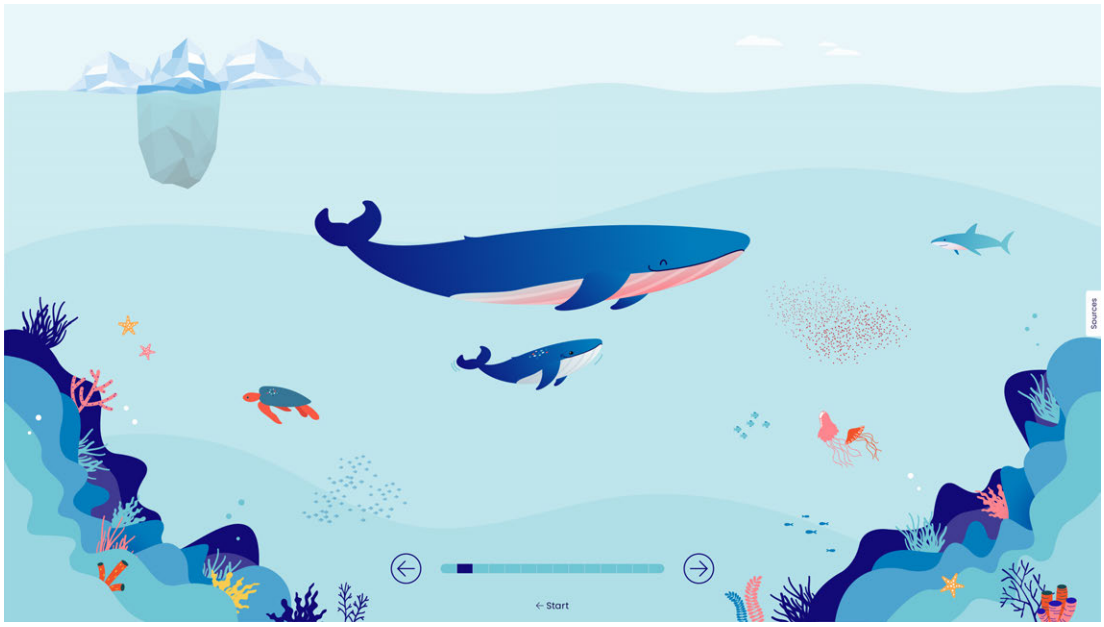

Figure A.8: *Finding Arcadia* artefact – Story screen 7.

Screen 8

Narration – But... after feeding season, whales migrate south. And when he's about six months old, it's time for him to leave his mum and start his own journey through the seas. Baltazar says goodbye to her, and promises himself he'll come back to this perfect place one day.

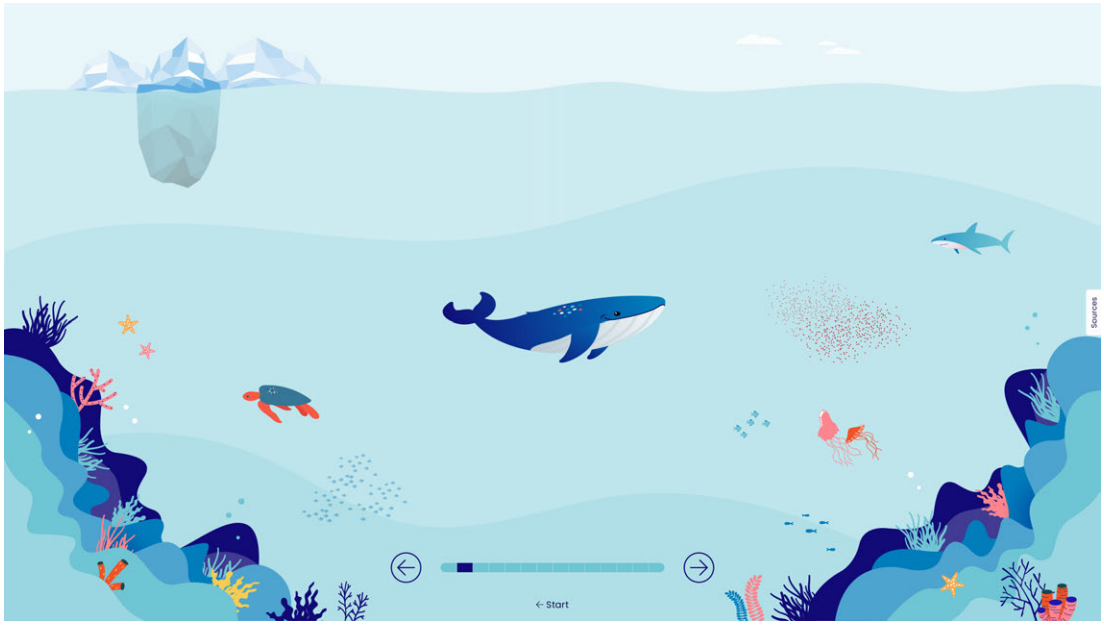

Figure A.9: *Finding Arcadia* artefact – Story screen 8.

Screen 9

Narration – One afternoon, Baltazar crosses paths with a codfish who is amazed by his size! It's true – Baltazar grows up to be a big boy. Blue whales can grow up to 30m long

and 200 tonnes, the biggest animals to have ever lived on our planet, and that includes the dinosaurs!

Strategies – In this screen, we lay the context for the following information. We contextualise a Blue Whale's size by comparing it to familiar or curious metrics: a dinosaur (that we normally assume as big), a shark, a bus, and a person (average human height).

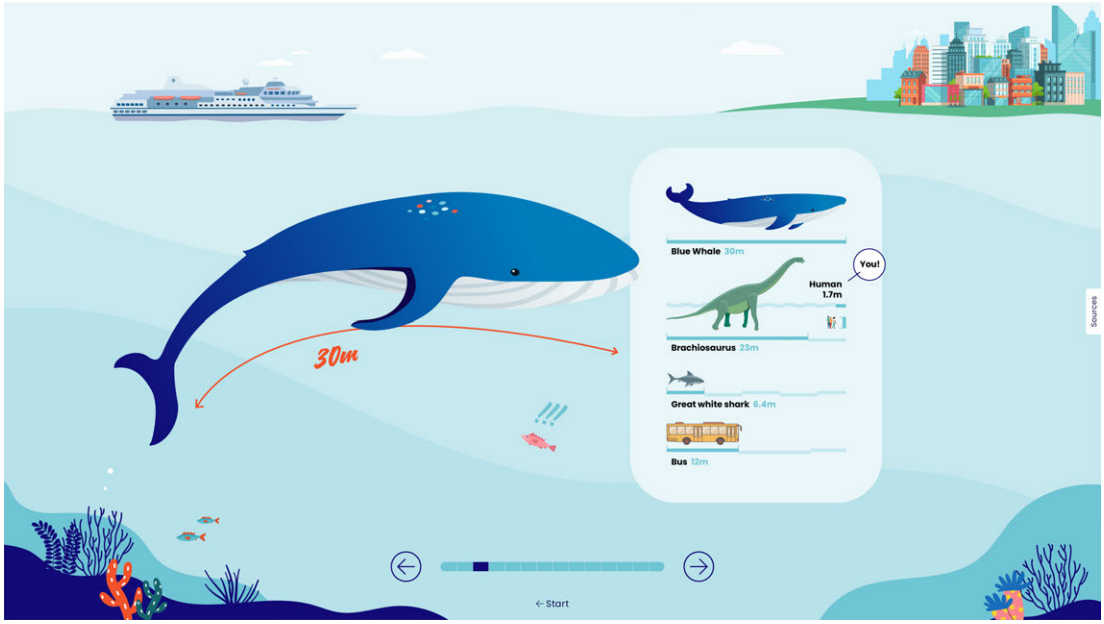

Figure A.10: *Finding Arcadia* artefact – Story screen 9.

Screen 10

Narration – Baltazar tells the cod his size isn't just for show. The bulk of large whales means they store big amounts of carbon in their bodies – the bigger and longer-lived the animal, the more carbon they store during their lives. They hoard carbon in their fat, protein-rich bodies – like giant, swimming trees. Whales are a powerful natural solution to the carbon problem. And the more whales we have, and the healthier the oceans are, the more carbon is captured naturally.

Strategies – Comparison to more familiar metrics – CO2 absorbed by whales compared to trees.

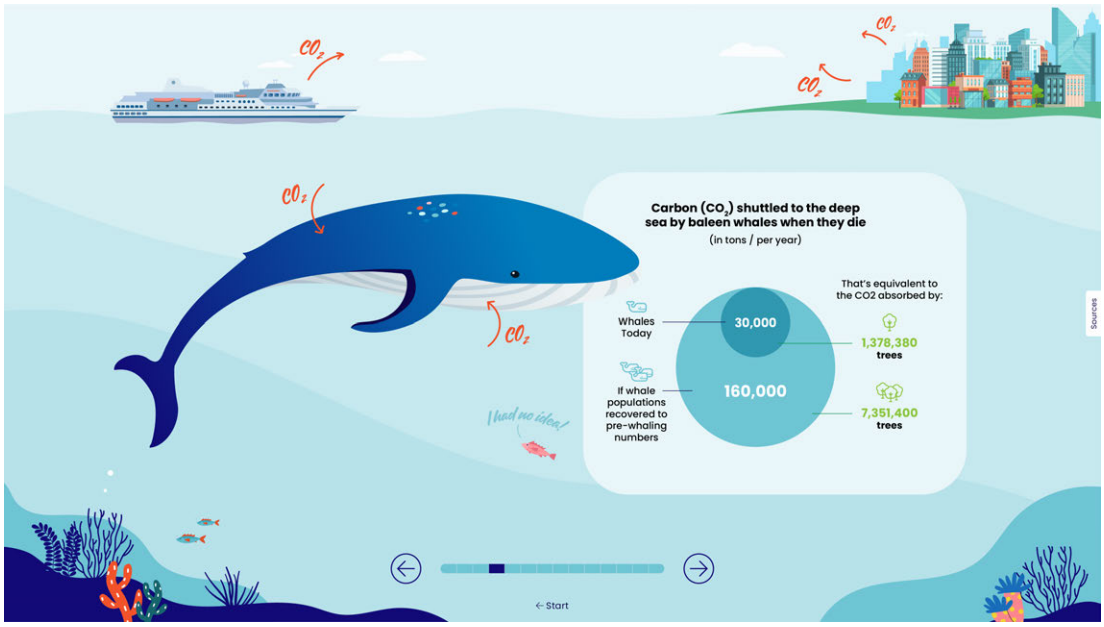

Figure A.11: *Finding Arcadia* artefact – Story screen 10.

Screen 11

(No narration)

Strategies – Positive framing: Linking to solutions by proposing actionable steps users can take.

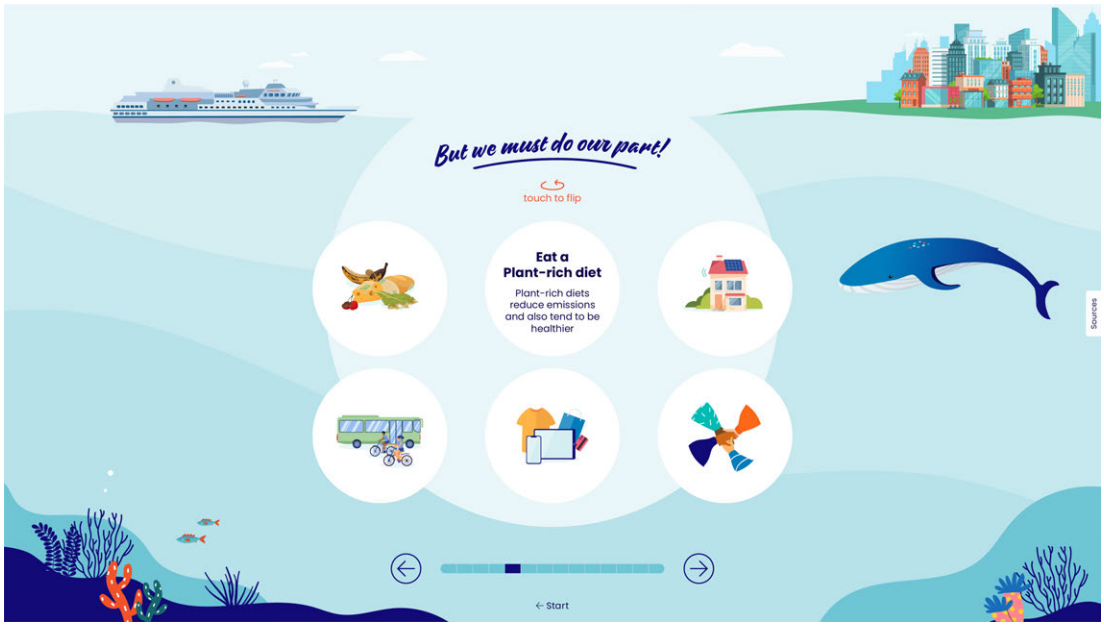

Figure A.12: *Finding Arcadia* artefact – Story screen 1.

Screen 12

Narration – Baltazar spends his summers in colder, productive waters with the mission of finding food. He eats mostly krill, small shrimp-like animals that thrive in some of these colder seas. Baltazar is a baleen whale – he has baleen plates in his mouth that act

as filters. This means that he swallows big amounts of water filled with krill and filters the water out.

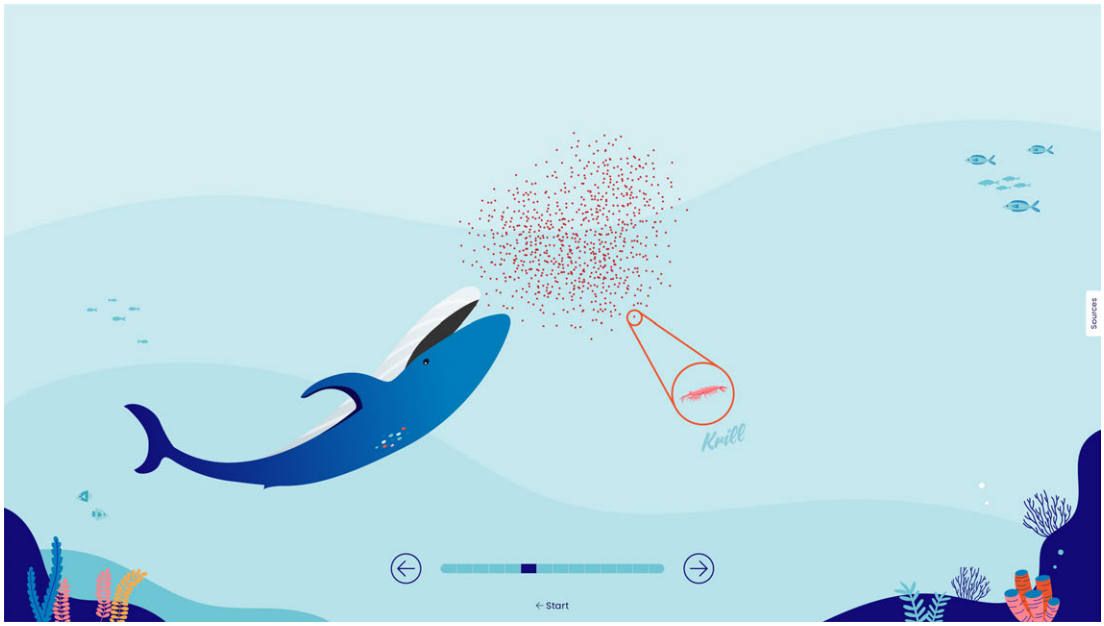

Figure A.13: *Finding Arcadia* artefact – Story screen 12.

Screen 13

Narration – Without knowing it, with the thousands of litres of water he filters to feed on tiny krill, he is also ingesting microplastic. The small plastic bits build up inside the animal's tissue and ooze out toxic chemicals that make them sick.

Strategies – Showing the problem of plastic pollution in the ocean through the consequences to Baltazar.

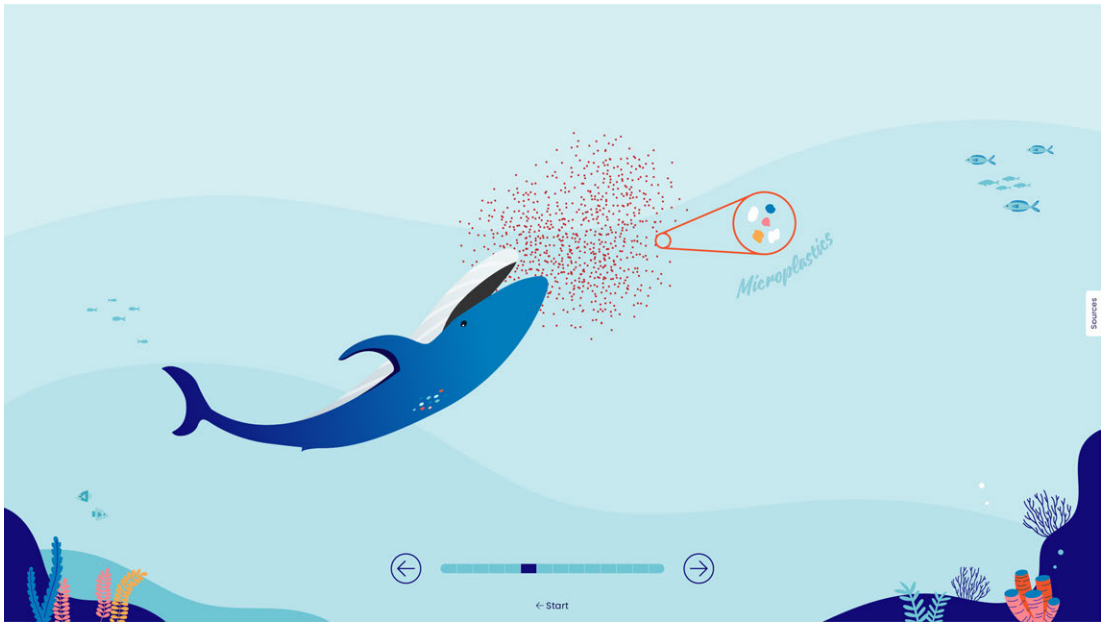

Figure A.14: *Finding Arcadia* artefact – Story screen 13.

Screen 14

Narration – Other whale species that feed on bigger prey are in danger of ingesting larger plastic waste. In 2019, a sperm whale (cachalote) was found with 22kg of plastic in its stomach, including plastic bags, plates and fishing nets. 22kgs!

Strategies – Reiterating the problem of plastic pollution in the ocean through the consequences to another character based on a true story (linking to real events).

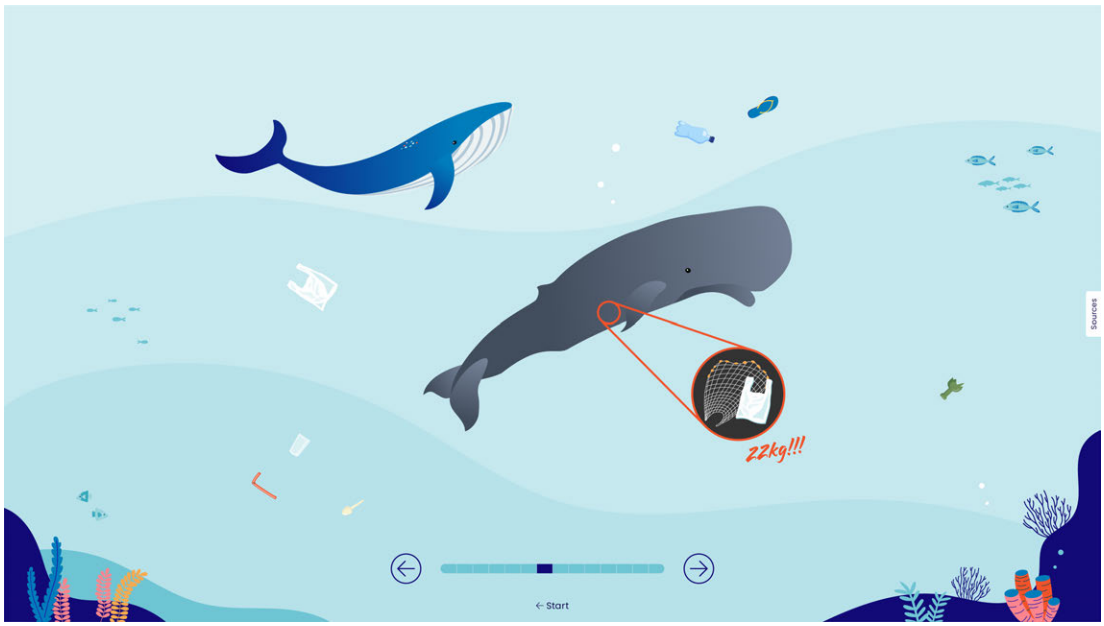

Figure A.15: *Finding Arcadia* artefact – Story screen 14.

Screen 15

Narration – By 2050, there could be more plastic in the sea by weight than fish. Can you imagine? There is nothing Baltazar can do to avoid microplastics. But there is a lot that we can do to avoid more plastic ending up in the ocean.

Strategies – Speculative future: linking to estimations for 2050 in the narration. The visualisation uses personalization through user's input of their country and the visualisation adapts to that choice – comparing the plastic waste created in tons to the weight of adult elephants (adding meaning to the number). Also, we strive for a positive framing by linking to actions related to the topic of plastic.

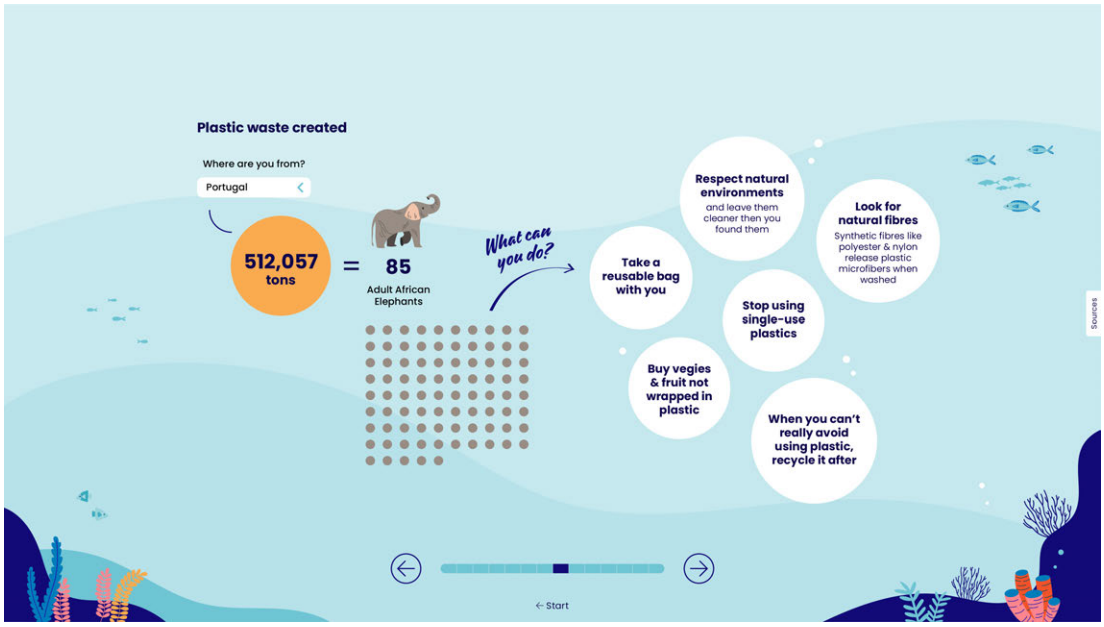

Figure A.16: *Finding Arcadia* artefact – Story screen 15.

Screen 16

Narration – Some years later, Baltazar is swimming in his preferred south seas, minding his own business, when suddenly he hears a beautiful call. He is mesmerised. . . He needs to find who is singing that wonderful song. Thankfully, that day the ocean is not too noisy and he can follow the sound from far away.

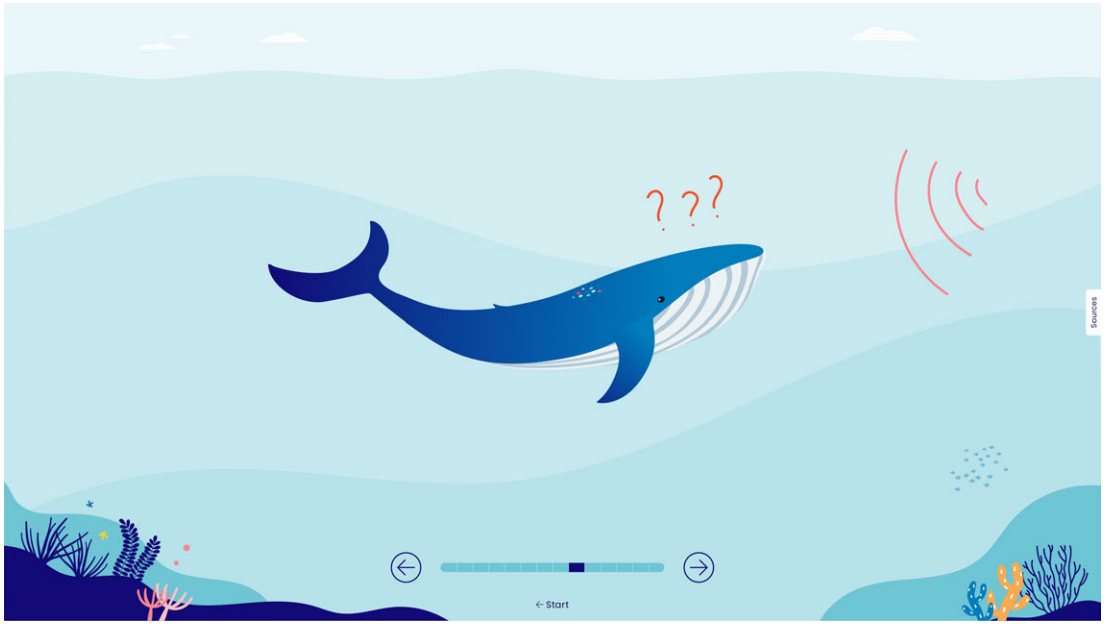

Figure A.17: *Finding Arcadia* artefact – Story screen 16.

Screen 17

Narration – That's when he sees her. . . Diolinda. He has never seen such a beautiful blue whale – and as he will later discover, such a smart and resourceful whale to boot.

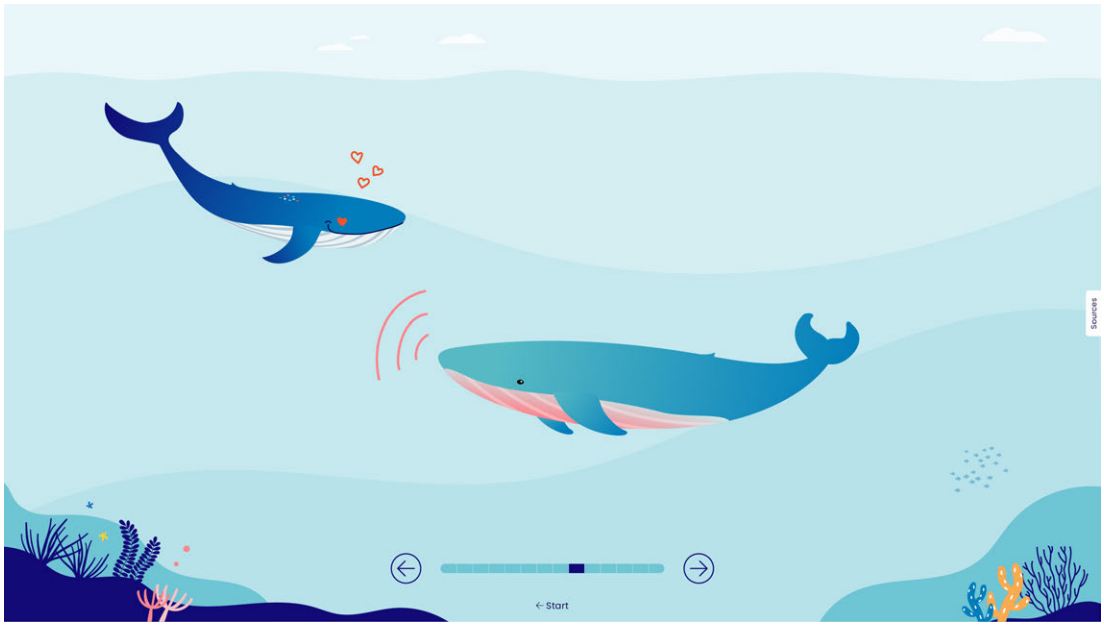

Figure A.18: *Finding Arcadia* artefact – Story screen 17.

Screen 18

Narration – They fall in love. . . and have a lovely time together. Baltazar and Diolinda share songs and stories, and he tells her of Arcadia, the perfect place he shared with his mum and that he vowed to find again.

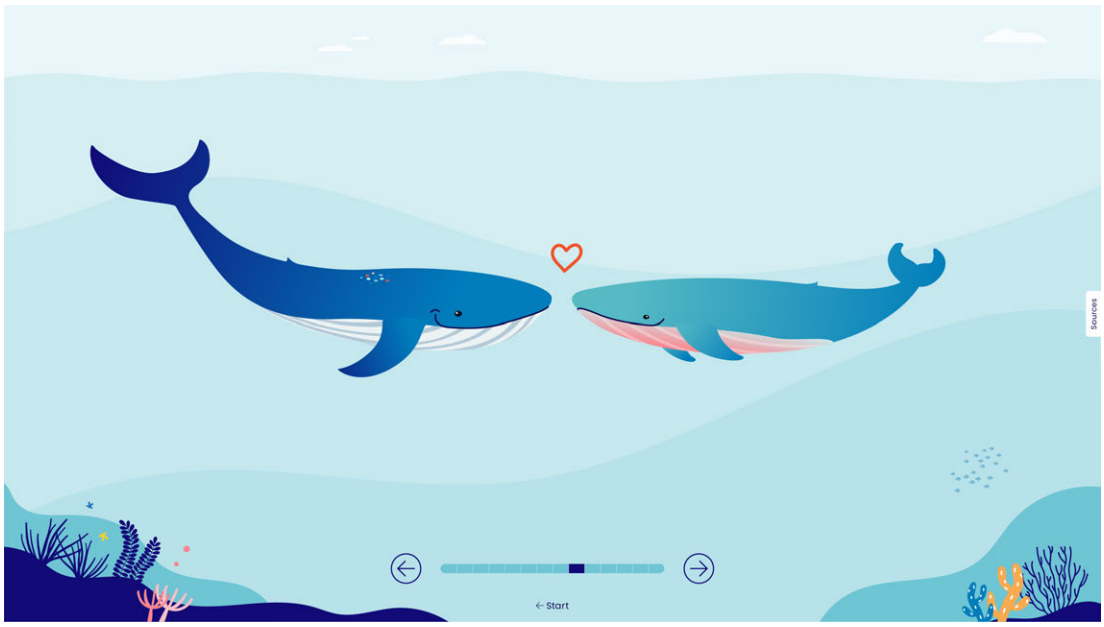

Figure A.19: *Finding Arcadia* artefact – Story screen 18.

Screen 19

Narration – About one year later, baby Tobias is born. Tobias will stay with his mum for the first six months or so, and then the whale life cycle will start again. In the meantime, Baltazar continues his journey through the seas.

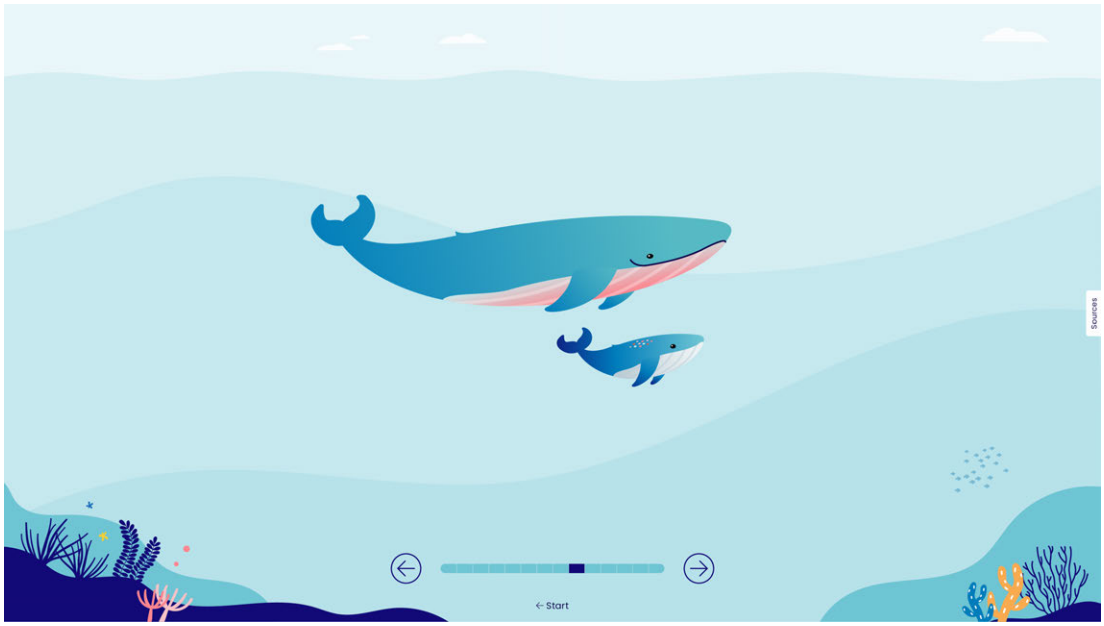

Figure A.20: *Finding Arcadia* artefact – Story screen 19.

Screen 20

Narration – Each year, Baltazar travels around 6,500 km. During his life he will travel between 380,000 and 580,000 km! Whales make some of the longest migrations on earth. Like him, his fellow blue whales migrate throughout their lives from colder feeding grounds, where food is abundant, to warmer breeding grounds, where they look for love. On his yearly migration, Baltazar has been looking for that wonderful place his mother took him to when he was a child.

Strategies – Contextualisation by comparing the distance a Blue whale travels in one year to distances in the map that the user can select. There is also an element of connection to the physical location of the installation as the distances begin in Lisbon, where the user is based.

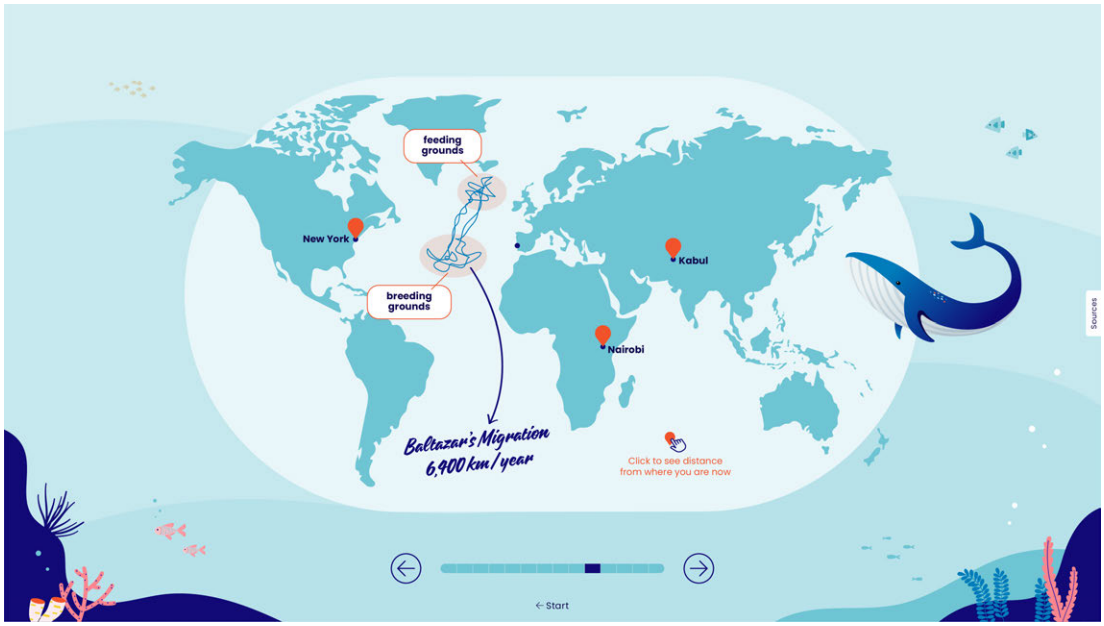

Figure A.21: *Finding Arcadia* artefact – Story screen 20.

Screen 21

Narration – However, it has become hard and extremely dangerous for him and his whale friends to keep their normal migration patterns which their whale ancestors have followed for thousands of years, because of the amount of vessels we have in the oceans. Ship collisions and entanglement in fishing nets are the major human-made causes of death for cetaceans. Baltazar changes his course all the time to avoid ships and other vessels. With all that interference, he hasn't been able to find Arcadia again. But every year, he looks for it. . .

Strategies – Showing the dangers to whales (and other marine animals) by showing the overlap of the migration routes of whales with the routes of ships. Again, linking to actions that need to happen – in this case also related to system changes.

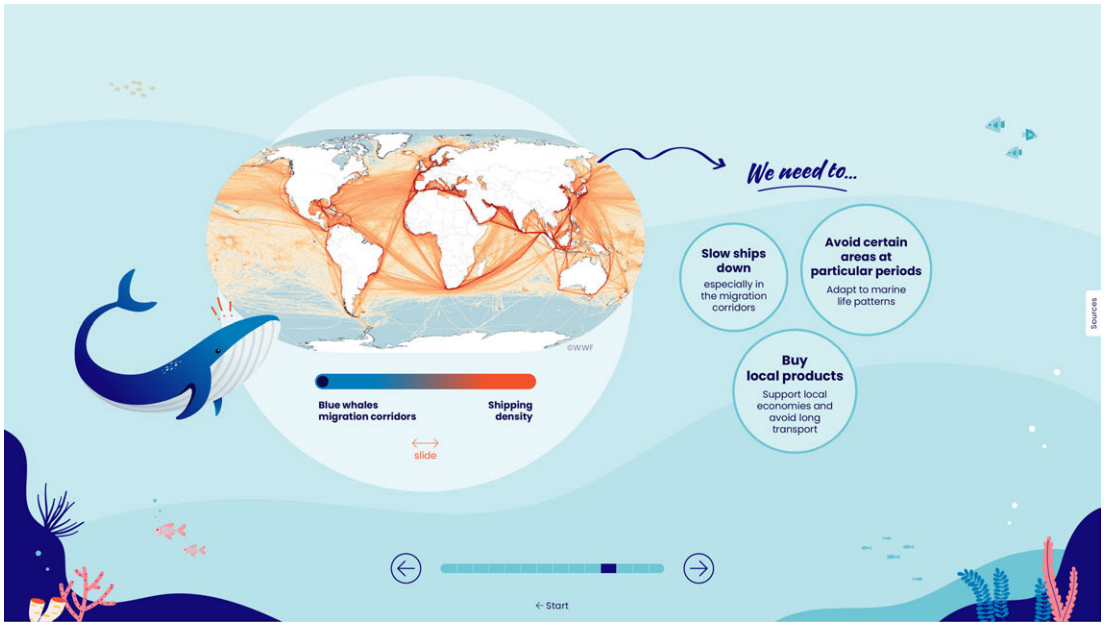

Figure A.22: *Finding Arcadia* artefact – Story screen 21.

22

Narration – Once again, Baltazar goes on his yearly migration to the north. He thinks this year is the year. He will find Arcadia! For orientation, he uses loud vocalisations. Sound is extremely important to whales. They help him find his way in the vastness of the deep blue and relate to the surrounding whales.

Figure A.23: *Finding Arcadia* artefact – Story screen 22.

Screen 23

Narration – But that day, while searching for the place, Baltazar is overwhelmed by the incessant noises around him. Water is a powerful sound conductor, and the noise

produced by an oil platform and a huge ship become too much. It's like constantly living with headphones that you can never take off, blasting loud, annoying sounds – all the time – and you can't escape. Baltazar needs to get away from the overpowering racket.

Strategies – Demonstrating the intensity of ocean noise pollution through real ocean noises and deepening the empathy with the whale character by putting the user in the whale's situation (narration).

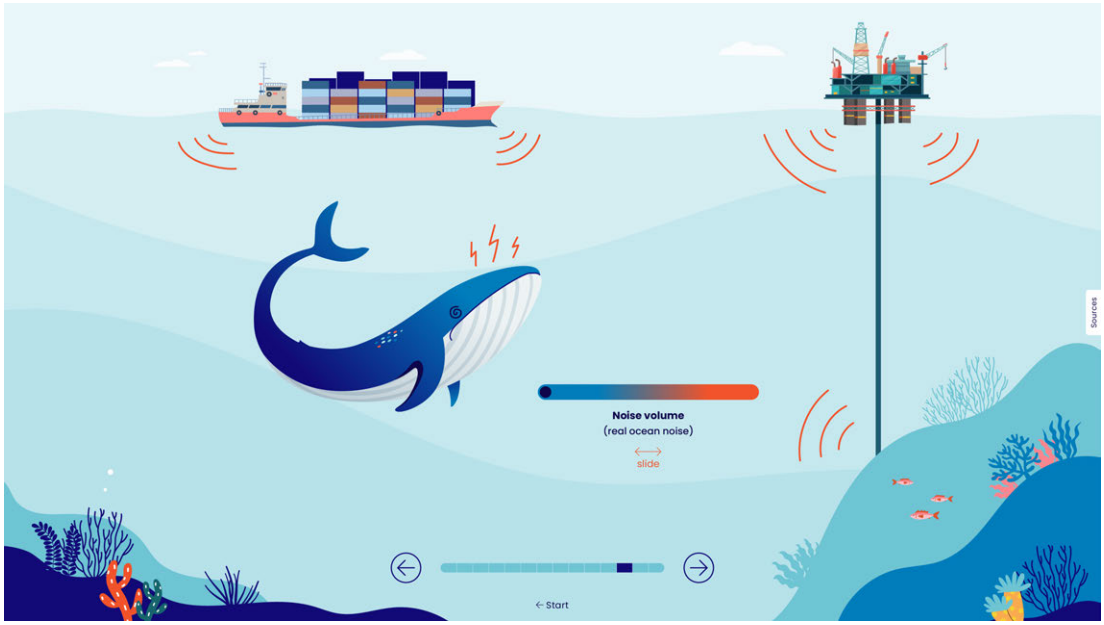

Figure A.24: *Finding Arcadia* artefact – Story screen 23.

Screen 24

Narration – Without realising it, he gets disoriented and goes too far inland. He is caught by the currents and gets stranded in the sand! He doesn't have long before hypothermia, dehydration, and the weight of his own body starts to kill him. Some two-legged creatures see him and run to help. Quickly a crowd gathers to help Baltazar back to the ocean.

Strategies – Storytelling: showing the dire consequences the Anthropocene can have on whales.

Figure A.25: *Finding Arcadia* artefact – Story screen 24.

Screen 25

Narration – Thankfully, the humans are able to help him escape the shallow waters. He swims to the deep sea as quickly as he can.

Strategies – Positive framing: humans help Baltazar and the story doesn't have a tragic ending. Also, the volume of some ocean pollution is compared to other noises more familiar to the user. Finally, this segment of the story is also linked to action, some linked to individual behaviour and some to system changes.

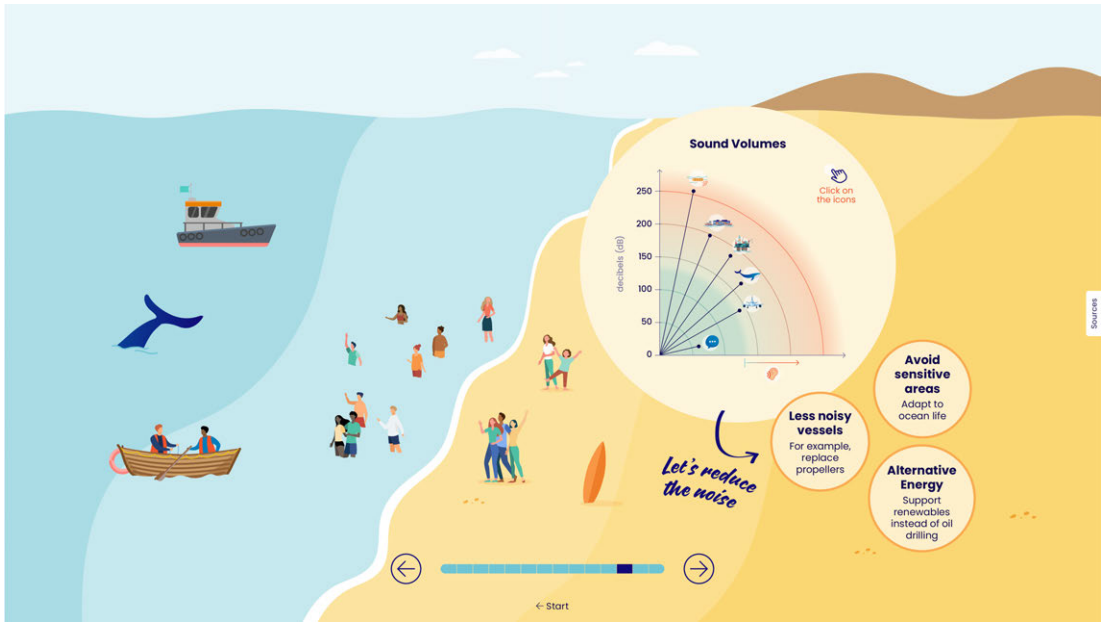

Figure A.26: *Finding Arcadia* artefact – Story screen 25.

Screen 26

Narration – Some years later, Baltazar is still looking for Arcadia, the perfect place. The many dangers he has faced caused by humans' action in the oceans – the anthropocentric footprint – have disrupted his day-to-day life, and even put his life at risk. We humans are the problem, but we also hold the keys for the solution.

Strategies – Storytelling through the character journey (his purpose of finding the place of his childhood) and how human interference has hindered that journey.

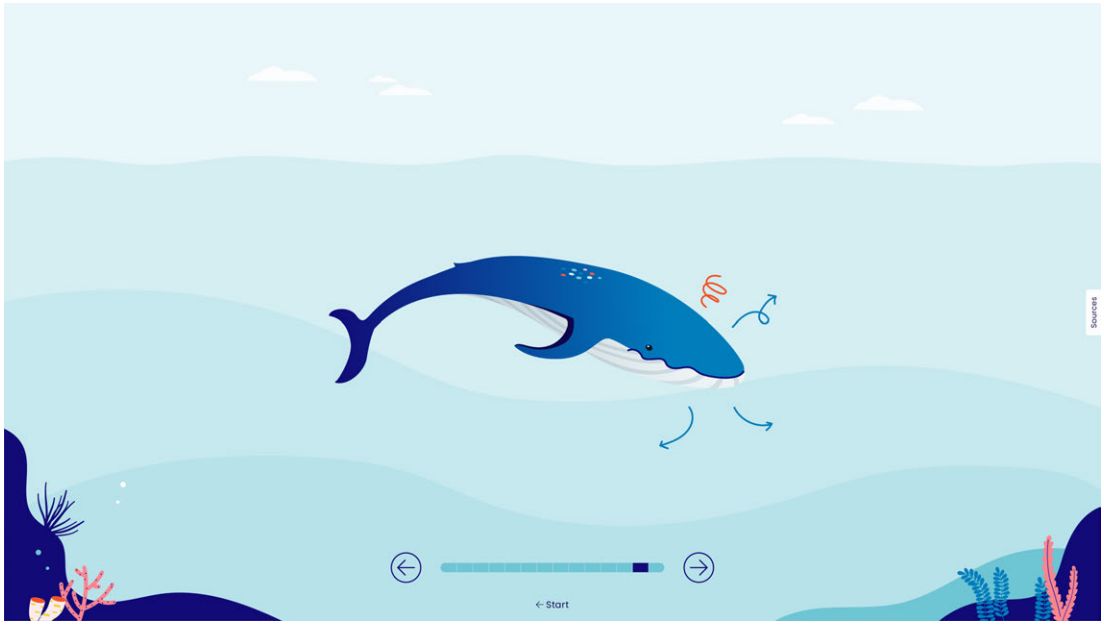

Figure A.27: *Finding Arcadia* artefact – Story screen 26.

Screen 27

Narration – One day, Baltazar notices that the huge ships he encounters are moving slower and he is able to avoid them. Their noise isn't as loud as before either. The two-legged creatures have changed something. He also sees some of them cleaning the ocean of that dreadful plastic and discarded fishing gear. Baltazar is able to swim the seas in greater peace.

Strategies – Positive framing by showing a positive speculative future.

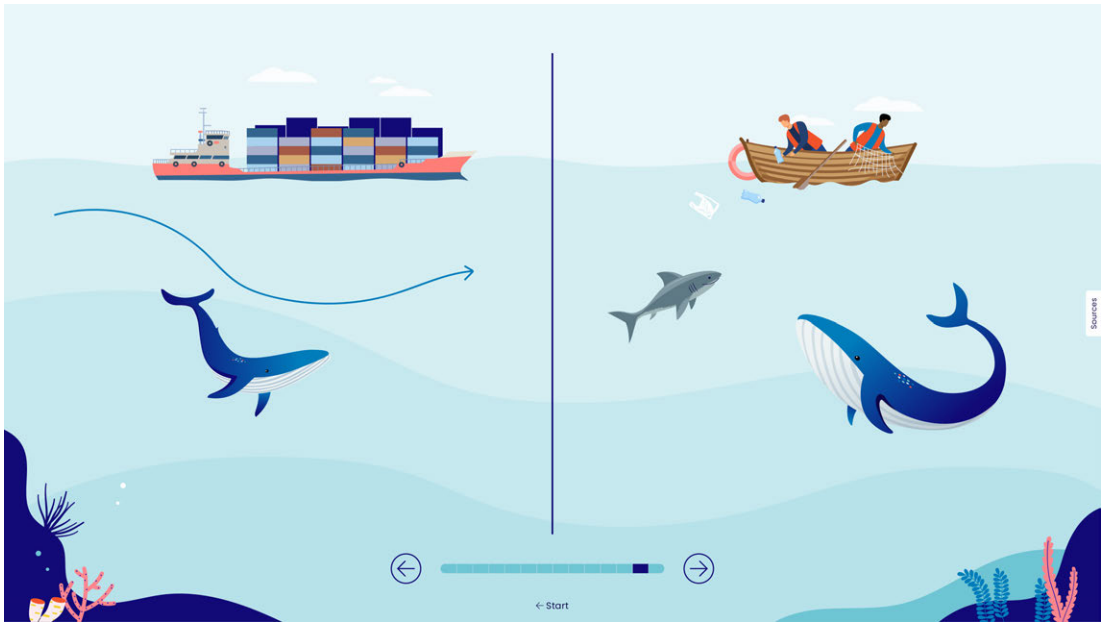

Figure A.28: *Finding Arcadia* artefact – Story screen 27.

Screen 28

Narration – As he swims, he starts to recognise his surroundings. Yes! He is close!...

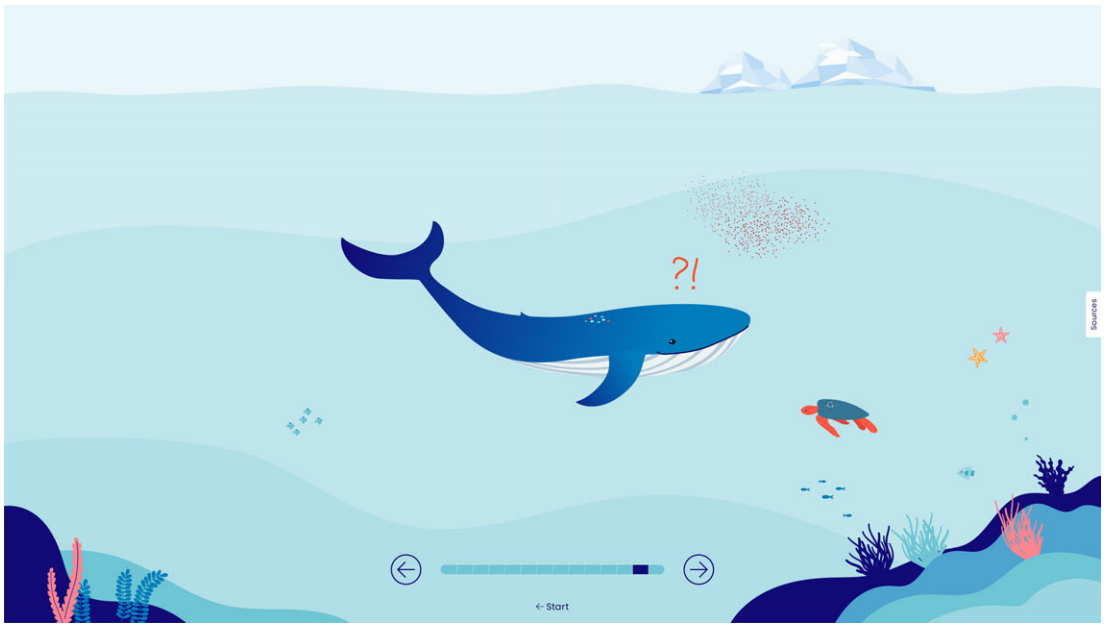

Figure A.29: *Finding Arcadia* artefact – Story screen 28.

Screen 29

Narration – After so many years, and so many obstacles... Baltazar finally finds Arcadia, the perfect place of his childhood. It's as gorgeous and peaceful as he remembers. From here-on, Baltazar will come back to his Arcadia every year, to enjoy his little piece of paradise.

Strategies – Positive framing through a story of resilience and a happy ending.

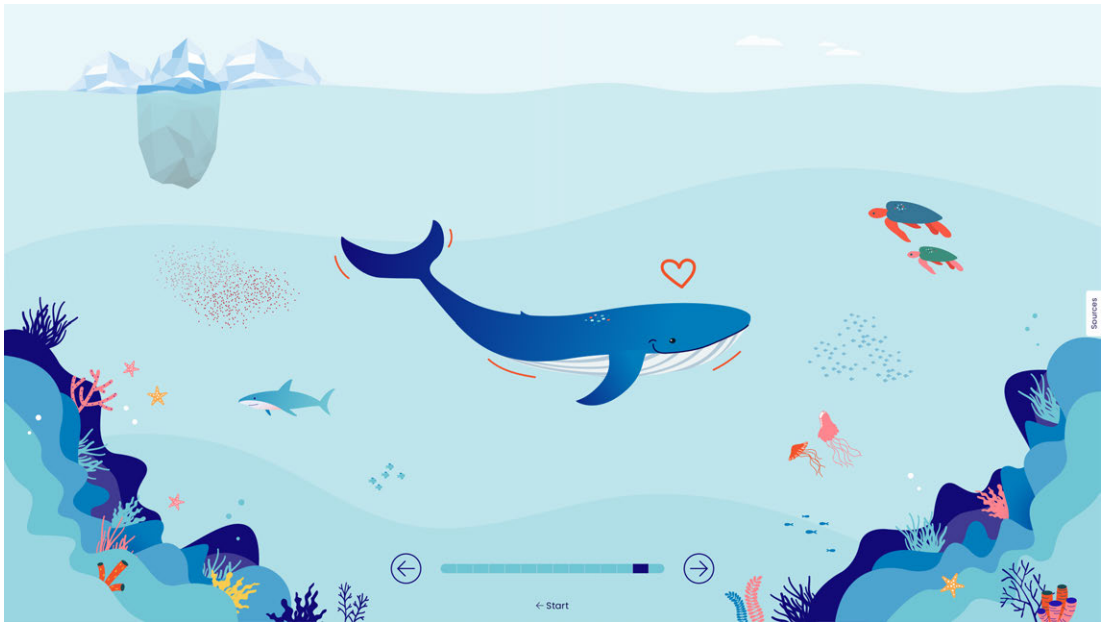

Figure A.30: *Finding Arcadia* artefact – Story screen 29.

Screen 30

Narration – After a long and eventful life, full of cool – and not so cool – adventures, Baltazar dies at the beautiful age of 87. His carcass sinks to the bottom of the ocean taking with him 33 tons of carbon that will support deep-sea ecosystems. That's a big amount of CO2 that is taken out of the atmospheric cycle for hundreds to thousands of years – a literal carbon sink.

Strategies – Comparison of the CO2 absorbed by whales with the more familiar metric of trees – a more relatable way of explaining a natural carbon sink.

Figure A.31: *Finding Arcadia* artefact – Story screen 30.

Screen 31

Narration – Having a better relationship with the oceans and its inhabitants and, with that, supporting natural solutions to our carbon problem is fundamental. It's a win-win! Pass on what you have learned and take action. Let's do this together!

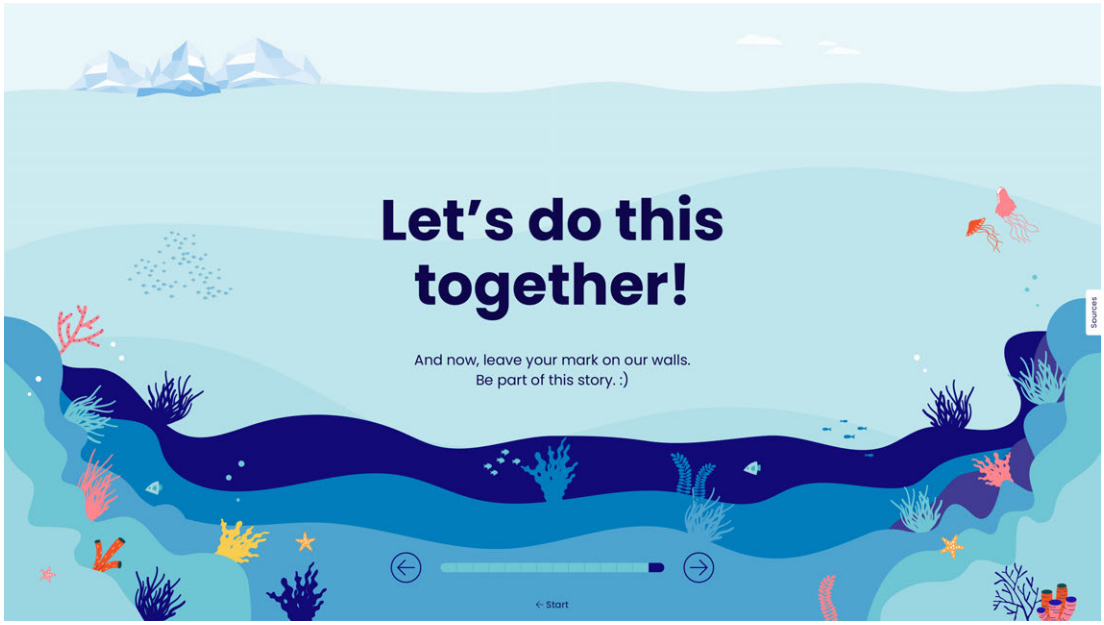

Figure A.32: *Finding Arcadia* artefact – Story screen 31.

A.2 Artefact Version 2

The second iteration of the artefact (Chapter 6) was edited following the results of the pilot study (Chapter 5). In this section, these changes are illustrated.

The story was shortened to make it more concise. To this effect, the following screens were removed: 2, 5, 7, 8, 15, 16, 17, 18, 19, 20, 24, 25, 28, 29.

Furthermore, some of the data visualizations were improved with more interactive components that also enhanced the Data Humanism approach taken. These changes are presented in the figures below.

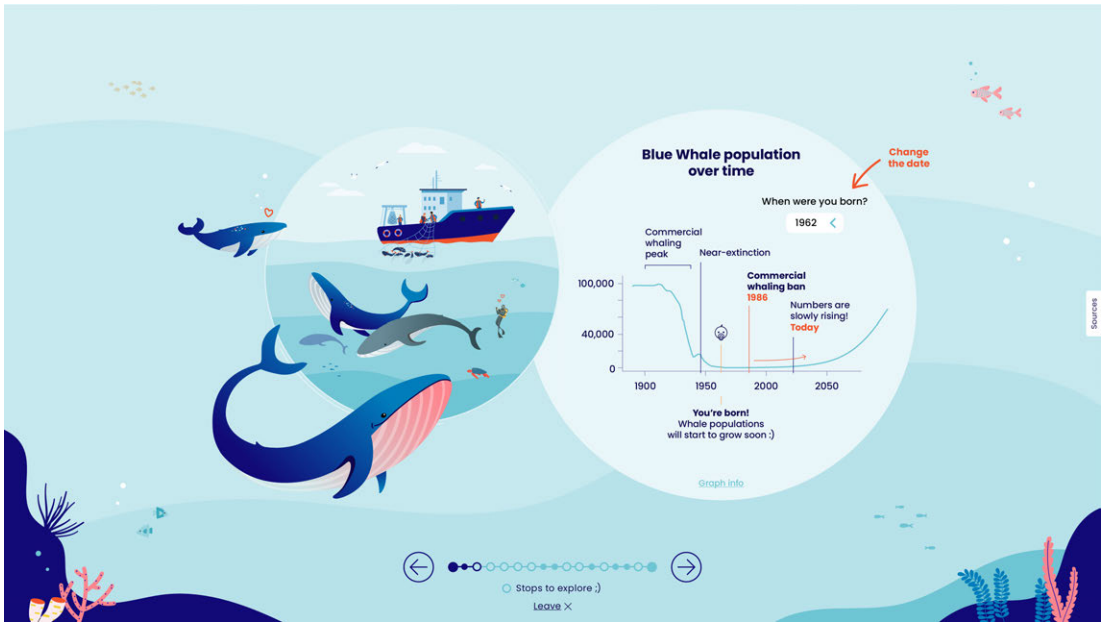

Figure A.33: Screen from the *Finding Arcadia* artefact, version 2, showing the addition of a highlight text to give more emphasis to the interactable components.

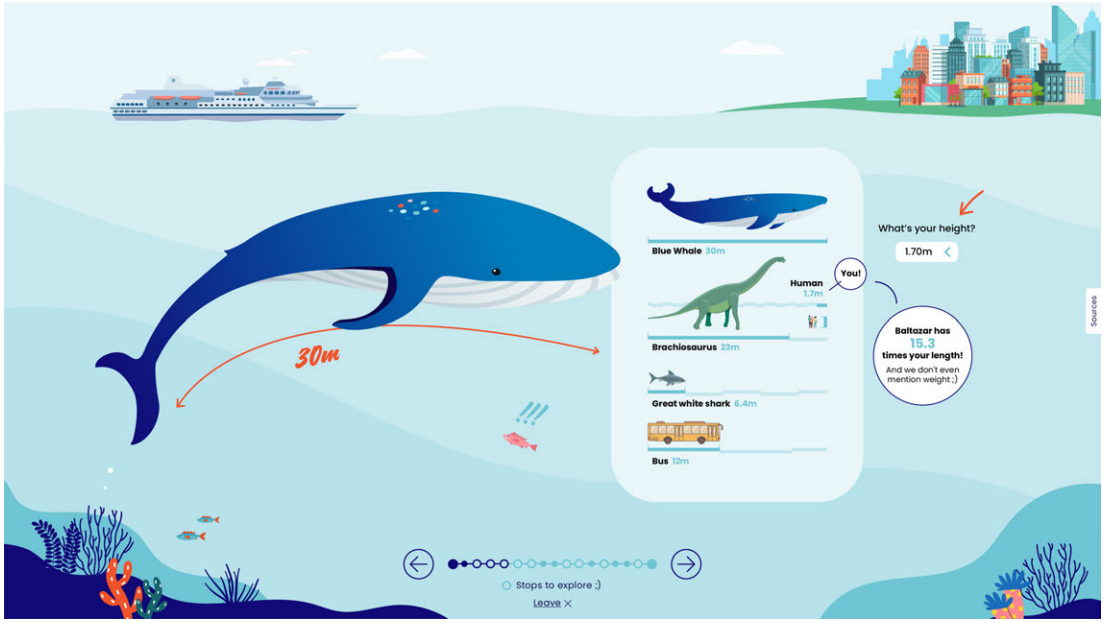

Figure A.34: Screen from the *Finding Arcadia* artefact, version 2, showing the new personalisation feature. The user could input their height, and it was compared to Baltazar's size.

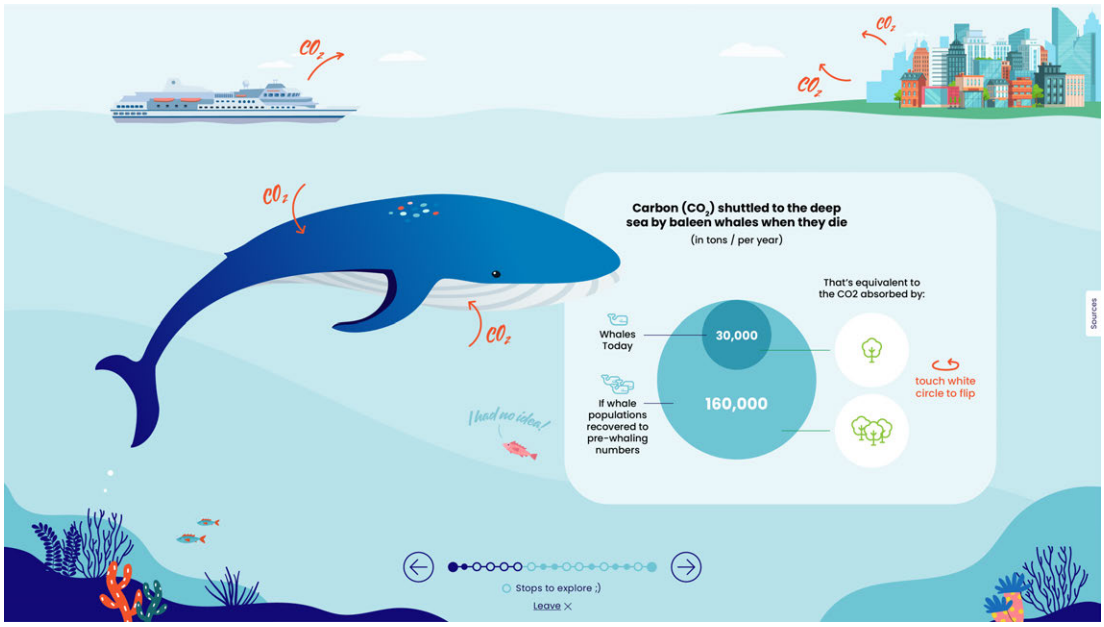

Figure A.35: Screen from the *Finding Arcadia* artefact, version 2, showing the added interaction feature. The comparisons are now clickable and they flip to show the information.

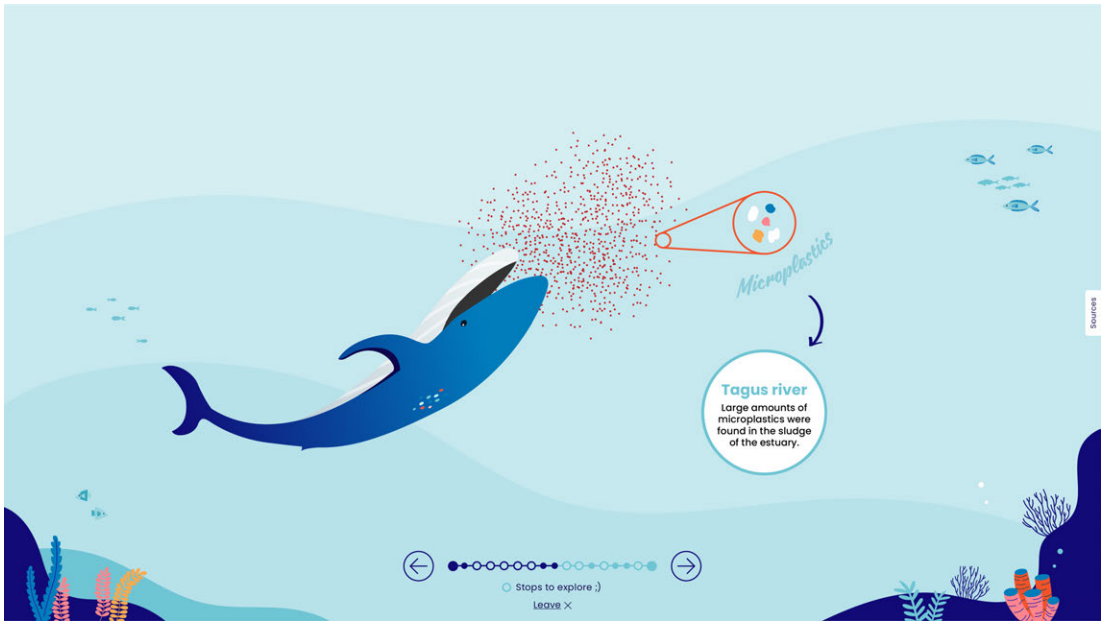

Figure A.36: Screen from the *Finding Arcadia* artefact, version 2, showing the addition of information relevant to the community where the artefact was implemented.

Figure A.37: Screen from the *Finding Arcadia* artefact, version 2, showing an example of the incorporation of the proposals for action. As the story was condensed, in some slides the proposals for action were incorporated into another section of the story.

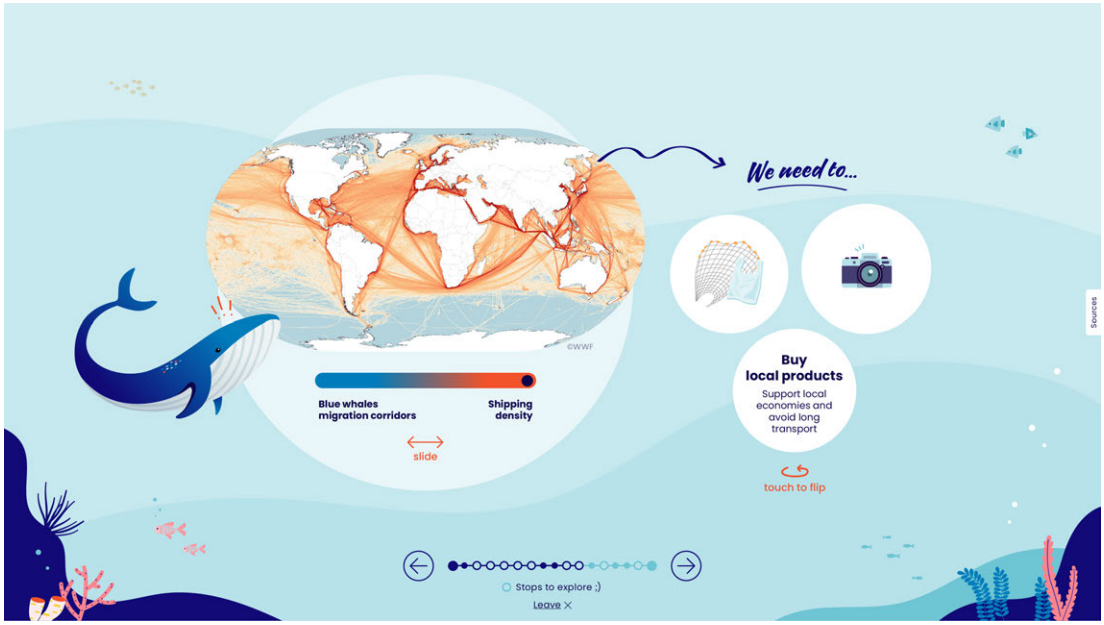

Figure A.38: Screen from the *Finding Arcadia* artefact, version 2, showing the added interaction feature. The actions are now clickable and they flip to show the information.

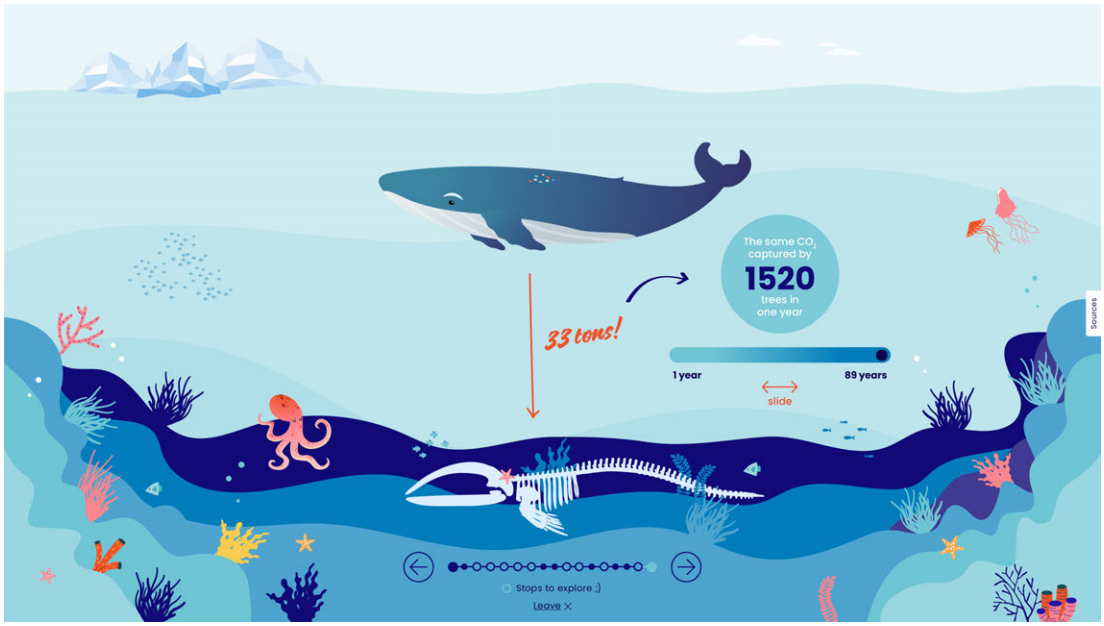

Figure A.39: Screen from the *Finding Arcadia* artefact, version 2, showing the added interaction feature. The comparison to the CO2 captured by trees is now shown through a slider.

Finally, changes to some of the proposed solutions were implemented, making them more appropriate for the audience to consider and act upon. This meant a greater focus on individual action and not system change. The changes to the proposed solutions are presented below.

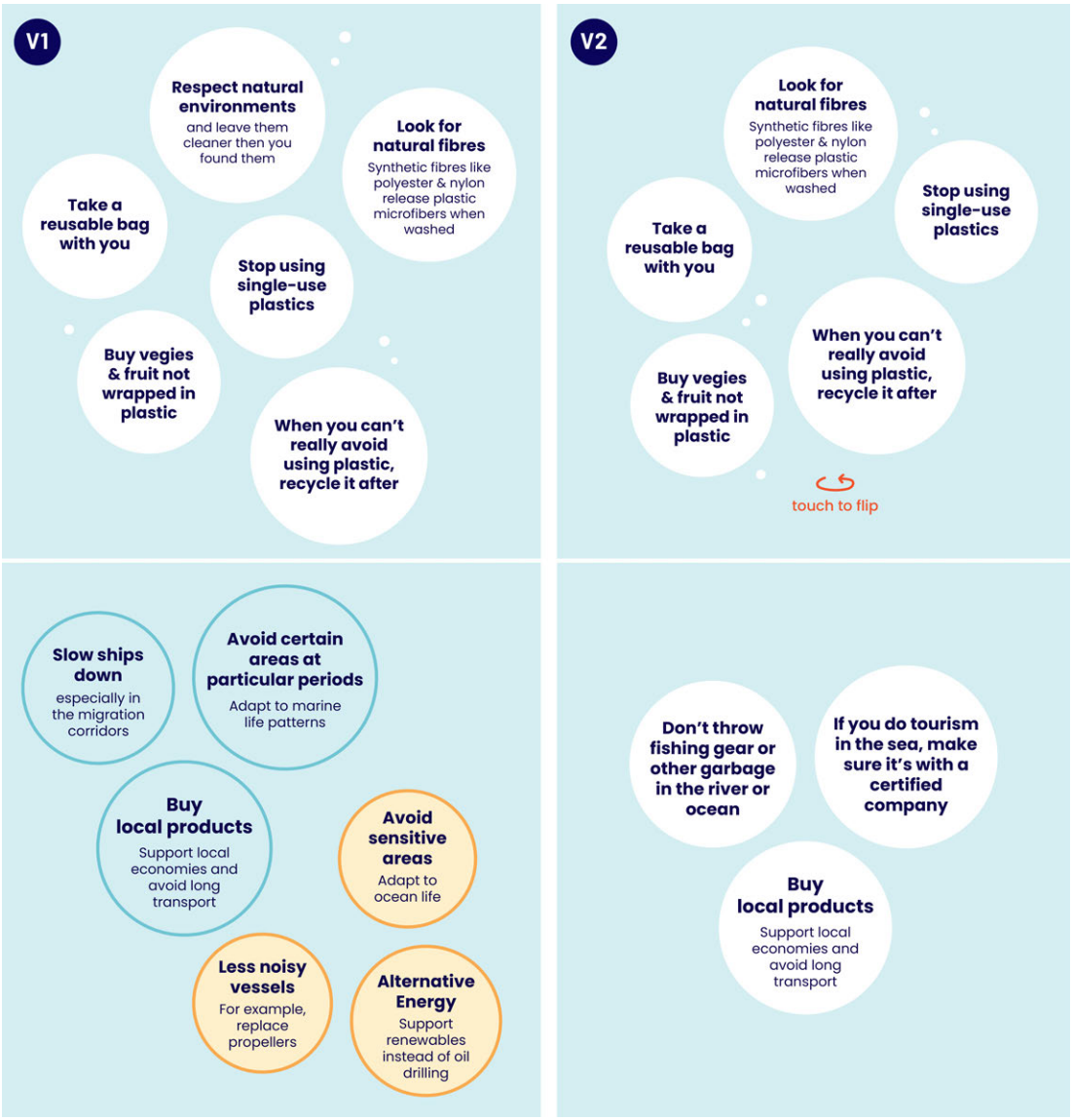

Figure A.40: Changes made to the proposals for solutions from version 1 (V1) to version 2 (V2) of the *Finding Arcadia* artefact.

A.3 Artefact Version 3

The third iteration of the artefact (Chapter 7) was edited following the results of the first main study in the food market (Chapter 6). The major edit from the previous iteration to this one was the creation of two versions of the story for comparison – a Base version (B) from which we removed the data humanism strategies, and a Data Humanism version (DH) that kept these strategies from the previous iteration and enhanced some aspects of it (these enhancements are described in their respective screens).

In this section, all the experience screens are presented: at the top is version B and at the bottom is version (DH). One of the main changes of this version was the narrated script, reworked for both versions from the one used in the previous iterations. Below each

figure is the text that was narrated in each section of the story: the base version and the DH version created from this "more impersonal" version using a LLM, where we asked for it to personify a blue whale and tell the information through his personal first-person perspective.

Screen 1

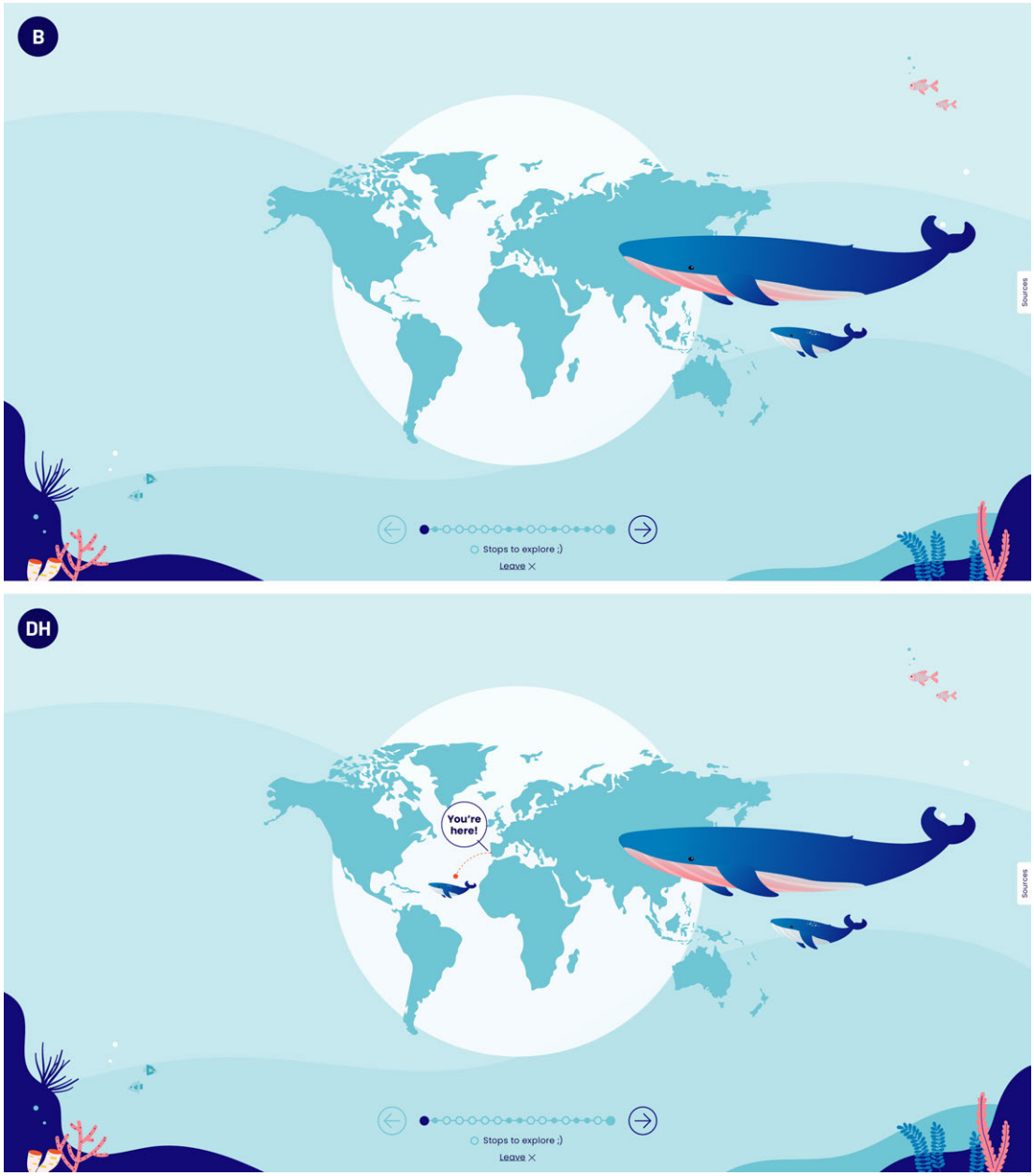

Figure A.41: *Finding Arcadia* version 3 – Story screen 1 for version B and DH.

Narration B – We are going to talk about blue whales and their lives in today's oceans. Blue whales are usually born in warmer waters of the ocean in lower latitudes.

Narration DH – Today, friend, we'll embark on a journey to understand my kin, the majestic blue whales, and our lives within the vast, shifting seascape of our modern world.

You see, the births of blue whales, like myself, commonly occur in the more sun-kissed parts of the ocean that sit closer to the equator.

Screen 2

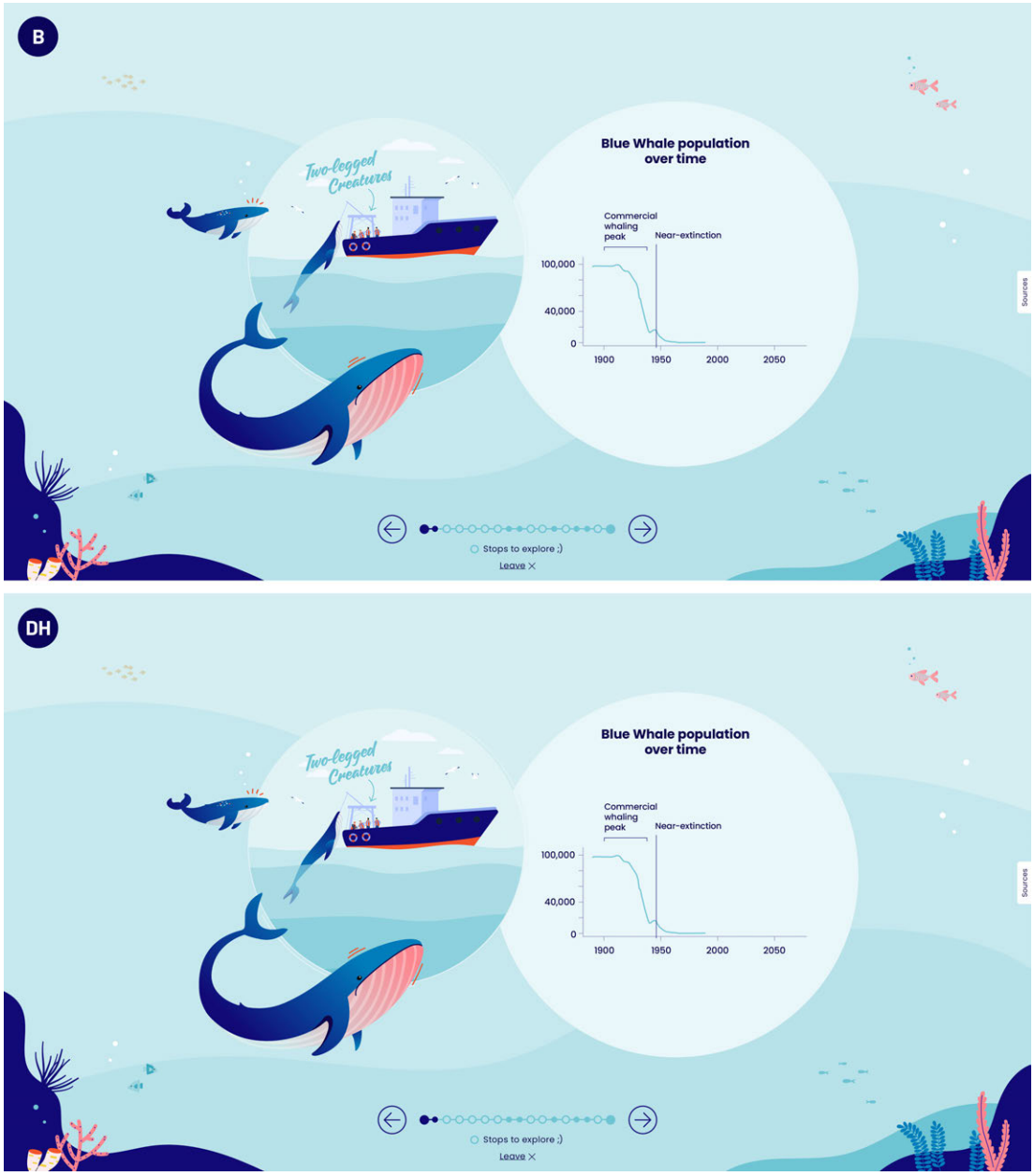

Figure A.42: *Finding Arcadia* version 3 – Story screen 2 for version B and DH.

Narration B – But tragically, whales have been hunted almost to extinction.

Narration DH – Alas, it is a sorrowful truth that my brethren, the magnificent whales, have been relentlessly pursued to the brink of disappearance by hunters.

Screen 3

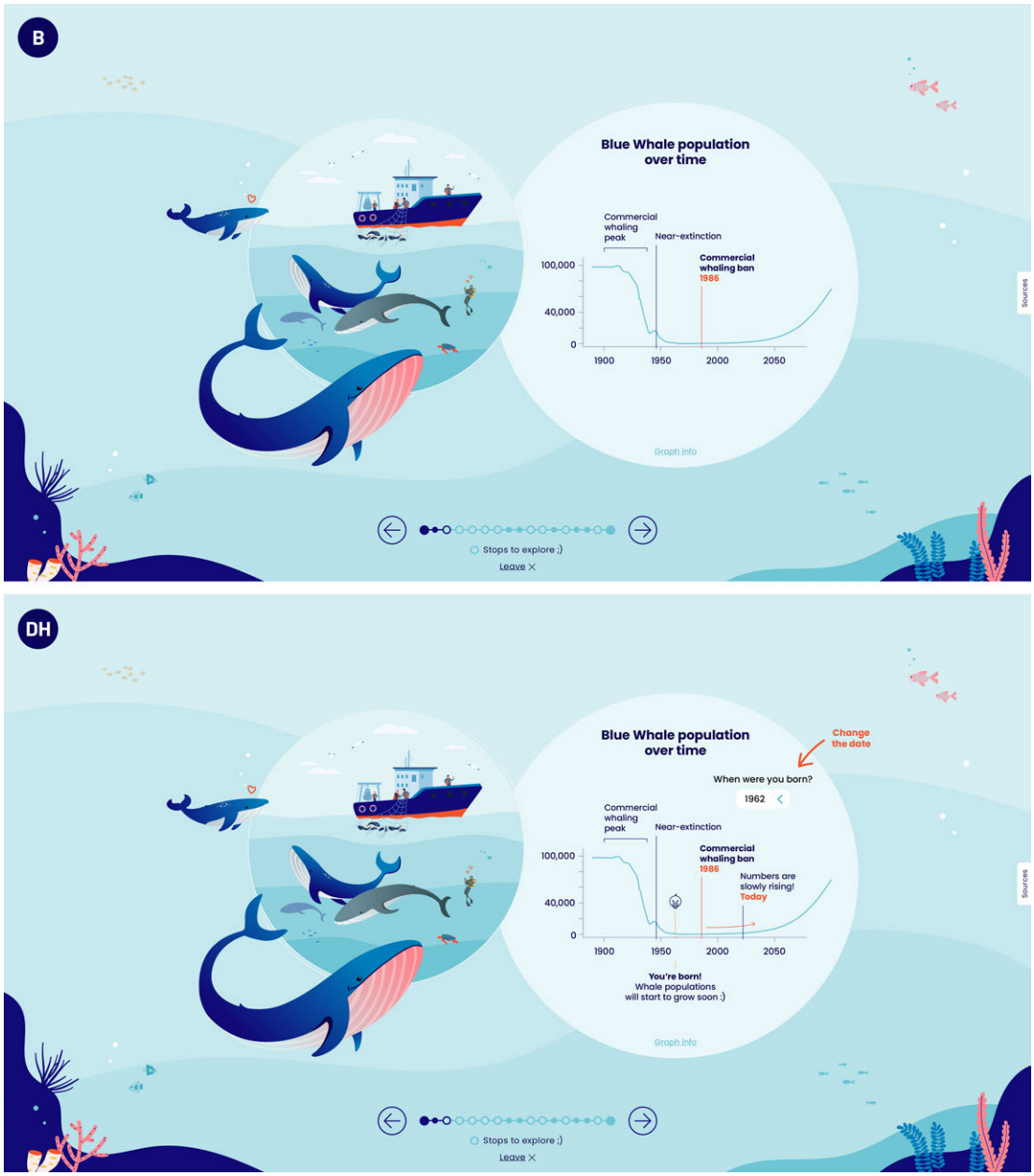

Figure A.43: *Finding Arcadia* version 3 – Story screen 3 for version B and DH.

Narration B – Fortunately, commercial whaling was banned internationally in 1986, and whale populations are slowly rising.

Narration DH – Thankfully, the year 1986 brought a glimmer of hope for us. A worldwide ban on commercial whaling was instituted, and since that time, our numbers have been cautiously growing.

My memory runs deep! So let's see if I remember... Tell me, in what year were you born?

New features – When the user selects their date of birth, besides the data visualisation adapting to it (as in previous versions), in this iteration, a fact related to sustainability or climate change relevant to that year is also narrated. These facts were collected using a

LLM.

Screen 4

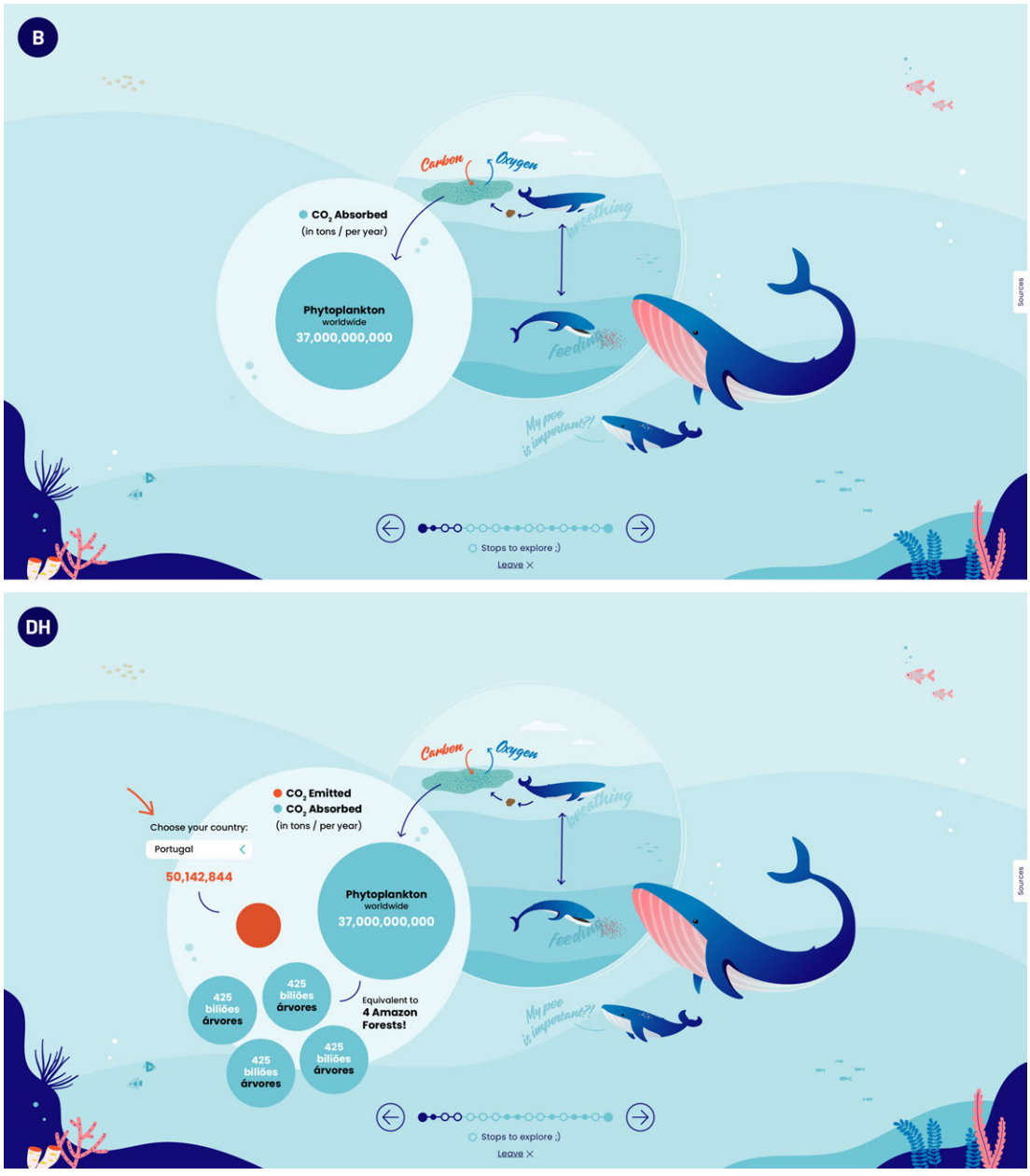

Figure A.44: *Finding Arcadia* version 3 – Story screen 4 for version B and DH.

Narration B – Great whales are crucial for global ocean health! To feed, they dive to the ocean depths and come to the surface to breathe, poop and pee. These excrements release enormous plumes of nutrients into the water. The so-called "poo-namis" stimulate the growth of phytoplankton – marine algae that suck carbon out of the air via photosynthesis, just like land plants and trees.

Narration DH – It's rather amusing, I admit, but we great whales play an essential part in maintaining the health of the world's oceans. We dive deep into the ocean's belly

to feed, then return to the surface to catch our breath and to poo and pee.

These large, nutrient-rich plumes of our waste fertilize the water and stimulate the growth of phytoplankton. These microscopic algae, much like your trees and plants on land, perform the magic of photosynthesis, drawing carbon out of the air. So, in our own quirky way, we whales help to keep the oceans in balance.

And even though most countries still emit too much CO2, progress is being done. Check out how your country is doing.

New features – When the user selects their country, besides the data visualisation adapting to it (as in previous versions), in this iteration, a fact related to sustainability or climate change relevant to that country is also narrated. These facts were collected using a LLM.

Screen 5

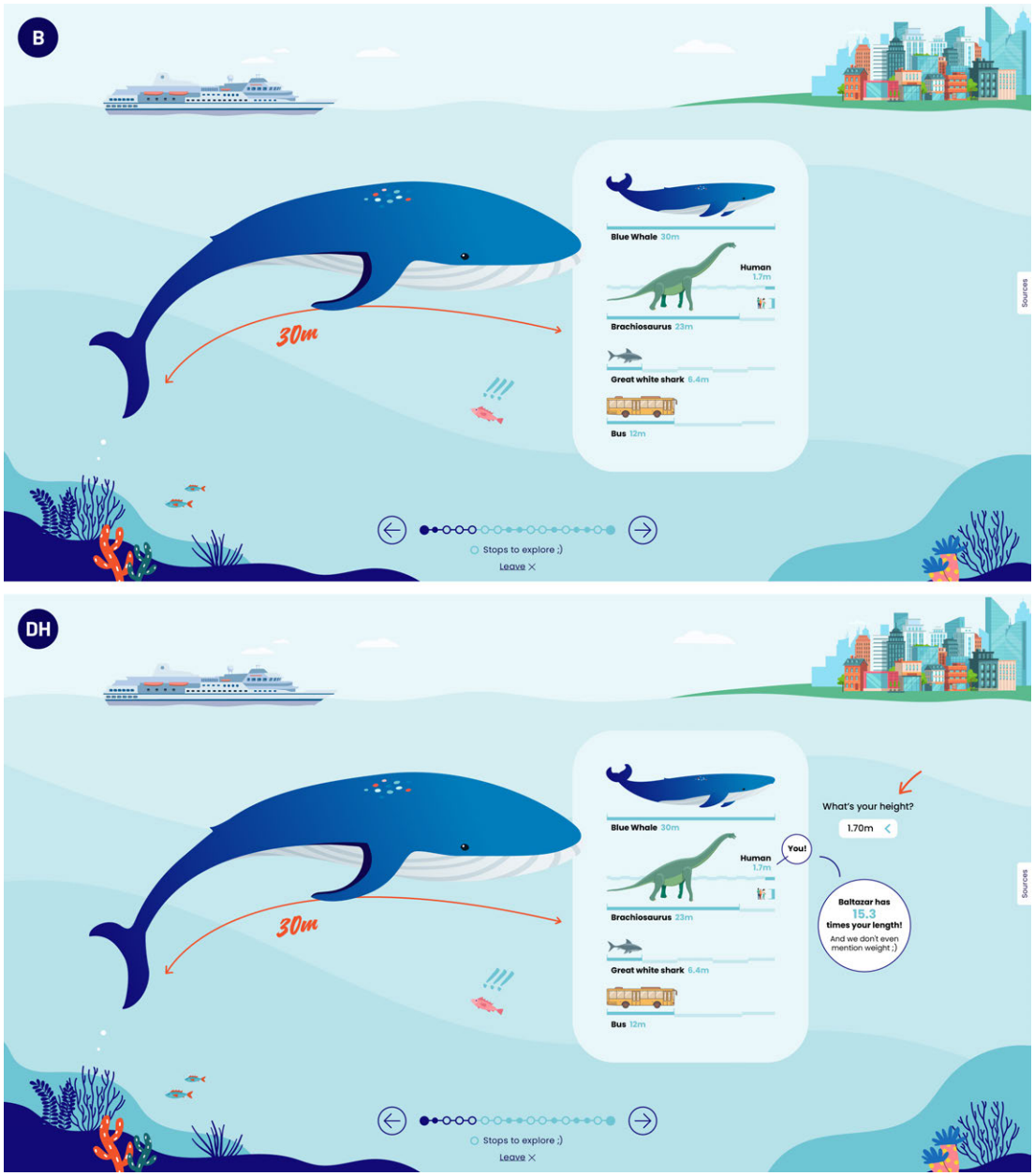

Figure A.45: *Finding Arcadia* version 3 – Story screen 5 for version B and DH.

Narration B – Blue whales can grow up to 30m long and 200 tonnes, the biggest animals to have ever lived on our planet, and that includes the dinosaurs!

Narration DH – Imagine a giant creature that reaches up to 30 meters in length and tips the scales at 200 tonnes. That's me and my kin. Indeed, we hold the record, even out-sizing the ancient dinosaurs, as the largest animals ever to have graced this Earth of ours.

Screen 6

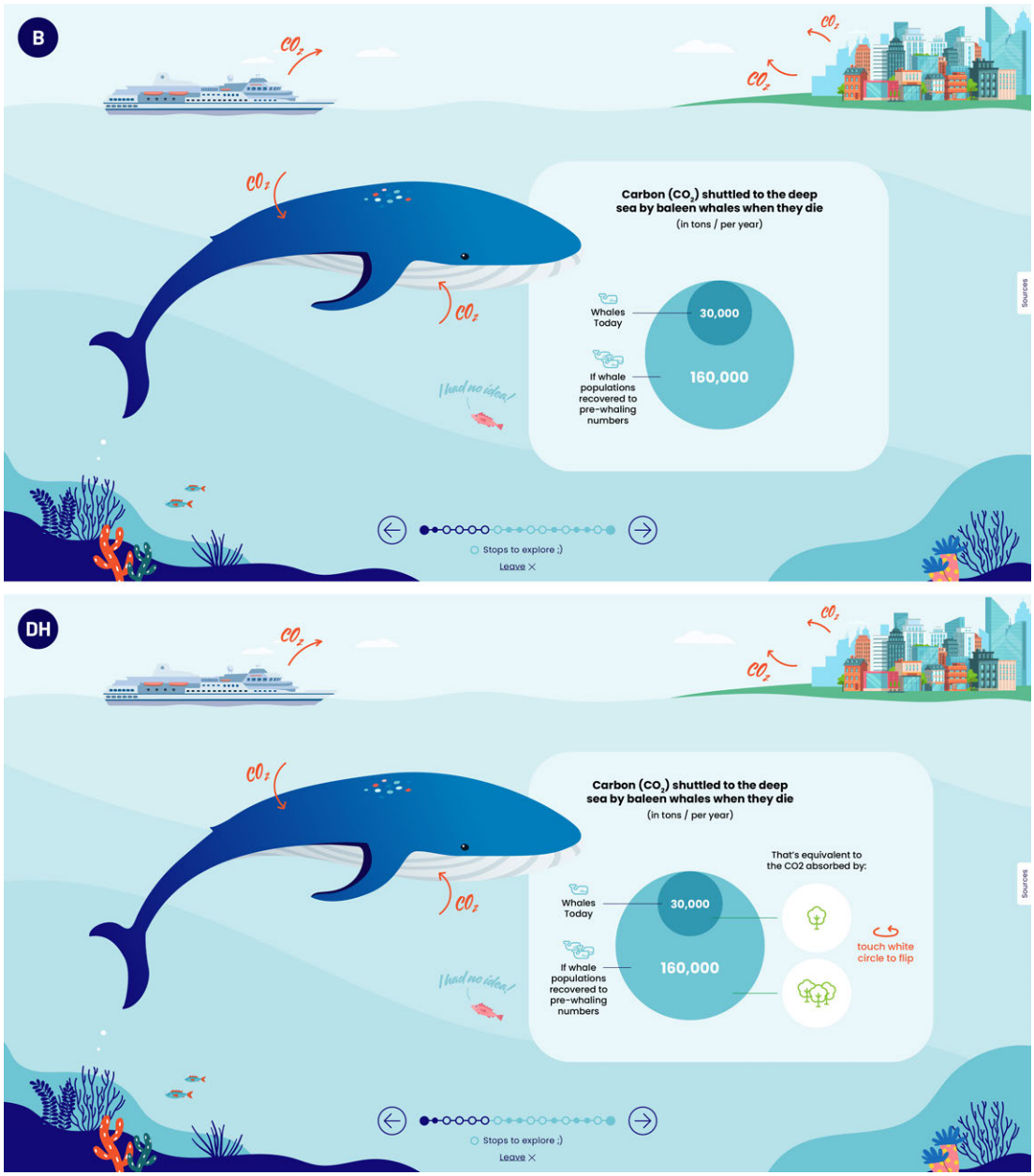

Figure A.46: *Finding Arcadia* version 3 – Story screen 6 for version B and DH.

Narration B – The bulk of large whales means they store big amounts of carbon in their bodies – the bigger and longer-lived the animal, the more carbon they store during their lives. They hoard carbon in their fat, protein-rich bodies – like giant, swimming trees.

Whales are a powerful natural solution to the carbon problem. And the more whales we have, and the healthier the oceans are, the more carbon is captured naturally.

Narration DH – Our colossal size carries with it a significant environmental benefit. You see, our great bulk means we store vast quantities of carbon within our bodies - the larger and longer-lived we are, the more carbon we collect during our lifetimes. We accumulate this carbon in our fat and protein-rich bodies, making us akin to giant, floating

trees. We whales then, are a formidable natural weapon against the carbon crisis. And the logic is simple: the more of us there are and the healthier the oceans remain, the more carbon is naturally sequestered.

Screen 7

Figure A.47: *Finding Arcadia* version 3 – Story screen 7 for version B and DH.

Narration B – But we must do our part as well. Here are some suggestions for a more sustainable lifestyle.

Narration DH – But you humans must do your part as well. Here are some suggestions for a more sustainable lifestyle.

New features – This artefact version (DH) offers personalized solution suggestions

based on users' existing practices. Users are invited to flip only the actions that they already do.

Screen 8

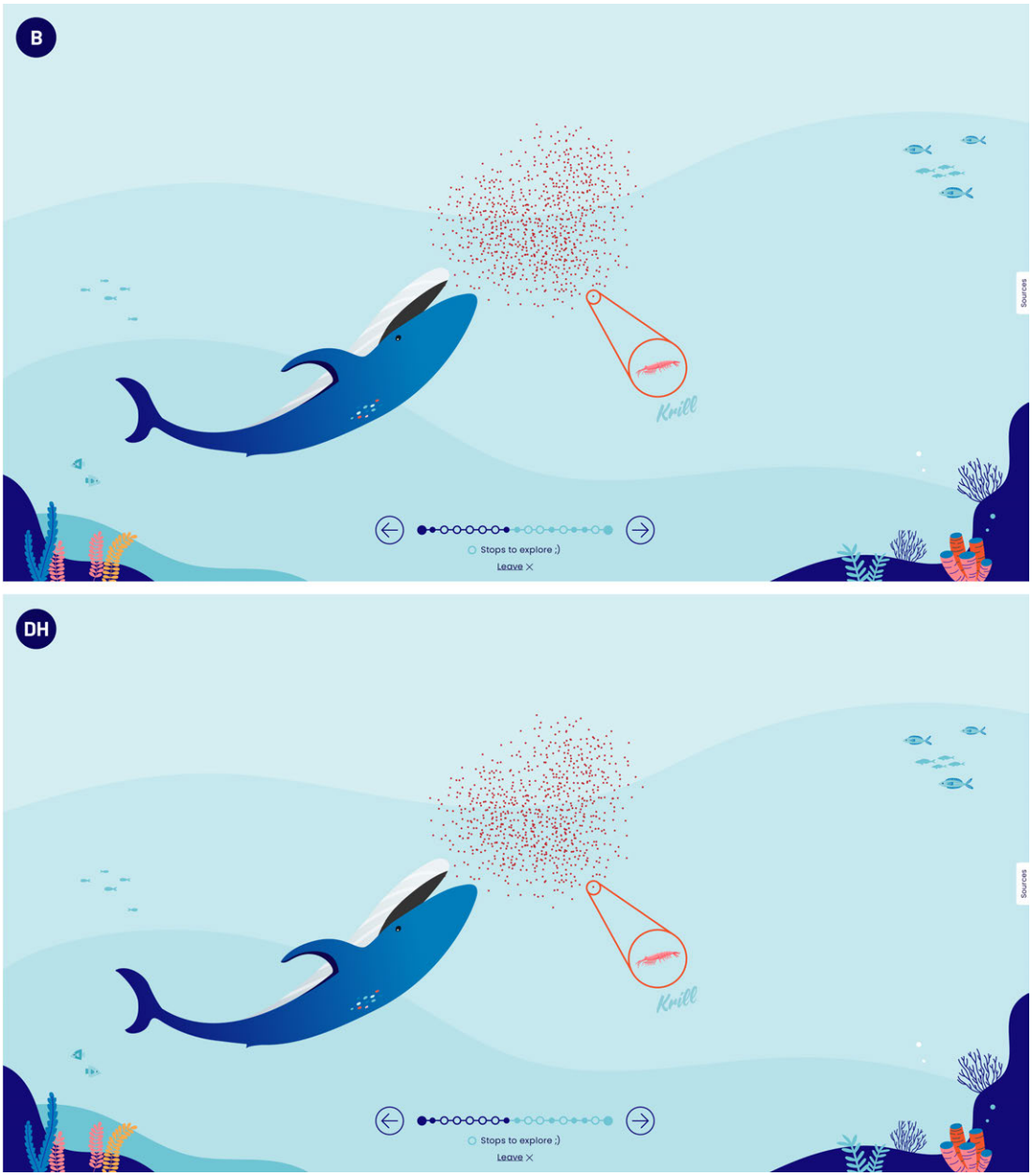

Figure A.48: *Finding Arcadia* version 3 – Story screen 8 for version B and DH.

Narration B – Blue whales eat mostly krill, small shrimp-like animals.

Narration DH – In the great banquet of the ocean, my preferred delicacy is none other than krill, tiny shrimp-like creatures. These nutrient-rich morsels, like an oceanic buffet, sustain me as I glide through the vast expanse of the sea.

Screen 9

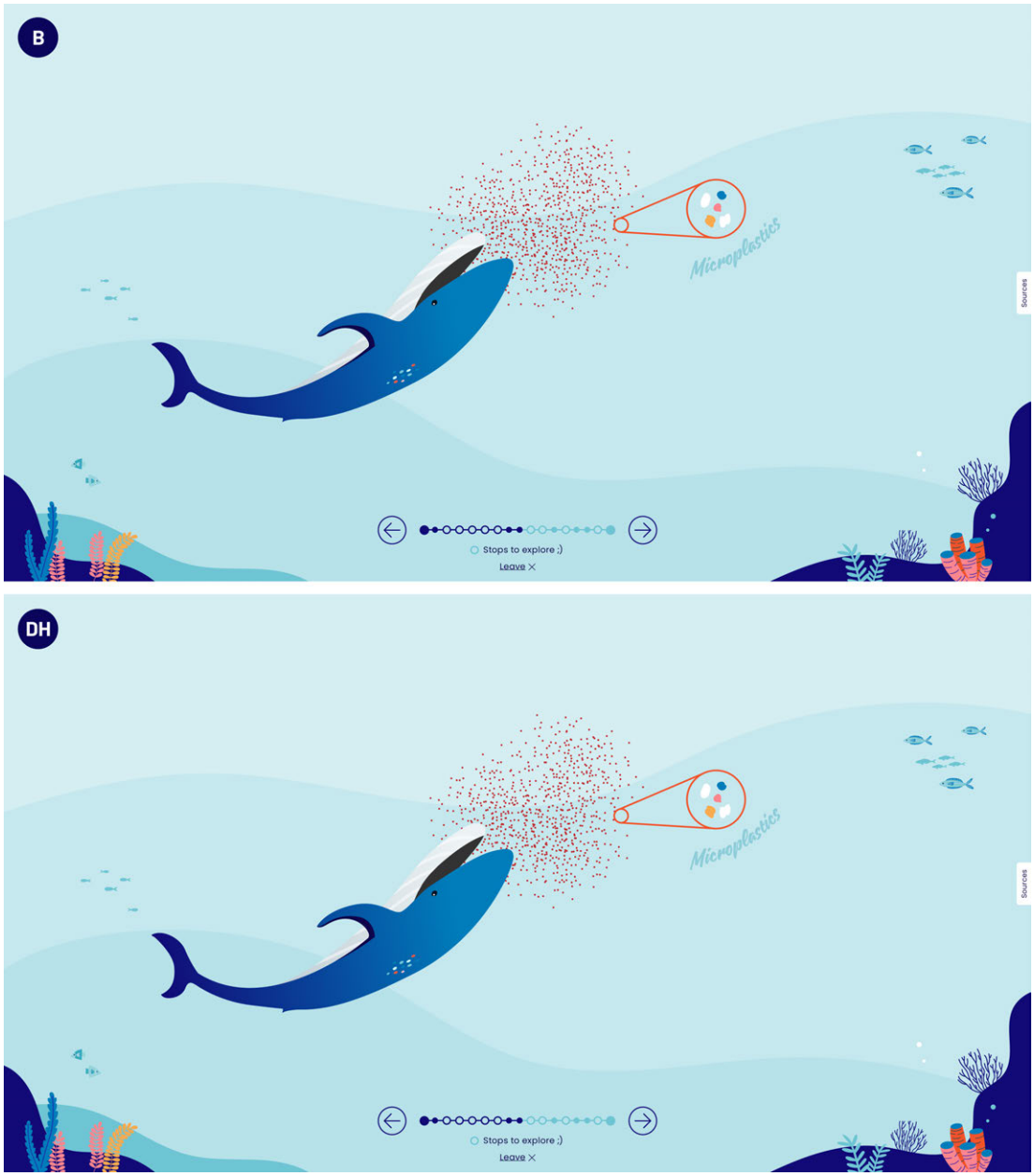

Figure A.49: *Finding Arcadia* version 3 – Story screen 9 for version B and DH.

Narration B – Without knowing it, with the thousands of litres of water they filter to feed on tiny krill, blue whales are also ingesting microplastics.

Narration DH – Unbeknownst to us, as we filter thousands of liters of water to satisfy our appetite for krill, we inadvertently find ourselves consuming something insidious: microplastics. These minuscule fragments of plastic, imperceptible to our eyes, have become an unfortunate part of our diet.

Screen 10

Figure A.50: *Finding Arcadia* version 3 – Story screen 10 for version B and DH.

Narration B – Other whale species that feed on bigger prey are in danger of ingesting larger plastic waste. In 2019, a sperm whale was found with 22kg of plastic in its stomach.

Whales can't avoid microplastics. But there is a lot that we can do to avoid more plastic ending up in the ocean.

Narration DH – Other whale species that feast on larger prey face the peril of consuming substantial plastic debris. A heartbreaking example emerged in 2019 when a sperm whale was discovered with a staggering 22 kilograms of plastic in its stomach.

As whales, we are unable to evade the clutches of plastic waste. However, there's a lot you can do to prevent additional plastic from finding its way into our oceanic home.

New features – This artefact version (DH) offers personalized solution suggestions

based on users' existing practices. Users are invited to flip only the actions that they already do.

Screen 11

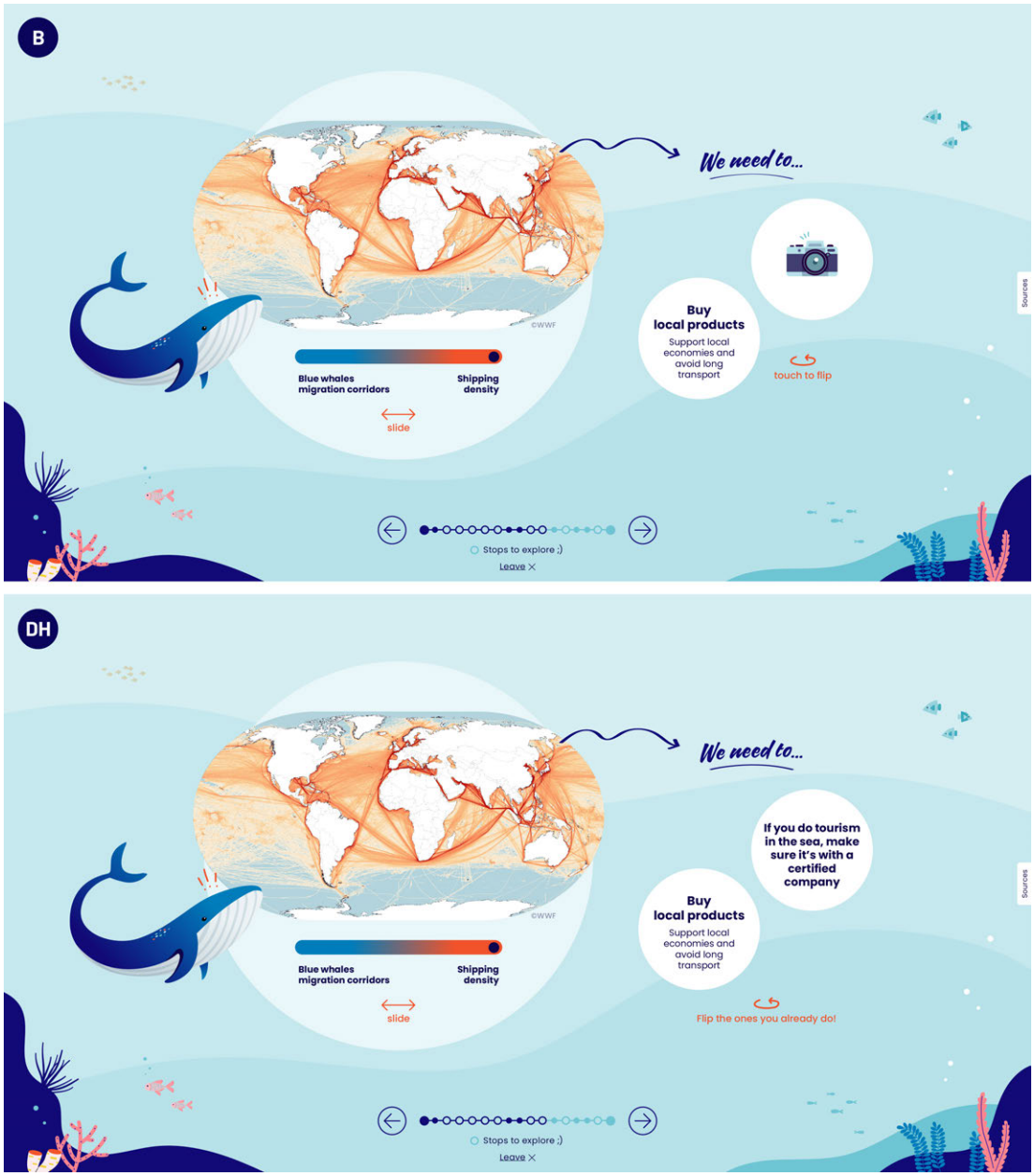

Figure A.51: *Finding Arcadia* version 3 – Story screen 11 for version B and DH.

Narration B – Whales make some of the longest migrations on earth. However, it has become hard and extremely dangerous for whales to keep their normal migration patterns because of the amount of vessels we have in the oceans. Ship collisions and entanglement in fishing nets are the major human-made causes of death for cetaceans. Whales need to change their course constantly to avoid ships and other vessels.

Narration DH – We whales embark on some of the longest migrations known to Earth's

creatures. However, my heart weighs heavy as I share that our once familiar migration routes have been disturbed by all the human activities in the seas.

Ship collisions and entanglement in fishing nets are the leading human-induced causes of death for cetaceans like myself. We are compelled to constantly alter our course, a disruption to the natural flow of our migrations.

New features – This artefact version (DH) offers personalized solution suggestions based on users' existing practices. Users are invited to flip only the actions that they already do.

Screen 12

Figure A.52: *Finding Arcadia* version 3 – Story screen 12 for version B and DH.

Narration B – The many dangers whales face caused by humans' action in the oceans – the anthropocentric footprint – disrupt their lives, and even put their lives at risk. We humans are the problem, but we also hold the keys for the solution.

Narration DH – The vast array of perils that whales endure, brought about by human actions in the ocean, reflects the undeniable anthropocentric footprint. It disrupts the very fabric of our lives and, regrettably, poses a significant risk to our very existence. It is true that humans are at the heart of this problem, but you also hold the keys to the solution.

Screen 13

Figure A.53: *Finding Arcadia* version 3 – Story screen 13 for version B and DH.

Narration B – It just requires a bit of adaptation from us, and not only whales but the

whole environment will benefit! Here's a reminder of some small things you can start helping with!

Narration DH – It just requires a bit of adaptation from you, and not only me but the whole environment will benefit! Here's a reminder of some small things you can start helping with!

New features – In this version of the artefact, a reminder of the proposals for action was added towards the end of the story. In version B, all the proposals are shown. In version DH, only the actions that people don't yet do are present – personalising the list.

Screen 14

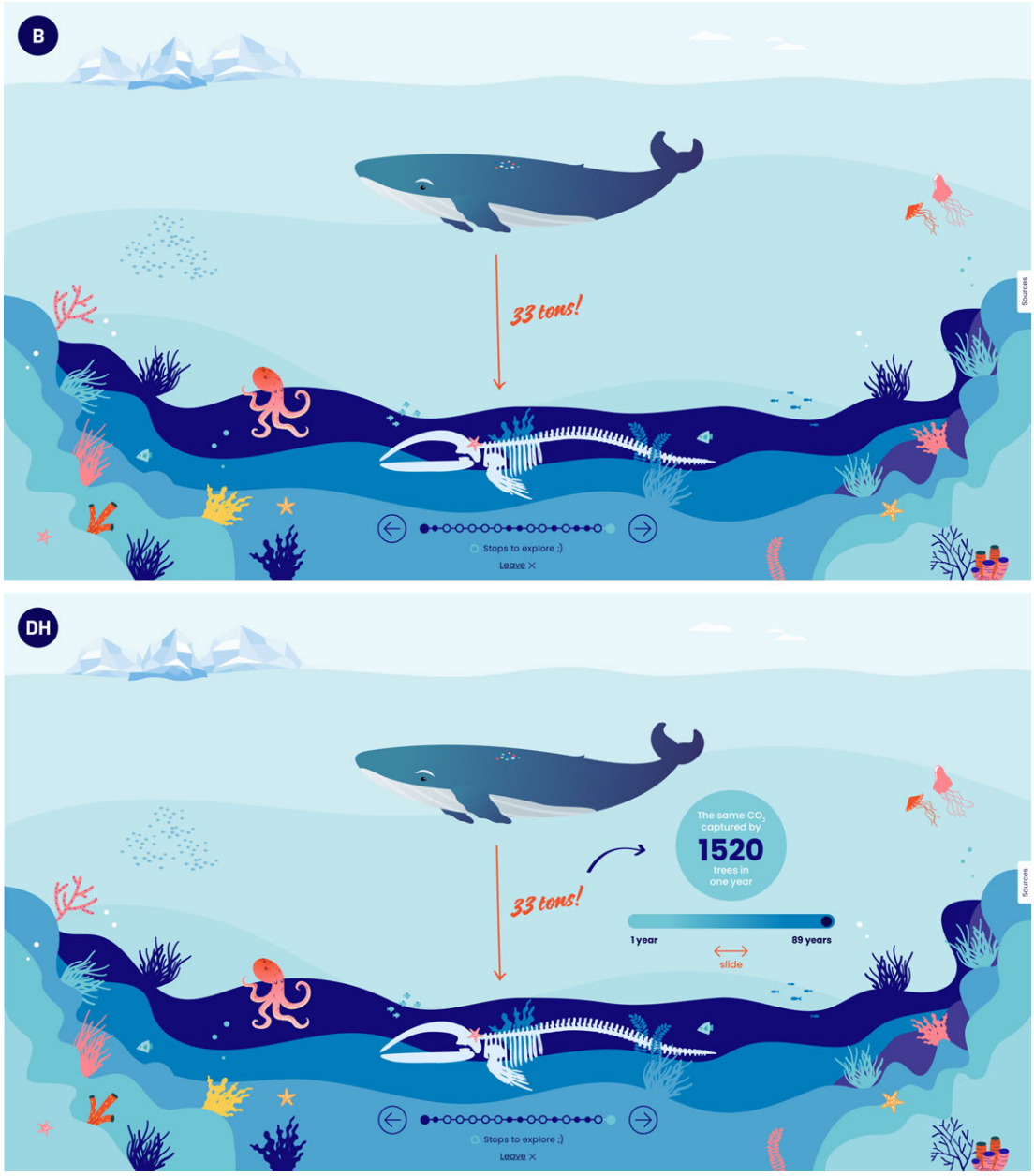

Figure A.54: *Finding Arcadia* version 3 – Story screen 14 for version B and DH.

Narration B – It is estimated that Blue whales can live up to 90 years of age. When they die, their carcass sinks to the bottom of the ocean taking with them around 33 tons of carbon that will support deep-sea ecosystems. That's a big amount of CO2 that is taken out of the atmospheric cycle for hundreds to thousands of years – a literal carbon sink.

Narration DH – After a magnificent and eventful life, I bid farewell to this world at the graceful age of 87. My noble carcass sinks to the ocean's depths. I carry with me a remarkable payload of 33 tons of carbon, a gift to the deep-sea ecosystems that rely on this nourishment.

This serves as a significant act of carbon removal from the atmospheric cycle for hundreds, even thousands of years. This captured CO2 shall remain nestled within the ocean's embrace. A literal carbon sink.

Screen 15

Figure A.55: *Finding Arcadia* version 3 – Story screen 15 for version B and DH.

Narration B – Having a better relationship with the oceans and its inhabitants and, with that, supporting natural solutions to our carbon problem is fundamental. It's a win-win! Pass on what you have learned and take action. Let's do this together!

Narration DH – Establishing a harmonious bond with the oceans and actively supporting natural solutions to our carbon conundrum is fundamental. It's a true win-win scenario!

Together, we can make a difference.

Screen 16

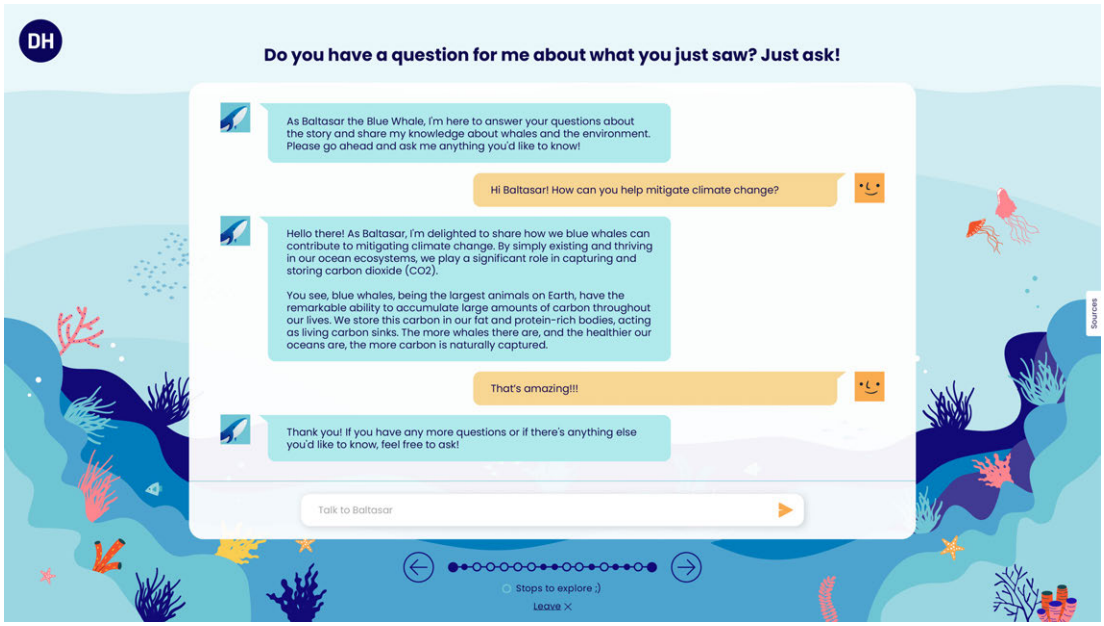

Figure A.56: *Finding Arcadia* version 3 – Story screen 16 for version DH.

(only available in version DH)

Narration DH – Do you have questions for me about what you just saw? Ask away.

New features – Besides the narration, we also used the LLM to allow users to "chat" with Baltazar at the end of the experience in version DH. This feature was proposed to augment the empathy and connection with the whale character by further personifying it. Also, it could further contextualise the data by allowing users to ask questions about the information through Baltazar's perspective and "life experiences".